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Skylab Sleep Monitoring Experiment
(Experiment M133)

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Submitted by

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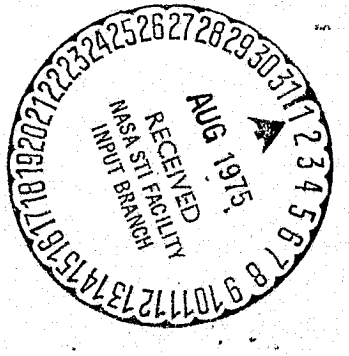

FOREWORD

This document contains a summary of the conceptual design of the Skylab M133 Sleep Monitoring Experiment and a comprehensive compilation of the data-analysis results from the three Skylab missions. Preliminary research directed toward the automatic monitoring of sleep during space-flight was begun in the Neurophysiology Laboratories of The Methodist Hospital and Baylor College of Medicine, Houston, in 1966. This and subsequent contractual support from the National Aeronautics and Space Administration led eventually to the finalization of flight-hardware design and to the specific experimental protocol.

Detailed information regarding particular aspects of the M133 system and its performance during preflight testing procedures is provided in the progress and final reports submitted to NASA in association with the individual contracts. In addition, detailed specifications for the flight hardware and experimental requirements are summarized in the following documents of the National Aeronautics and Space Administration (Skylab Program, Lyndon B. Johnson Space Center, Houston, Texas):

1. End Item Specification: Flight Hardware for Sleep Monitoring Experiment (Experiment M133), March 3, 1971, and updated (MSC-02791)

2. Experiment Requirements Document for Sleep Monitoring Experiment (Experiment M133), March 3, 1971, and updated (MSC-02790)

The results of extensive preflight testing of the M133 system are included in the report of the Skylab Medical Experiments Altitude Test (SMEAT), published by the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center (NASA TMX-58115, 1973).

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ABSTRACT

Astronauts on pre-Skylab missions commonly complained of insomnia, and in some cases periods of sleep loss degraded crew performance. Investigation of this situation was important in planning future long-term flights; subsequently, the first objective measurements of man's ability to obtain adequate sleep during prolonged spaceflight were made during the three Skylab flights.

EEG (electroencephalographic), EOG (electro-oculographic), and head-motion signals were acquired during sleep by use of an elastic recording cap containing sponge electrodes and an attached miniature preamplifier/accelerometer unit. A control-panel assembly, mounted in the sleep compartment, tested electrodes, preserved analog signals, and automatically analyzed data in real time (providing a telemetered indication of sleep stage).

One astronaut was studied per flight, and while there was considerable individual variation, several characteristics were common to all three: (1) Stage 3 sleep increased inflight and decreased in the postflight period. (2) Stage 4 was consistently decreased postflight, although this stage was variable inflight. (3) Stage REM (rapid eye movement) was elevated, and REM latency decreased in the late postflight period (after day R+3). (4) The number of awakenings during sleep either showed no change or decreased inflight.

In only the 28-day mission was there a significant decrease in total sleep time; in that case it was a result of voluntarily reduced rest time and was not due to difficulty in sleeping nor frequent awakening. The subject on the 84-day mission experienced some difficulty in the first half of the flight, showing a decreased total sleep time and increased sleep latency, but this resolved itself with time. Sleep latency presented no problem in the other flights. While many of the findings are statistically significant, in no case would they be expected to produce a noticeable decrement of performance capability.

These findings suggest that men are able to obtain adequate sleep in regularly scheduled eight-hour rest periods during extended space missions. It seems likely, based upon these results, that the problems encountered in earlier spaceflights did not arise from the zero-g environment per se, but possibly were a result of more restricted living and working areas in the pre-Skylab spacecraft.

INTRODUCTION

Prior to Skylab, very little objective information had been obtained concerning the ability of man to sleep in space. Only by continuous EEG (electroencephalographic) monitoring can such information be obtained, and the technical problems associated with acquisition and analysis in space are significant. Before the advent of manned spaceflight, there was some concern about the possible adverse effects of this weightless environment upon sleep characteristics (Berry, 1970). During the Gemini program, however, it became apparent that fairly long duration spaceflight was not associated with drastic alterations of sleeping behavior. Astronauts could sleep in space and, on at least some occasions, did so fairly well. In the Gemini and Apollo programs, though, it became clear that in many instances insomnia was a problem. Sleep loss, while not absolute, was sufficient in some instances to result in performance decrements. In some instances, sleeping difficulties resulted in the use of hypnotic drugs to promote sleep and amphetamine-type medication to increase alertness following sleep loss.

It has long been recognized that sleep deprivation is associated with degradation of performance, the amount or severity of the performance decrement generally increasing in proportion to the length of the sleep loss (Naitoh, 1969). Since crew members are expected to perform at a high level throughout a mission, their ability to obtain sufficient sleep becomes an important variable in terms of overall mission planning and scheduling of daily work-rest periods.

The United States' first attempt to record the electroencephalogram during spaceflight was carried out during the Gemini VII mission in 1965 (Maulsby, 1966; Maulsby and Kellaway, 1966; Adey et al., 1967; Burch et al., 1971). Technical difficulties associated with electrode attachment limited recording to slightly under 55 hours. During that time, two sleep periods were observed, and while the first was found to be inadequate in terms of duration and quality, the second was considered to be normal. Postflight examination of the recorded EEG disclosed no pathological changes nor definite alterations which could be attributed to the weightless state. The limited duration of this recording did not permit an adequate analysis of sleep characteristics during long-term spaceflight, and consequently, the purpose of the sleep monitoring experiment developed for Skylab was to obtain the first truly objective evaluation of man's ability to sleep during extended space travel. An historical overview of the development of the experiment is illustrated in Fig. 1 in which specific contract support to this laboratory is acknowledged.

Each three-man crew carried out a wide variety of work during the three Skylab missions, accomplishing a number of research projects

covering the physical and biomedical sciences. The working volume of the Skylab orbiting laboratory was over 12 000 ft^3, and consequently it was comparable to a moderate-sized house. There was adequate space to provide separate facilities for work, recreation, meals, and sleep, and the crews followed a 24-hour schedule based upon Central Standard Time, to which they were accustomed on the ground. At an altitude of approximately 270 statute miles, Skylab circled the Earth approximately every 93 minutes.

Each astronaut had his own sleeping compartment, which was equipped with a sleep-restraint system quite similar in appearance and function to a sleeping bag. An eight-hour rest period was typically scheduled between 10 p.m. and 6 a.m. for all three crew members, although variations in this protocol were occasionally necessitated by specific work requirements.

Sleep was studied in an objective manner on three of the Skylab astronauts, one each during the 28-, 59-, and 84-day missions.

METHODS

A complete system for analyzing sleep during spaceflight was designed for this experiment and included data-acquisition hardware, onboard-analysis components, and a capability for real-time telemetry.

Automatic analysis of the electroencephalogram (EEG), electro-oculogram (EOG), and head-motion signals was accomplished by onboard equipment. The system's output, consisting of sleep-stage information, was telemetered in near real time to Mission Control, where a profile of sleep stage versus time was accumulated. The analog signals (EEG, EOG, and head motion) were also preserved by onboard magnetic-tape recorders, thus allowing a more detailed postflight analysis.

The flight-hardware components are shown in Fig. 2. When sleep monitoring was desired, the astronaut wore a recording cap that contained electrodes for detecting EEG and EOG. Signal amplification was accomplished by a preamplification unit which attached to the cap near the vertex of the head. A dual-axis accelerometer, included within the preamplifier housing, provided information concerning movement of the subject's head. A control-panel assembly was mounted in the subject's sleep compartment and attached to the preamplifier by means of a flexible cable. Within the control-panel assembly, additional circuitry accomplished automatic electrode testing, sleep analysis, and generation of the telemetry output signal indicative of the subject's current level of consciousness. Analog recording was accomplished by two tape recorders attached to the rear portion of the control-panel assembly.

Data Acquisition

Recording Cap

In developing the sleep monitoring system, we directed considerable effort toward the problems associated with data acquisition. Biomedical electrodes have always presented problems in spaceflight because they require excessive time for proper application, are often uncomfortable, and are prone to dislodgment during the subject's activity. Several years ago, Kado and Adey (1968) and Hanley et al. (1971) considered the particular problems posed by long-term EEG monitoring, resulting in the development of a sponge-type electrode mounted in an elastic cap. This general concept was extended in evolving the Skylab system, and a new, disposable recording cap was developed (Frost et al., 1970; Frost, 1971, 1972, 1973) which contained miniaturized, flexible, sponge electrodes prefilled with an electrolyte solution to minimize preparation time.

The recording cap is illustrated in Fig. 3; the picture was taken during the 59-day mission (Skylab 3). The electrodes, attached inside the elastic cap, were joined by wires to a miniature connector at the vertex, which permitted rapid linkage with the preamplifier assembly. The cap contained seven electrodes; four electrodes (left and right central positions, C_1 and C_2, and left and right occipital positions, O_1 and O_2) provided a composite EEG channel (C_1 and C_2 paired and referenced to O_1 and O_2 paired); two (one lateral to and one above the left eye) provided one EOG channel; and one served as a ground. Following the sleep period, the preamplifier was disconnected, and the used cap was discarded; i.e., a new cap was used for each recording session.

Recording Electrode

The base was flexible silicone rubber, with a silver-silver chloride disc incorporated in one surface (see Fig. 4A). A conical, silicone-rubber sponge was attached to the base so that it made contact with the surface of the disc.

The sponge apex terminated in a cylindrical protrusion (the filling and sealing tab), and the entire electrode was covered with a thin, flexible, nonporous coating (Fig. 4B). This coating consisted of three layers of vinyl plastic and an extremely thin outer layer of Parylene C polymer material (Union Carbide). During the manufacturing process, an electrically conductive gel was injected through the electrode's tab into the body of the sponge until the porous structure became saturated. The injection needle was then withdrawn and the tip resealed. The completed electrode was then attached to the cap, which could be stored indefinitely in a laminated metalized plastic bag.

To prepare for a recording period, the subject simply removed the cap from its protective bag, attached the preamplifier unit, and, using a scissors, snipped the sealing tabs from the seven electrodes. The cap was then donned, and the exposed portions of the electrodes (see Fig. 4C) made contact with the scalp. The cap was held in place during a sleep period by a padded chin strap attached with velcro fasteners.

Preamplifier Assembly

Matched pairs of field-effect transistors provided a gain of approximately 10 and preamplified EEG and EOG signals within this unit. A dual-axis accelerometer and its associated preamplifier also were included for detecting head motion in the lateral (side-to-side) and vertical (up-down) axes. The amplified signals passed through a four-ft cable (see Fig. 2) to the control-panel assembly, which provided final amplification.

Circuitry within the preamplifier also provided electroshock protection for the subject and electrostatic protection for the system's electronic components. Each electrode lead was actively protected against current flow in excess of 200 μA (peak).

Control-Panel Assembly

This unit was mounted on the wall of the subject's sleep compartment, within easy reach of the sleep restraint. Front-panel controls included the power switch, a mode-selection switch, tape-recorder-selection switch, and a subject gain-factor potentiometer. The circuitry accomplished electrode testing, signal amplification, and data analysis, and provided outputs to the analog-tape recorders and the spacecraft telemetry system.

The electrode-test section of the control-panel assembly performed automatic testing of each recording electrode before the sleep period began. The front panel, readily visible to the subject in the sleep compartment while applying the cap, contained a series of indicator lamps, each representing one sponge-electrode sensor in the cap. The lamps were arranged in a configuration simulating the relative position on the head. After the subject donned the cap, he moved the mode-selection switch from the off to the test position, thereby activating the test circuitry. A small test current ($\approx$10 μA) passed through the single ground electrode to each of the six recording electrodes in succession, and the amount of current passed by each electrode was sensed to provide an indication of interelectrode resistance. If a given electrode were in proper scalp contact, its resistance was 50 000 Ω or less, and this condition was indicated by illumination of the corresponding lamp on the panel display. Improper contact, indicated by failure of any lamp to illuminate, usually could be resolved by slightly rocking the sensor to position the electrode tip through the hair and against the scalp.

Inflight Data Analysis

The data-analysis equipment also had been designed to meet the limitations imposed by spaceflight. To supply sleep-stage information in near real time while minimizing telemetry time and bandwidth, the EEG, EOG, and head-motion signals were processed onboard by a small, special-purpose computational device. Since the unit's output was expressed in terms of sleep stage (i.e., restricted to one of seven possible states) and changed only slowly, the information content could be telemetered adequately by transmitting only three bits at a rate of 1.25 samples/sec (as opposed to approximately 32 bits at a rate of 100 samples/sec, which would be required to transmit the unprocessed data).

The clinical criteria for evaluating sleep are based upon changes in the EEG and EOG patterns accompanying the observed behavioral changes during the transition from the awake condition to one of deep sleep (Rechtschaffen and Kales, 1968). The awake, or nonsleep, state is characterized electroencephalographically by alpha activity (8-12 Hz) and/or low-amplitude, mixed-frequency activity. Stage 1, or very light sleep, is characterized by low-amplitude EEG signals of a predominantly lower frequency (5-7 Hz) than the awake state. During stage 2 sleep, the EEG exhibits a somewhat random frequency, low-amplitude background activity upon which is superimposed occasional bursts (spindles) of 12-14 Hz activity and/or relatively high voltage transient forms exceeding 0.5 sec in duration (K complexes). Stage 3 is identified by the occurrence of relatively high amplitude (>75 μV) activity of 2 Hz or slower, which is present between 20 and 50% of the time, while stage 4 is indicated if such activity is present more than 50% of the time. The rapid eye movement (REM) sleep stage, which has been highly associated with dreaming, is characterized by EEG signals much like stage 1 in appearance, but it is most notably differentiated by rapid, jerking-type eye movements as detected by the EOG. A seventh category, stage 0, has been included in the analysis schema to indicate interruption of data or loss of physiological signals.

Operation of the automatic onboard analysis equipment is indicated in a simplified form in Fig. 5, showing the various logic functions involving the three input signals. In general, EEG alone was used to determine stages awake and 1, 2, 3, and 4 of sleep. EEG and EOG signals detected stage REM, and the EEG and accelerometer outputs recognized periods likely to be contaminated by artifactual signals.

The EEG-analysis section (Fig. 5, Section 1) considered activity in the 0.7-13 Hz range derived from the paired central to paired occipital electrode array. The circuit behaved as an amplitude-weighted frequency meter for the dominant EEG activity (Frost, 1970). Each comparator was set to detect a different EEG signal amplitude: high, or 100%; intermediate, or 20%; and low, or 1%. The input EEG signal gain factor was adjusted once for each subject (determined during preflight baseline studies), such that the average

peak amplitude of the eyes-closed, waking EEG was made to fall midway between levels 2 and 3, i.e., approximately 60%. Thus, higher-voltage activity during sleep frequently crossed the third level, whereas the lower-voltage signals of stage 1 usually exceeded only level 1 or 2.

The bistable circuit, associated with the level 1 and level 2 comparators, triggered the negative-pulse generator if, and only if, level 1 and level 2 were crossed successively in a negative-going direction. As a result, the number of constant-amplitude pulses produced by the negative-pulse generator was proportional to the dominant frequency of the EEG and relatively independent of minor inflections. The positive-pulse generator, with output one-half the amplitude of the negative-pulse generator, was triggered each time the voltage exceeded level 3. The pulses from the two generators entered the mixer amplifier, which supplied a composite pulse form to the integrator circuit. The integrator had a rise and fall time-constant of 10 sec, and consequently its output was a voltage level dependent upon the number and polarity of pulses recorded during the preceding 10-sec epoch.

In terms of its influence on the integrator-circuit output, an EEG wave of very low voltage, i.e., not exceeding level 2, had zero value; an intermediate-amplitude wave had maximum value (negative pulse); and a high-amplitude wave (exceeding level 3) had a value of 50%, since it produced a negative pulse and a positive pulse of one-half the amplitude. The schema included effective utilization of the progressive decline in frequency and the general increase in amplitude seen with increasing sleep depth. The individual's EEG state therefore was expressed as a voltage level at the output of the integrator. The awake state was associated with the highest output voltage, and progressive stages of sleep were accompanied by correspondingly lower output values.

The integrator output entered a series of comparator circuits in the output section (Fig. 5, Section 4), where it was compared to previously determined voltage ranges, each corresponding to one of the clinical stages. Thus, while the EEG-analysis output remained within the range specified for a particular sleep stage, a corresponding voltage was supplied to the output section of the analyzer.

The EEG-analysis section classified stage REM sleep as either stage 1 or 2, due to its similarity in frequency and amplitude; however, true stage REM is distinguished by the occurrence of bursts of rapid, jerking eye movements. Although these events are sporadic throughout a REM period, they typically occur with a frequency of at least one recognizable event in each 30-sec epoch. During true stage 1-2 sleep, these events are absent. The function of the REM-detection circuitry (Fig. 5, Section 3) was (1) detection of events in the EOG channel which might be rapid eye movements, and (2) indication of stage REM if such events occurred during an EEG period representative of stage 1 or 2.

Amplified EOG activity entered the REM-detection section and passed through a filter that limited the response to the 2.0-4.0 Hz range, thereby optimally separating true REMs from extraneous activity (e.g., EEG activity detected by the EOG electrodes, slow eye movements, movement artifacts). The signal next entered the EOG-transient-detector comparator, which detected the occurrence of transient EOG wave forms exceeding a value equal to 250% of either the average positive or the average negative voltage of the simultaneously occurring EEG signal. (Averaging occurred continuously, utilizing an RC circuit with a 15-sec time constant.) Thus, a change in EEG background-activity level during the sleep period caused the EOG-detection reference levels to reset automatically for proper relative values, thereby minimizing the chance of false triggering by EEG wave forms that might have been recorded by the EOG electrodes.

The EOG system also may have detected transient EEG events (such as K complexes), and since these arise abruptly from the background, it may have led to triggering of the EOG-transient detector in spite of the automatic threshold-adjustment feature. Consequently, the EEG-transient-detector circuitry sensed such events, operating on the EEG channel in a manner identical to that of the EOG-transient detector, and recognized EEG events which exceeded a value equivalent to 350% of the average positive or negative EEG voltage.

The remainder of Section 3 of the logic circuitry then permitted an output indication of stage REM only if the following criteria were met: (1) an EOG event was detected by the EOG-transient detector, (2) no EEG event was detected by the EEG-transient detector within a time window extending from 1.4 sec before until 1.4 sec after the EOG event, and (3) the EEG-analysis section indicated the presence of stage 1 or 2 of sleep. If these conditions were met, a 30-sec output indication of stage REM occurred and was fed to the output section, where its presence superseded the sleep-stage output of the EEG-analysis section in terms of final output to the telemetry system. Since each REM reset the 30-sec timer in the REM-detection section, if REMs were detected with a frequency exceeding one per 30 sec, a continuous output indication of stage REM occurred.

Although the data-acquisition methods were designed to minimize the occurrence of artifactual signals, it was not possible to eliminate them completely. The majority are related to major body movements of the subject, particularly when such motions result in changing forces exerted directly on the cap recording electrodes. The artifact-detection circuitry (Fig. 5, Section 2) was designed to prevent signals with a high probability of artifactual contamination from influencing the sleep-stage-determination systems.

The excessive-amplitude detector minimized the occurrence of false sleep-stage determinations by disabling the EEG-analysis section and the REM-detection section during and for 4 sec following the occurrence of an

excessively high (i.e., nonphysiological) EEG signal, thus preventing a change in the sleep-stage output section as a result of the artifact. A dual comparator produced a trigger pulse if either the positive or the negative phase of the EEG-signal voltage exceeded a value of 600% (using the same relative amplitude scale here as in the EEG-analysis section), which was considered to be in excess of the usual physiological range. The resultant pulse started the 4-sec artifact-detection timer, which in turn operated an electronic switch for the 4-sec period. If the timer received trigger pulses at a rate equal to or exceeding one per 4 sec, the disable switch remained continuously activated.

The accelerometer contained in the preamplifier served as another means for detecting periods when artifactual contamination was highly probable. Head motion produced an output voltage roughly proportional to the rapidity of the motion; thus, a relatively high voltage output from this device was more likely to be associated with artifact. The accelerometer comparator in the artifact-detection section was set such that it was triggered by voltages equivalent to changes in acceleration of approximately 0.2 g in either the vertical or the lateral axis. When triggered, the accelerometer comparator in turn reset the 4-sec artifact-detection timer, and the disable switch was consequently activated for the duration of and for 4 sec following the movement.

Outputs from the six sleep-stage comparators and the REM indicator were combined in the output section of the analysis circuitry (Fig. 5, Section 4) by an analog adder that provided the single output line to the spacecraft telemetry system. The analyzer output flowed to the spacecraft telemetry system at a rate of 1.25 samples/sec. During each pass over a ground receiving station, the telemetered information updated a comprehensive display terminal at Mission Control.

Ground-Based Data Analysis

Automatic Analysis Inflight

During a sleep monitoring session, true real-time data was available only during the few minutes when the spacecraft passed over a ground tracking station. Throughout the frequent periods when the spacecraft was out of communication range, the sleep-stage data was accumulated by the spacecraft telemetry recorder and transmitted to ground at a high rate during a subsequent tracking-station pass. The tracking stations, in turn, relayed the telemetered sleep-stage information to Mission Control. Consequently, the data ultimately received during a sleep period was somewhat sporadic, ranging from actual real time to delays of up to several hours. Data-processing equipment in Mission Control collated the incoming data so that the time relationships were preserved, and eventually a complete tabulation of sleep stage versus elapsed time evolved.

Although data was telemetered at a rate of 1.25 sleep-stage samples/sec (75 samples/min), a subject's sleep stage does not typically change more often than two or three times each minute, and it is often stable for several minutes without change. The data-processing system was consequently programmed to indicate only the time and the sleep stage when a change of level occurred. The resultant listing of sleep-stage information versus time was transferred to The Methodist Hospital, where the computer facilities of the Neurophysiology Laboratories and the Baylor Institute of Computer Science were employed to provide the final data analysis.

The end product was a compact graphic plot that showed the complete profile of sleep stage versus time over the course of a sleep period. The data was displayed at a horizontal resolution of approximately 2 in./hr, with a vertical span of approximately 4 in., thereby providing an observer with an overall summary or profile of the sleep period. A statistical summary of the all-night data was also supplied for each sleep period, and these values for the following sleep parameters were included: total rest-period time, total sleep time, total awake time, sleep latency, number of arousals, accumulated time in each sleep stage, percentage of total sleep time occupied by each sleep stage, and REM latency.

Visual Analysis Postflight

At the conclusion of each Skylab mission, the onboard data tapes were returned by the crew, and this data was then analyzed by conventional visual scoring techniques (Rechtschaffen and Kales, 1968) after playback onto a graphic recorder. The various aspects of the sleep recordings and the criteria used in scoring them follow.

(1) Total Rest Time: The period between the time of retiring to bed until the time of arising for the day.

(2) Total Awake Time: The total time spent in the awake state between the times of retiring to bed and arising for the day.

(3) Total Sleep Time: Total rest time minus total awake time.

(4) Sleep Latency: The elapsed time from retiring to bed until the subject attains a sleep stage other than stage 1 or awake.

(5) Sleep-Stage Percentage: The total time spent in a particular stage of sleep divided by the total sleep time.

(6) REM Latency: The elapsed time from sleep onset (occurrence of a stage other than awake or stage 1 after retiring to bed) until the onset of the first stage REM.

(7) Number of Awakenings: The total number of discrete awake periods occurring throughout the sleep period. (The period of wakefulness at the beginning of the rest period and the final awakening of the night were excluded from this measure.) A discrete awake period is a period extending from the first appearance of stage awake until the appearance of either stage 2, 3, 4, or REM. Thus, a section of awake, followed by a section of stage 1, followed by another awake section was classified as only one discrete awake period. Stage awake was scored only if an arousal persisted for at least 10 sec.

Experimental Design

One crew member participated in the sleep monitoring activities during each Skylab flight. Preflight baseline data was obtained on the participating subjects during three consecutive nights of sleep monitoring, using portable apparatus functionally identical to the onboard hardware. The astronaut studied during the 28-day mission was recorded in his own home two months prior to launch, while the subjects of the 59- and 84-day missions were monitored in the preflight quarantine facility two weeks before their respective launches. In addition, a standard clinical electroencephalogram was performed on each subject prior to the flight to permit precise EEG-amplitude determinations for calibration of the flight hardware.

Inflight monitoring was accomplished during 12 selected nights of the 28-day mission (nights 5, 6, 7, 10, 11, 15, 17, 19, 21, 24, 25, and 26), during 20 nights of the 59-day mission (nights 7, 8, 9, 12, 15, 18, 21, 24, 27, 29, 33, 36, 39, 42, 45, 48, 52, 55, 56, and 57), and during 18 nights of the 84-day flight (nights 3, 4, 10, 14, 19, 24, 29, 34, 40, 45, 50, 55, 60, 72, 77, 80, 81, and 82). Operational factors associated with the activation and function of various spacecraft systems prevented recordings during the initial period of each flight.

Crew bedtime was typically 10 p.m., and the scheduled sleep period terminated at 6 a.m., although occasional deviations from this schedule were necessitated by work requirements not associated with the sleep monitoring experiment. During the last week of the 28- and 59-day missions, sleeping schedules were adjusted forward by a total of four hours (i.e., typical bedtime became 6 p.m.). An adjustment of two hours was made on days 20 and 22 of the 28-day mission, and there was a similar change of two hours on days 51 and 53 of the 59-day mission. During the 84-day mission, schedule alterations were made during the last three days only, and consequently only one day (day 82) of sleep monitoring was affected. On this day the bedtime was advanced approximately two hours (to approximately 8 p.m.), and the subject was permitted a 10-hr total rest time (i.e., the time of awakening remained approximately 6 a.m.). These schedule alterations were necessitated

by the activities associated with splashdown and recovery operations, which required early awakening on the final day of the mission.

Upon return to Earth, postflight baseline studies were performed on each sleep monitoring participant. After the 28-day mission, recordings were done on nights 4, 6, and 8, and in the case of the 59-day mission, on the second, fourth, and sixth nights following splashdown. Following the 84-day mission, recordings were made on the first, second, and sixth nights.

Operational Factors

A period of elevated temperatures in the Skylab workshop prior to the arrival of the first crew (a result of loss of a portion of the solar heat shield during launch) resulted in two problems with respect to the sleep monitoring activities scheduled for the first mission. A number of the recording-cap electrodes suffered partial dehydration, and as a result, most of the data was lost during one scheduled recording night. In addition, the analog-tape recording system was damaged, and only two nights were successfully recorded.

The recording-cap problem during the first (28-day) mission necessitated use of caps intended for use on future flights and which had been stored in a cooler location on board the spacecraft.

The crew of the second manned Skylab mission (59 days) was supplied with a repair kit, which permitted refurbishment of the damaged recording caps by injection of supplementary electrolyte gel prior to use. In addition, repair of the recording system was attempted prior to the first night of recording. In general, these steps were successful, although one additional night was lost during the 59-day mission due to recording cap problems, and six nights of tape-recorded data were lost near the end of the mission when the recording system again failed.

Prior to launch of the Skylab workshop, the plan was to monitor sleep during only the first and second manned missions, and consequently only enough recording caps were placed on board to provide one for each scheduled night. When the schedule was later changed to include sleep monitoring on the final, or 84-day, flight, there were not enough caps remaining on board to permit use of a new unit for each recording session. Instead, the subject reused a single cap several times and injected additional electrolyte gel into the sponge electrodes before donning the cap each night. This technique was satisfactory, and the data quality remained high. Of the 18 sessions attempted during the 84-day mission, 17 were successfully accomplished. One night (night 50) was lost when power to the onboard hardware was lost after approximately two hours of recording.

A significant data loss also occurred on two additional nights of the 28-day mission and on one other night of the 59-day mission, stemming

from ground-based problems in the data-processing system.

In spite of the unforeseen problems, however, successful near real-time monitoring was accomplished on nine of the 12 attempted recording nights during the 28-day mission, on 18 of the 20 nights attempted on the 59-day mission, and on 17 of the 18 attempted sessions of the 84-day flight. Postflight return of the analog tapes permitted visual confirmation of the results on two of the nine nights of the 28-day mission, on 12 of the 18 nights of the 59-day mission, and on 17 of the 18 nights of the 84-day mission.

Statistical Analysis

The final results described below represent the best available estimates of the various sleep parameters. The results are, when possible, those obtained by visual analysis of the tape-recorded EEG, EOG, and head-motion signals, since this method is considered the most reliable and the least influenced by various artifactual components that may be present. In the instances where this was not possible, due to loss of recorded data on several nights, the results of onboard automatic analysis have been utilized after application of certain corrective factors based upon past performance of the system and, in the case of the 59-day flight, upon correlation of the inflight results with those of visual analysis for the nights on which both types of information were available.

Modification of Automatic-Analysis Results

The uncorrected results of automatic analysis consistently underestimated stage REM sleep. This occurred because the criteria for continuous stage REM indication used by the automatic system included the occurrence of at least one detectable rapid eye motion per 30-sec epoch. If such an eye motion did not occur, the output reverted to stage 1 or 2, as determined by EEG criteria alone. In most individuals, true stage REM occasionally occurs for periods longer than 30 sec in the absence of eye motion of sufficient amplitude to be detected by the automatic circuitry. Typically, then, the automatic system's output during a continuous stage REM period fluctuated between stages 1, REM, and 2. Such periods usually were readily identified by inspection of the plotted sleep profile. When the automatic data was modified by the assignment to stage REM of all time within such a period, the overall results were significantly enhanced. Such modification introduces an element of subjectivity into otherwise objective data; however, we believe this is justified in this case, since past experience has confirmed its validity.

Other than eliminating certain obviously artifactual sections of data (e.g., sections near the start of each sleep period, associated with cap-donning and electrode-testing procedures), the REM-modification step was the only corrective

factor instituted during the inflight portions of the Skylab missions.

Reliability of Automatic-Analysis Results

After the 59-day mission, we compared the results of modified inflight analysis with those of visual analysis of the taped data for 11 of the first 12 recording nights. The average (mean) error of automatic analysis based upon visually determined total rest-period time was as follows: total rest-period time, +1%; total sleep time, +4%; sleep latency, -0.3%. The average (mean) error of automatic analysis in sleep-stage determination (as compared to the same visually determined parameters) was as follows: % stage 1, +5.6%; % stage 2, -0.4%; % stage 3, -10.6%; % stage 4, -0.7%; % stage REM, +6.1%.

In most cases, then, automatic analysis gave satisfactory estimates of the actual value. The worst case, % stage 3 sleep, was apparently a result of the particular subject's sleeping pattern, in which a large proportion of the misclassified epochs were borderline in terms of stage 2 versus stage 3. The underestimation was consistent throughout all 11 comparison nights. The % stage REM overestimation, on the other hand, was not consistent and appeared to result solely from the inherent limitations of the automatic-analysis scheme in detecting this stage and in rejecting certain artifacts.

Similar comparisons between visual and automatic analysis were made following the 84-day flight for the 17 successful monitoring sessions. In this case, the average (mean) error of automatic analysis compared to the visually determined total rest-period time was as follows: total rest-period time, +1.2%; total sleep time, +4.4%; sleep latency, +0.9%. The average error of automatic analysis in sleep-stage determination (as compared to the visually determined parameters) was as follows: % stage 1, +1.6%; % stage 2, -11.4%; % stage 3, +7.9%; % stage 4, +6.1%; % stage REM, -4.2%.

Correction and Regression Techniques

Regression analysis, after correlation of automatic and visual results, provided a means for further modifying the results of automatic analysis for those six nights of the 59-day mission unconfirmed by visual analysis (i.e., nights 42, 45, 48, 52, 56, and 57, for which the analog-tape data was lost).

As noted above, the overall correlation between visual and automatic results for stage REM percentage was low and consequently could not be utilized for reliable prediction of the remaining six values. However, it was determined that stage REM values below 20%, as indicated by automatic analysis, were better correlated with visual results; consequently, regression analysis for this stage was based upon correlations of only six of the 11 nights (discarding nights 7, 8, 9, 12, and 29). Corrected REM values were thus predicted for five of the six remaining nights, discarding the value (30.4%) for day 48, which exceeded 20%.

These statistical maneuvers provided a consistent means for utilizing all the available information. The values obtained are included in the results presented below and were subjected to further statistical analysis along with the visual-analysis results, although it was determined that the overall significance of the results was the same, whether or not these values were included.

Analysis of Variance

Finally, for each mission, preflight, inflight, and postflight conditions for each parameter were treated by an analysis of variance. A posteriori comparisons were made in cases where the overall F test reached conventional levels of statistical significance ($p < 0.05$).

In summary, with respect to the final results outlined below (Results Section), of the nine nights recorded during the 28-day mission, only the first two are based upon visual analysis. The remainder are based upon the modified results of automatic analysis. For the 59-day mission, the results of the first 12 nights are based upon visual analysis, while the last six are automatic results modified both inflight in terms of REM period and postflight by the application of corrective factors based upon visual/automatic comparison on the first 12 nights. For the 84-day mission, all 17 nights are based upon the results of visual analysis.

Data Format

The data obtained during the three Skylab sleep monitoring experiments is presented in three forms: (1) sleep profiles showing the entire data set for each night in the form of a plot of sleep stage versus time; (2) tables in which parameters derived from the sleep profiles are listed for each recording session of the mission; and (3) graphs in which selected parameters are plotted versus mission day to illustrate trends and to compare data from the three flights.

Sleep Profiles

Preflight Baseline Studies

These profiles are based upon human visual analysis of the data obtained during the three preflight baseline studies of each participating crew member. Data for the 28-day mission, obtained two months prior to launch, is shown in Fig. 6. Results for the 59-day flight, obtained two weeks prior to launch, are illustrated in Fig. 7, and those for the 84-day mission, also obtained two weeks prior to launch, are presented in Fig. 8.

Inflight Data

The sleep profiles showing inflight data are of two types: those based upon onboard automatic analysis and obtained by telemetry in near real-time, and those obtained postflight by human visual analysis of the tape-recorded flight data returned by the crews.

Automatic-Analysis Profiles. The data presented in these plots illustrates the complete results of automatic analysis for the particular night under study. Occasional gaps in the plots indicate periods when the telemetry signal was lost (due to difficulties in the tracking and data-processing systems). The raw data presented in these illustrations was, as explained in the section on modification of automatic-analysis results, above, subjected to further modification techniques in order to eliminate artifacts and to increase the reliability of the stage REM indication. The areas subjected to modification are indicated by horizontal lines above the data plots (labeled M on the vertical scale), and the type of modification is indicated by the letter above the horizontal line. Thus, a line labeled R signifies that all data below the line was assigned to stage REM, regardless of the actual stage shown in the raw-data plot. Similarly, lines labeled A indicate that all data below the line is reassigned to the awake state.

These plots, with the indicated modifications, were utilized for sleep assessment during the inflight period of each mission, and they were the best estimate of the individual sleep characteristics prior to the analysis of the analog tapes after the conclusion of the mission. Data for the 28-day mission is presented in Figs. 9-12. Day 5 was of poor quality due to recording-cap problems (see above, Operational Factors). Day 7 was uninterpretable due to excessive data-loss periods. Day 11 was degraded because of further recording-cap problems, and day 25 was incomplete, since the subject neglected to don the recording cap at the start of the actual sleep period.

Automatic-analysis results for the 59-day mission are shown in Figs. 13-19. Day 39 was lost due to faulty electrode-cap function.

The results for the 84-day mission are presented in Figs. 20-26. Data was lost on day 50 after two hours, due to a power loss in the onboard hardware.

Visual Analysis. These profiles are the result of human visual analysis of the data played back from the onboard analog-tape recording system. These tapes were returned by the crew at the end of each mission, and the data thus serves as a check on the results obtained by automatic analysis during the mission.

The results for the 28-day mission are shown in Fig. 27 (days 5 and 6); data for the remaining 10 nights was lost due to a tape-recorder malfunction.

Visual-analysis results for the 59-day flight are shown in Figs. 28-32 (days 7, 8, 9, 12, 15, 18, 21, 24, 27, 29, 33, and 36). Results for the latter portion of the mission (days 35, 42, 45, 48, 52, 55, 56, and 57) were lost due to an onboard tape-recorder malfunction. Visual-analysis profiles for the 84-day mission are illustrated in Figs. 33-39.

Postflight Baseline Studies

As in the preflight studies, these profiles are based upon human visual analysis of the data obtained during three postflight monitoring sessions on each of the Skylab sleep monitoring experiment subjects. Following the 28-day mission, as shown in Fig. 40, data was obtained on the fourth (R+3), sixth (R+5), and eighth (R+7) nights following recovery. After the 59-day flight (Fig. 41), recordings were made on nights 2 (R+1), 4 (R+3), and 6 (R+5). The results for night 2 were incomplete, since the subject terminated recording after approximately four hours due to discomfort from the recording cap. Following the 84-day mission (Fig. 42), the subject was studied on the first (R+0), second (R+1), and sixth (R+5) nights.

Tables

The basic sleep data from each all-night sleep profile, described above, was subjected to further ground-based computer analysis in order to determine selective parameters of value in estimating the overall quantity and quality of sleep during the mission. In all cases, the results of visual analysis (V) were used whenever this information was available. For the case of the 28-day mission (Table I), visual-analysis results were available for the first two nights only. For the final seven nights, the data is based upon the modified results of automatic analysis (MA), as shown in Figs. 10-12.

During the 59-day mission (Table II), a tape-recorder malfunction resulted in data loss for visual analysis on days 39 through 57. The data shown for these nights in Table II was based upon modified automatic-analysis (i.e., Figs. 17-19) results, which were further enhanced by the correlation and regression analysis technique described previously (MCA).

All data in Table III for the 84-day mission is based upon visual analysis.

The average values shown in the tables represent the means of the values in each category, preflight, inflight, and postflight.

Graphs

The graphs of individual sleep parameters are utilized below in the discussion of changes in sleep characteristics during Skylab. These plotted values

are, in all instances, the same as those indicated in the tables for the corresponding mission.

Data Quality

Data quality, as evaluated by visual inspection of the signals played back from the analog tapes returned at the conclusion of each mission, was generally excellent. Although recorder malfunctions occurred during the 28- and 59-day missions, the data recorded prior to the failures was, in both instances, of high quality. During the 84-day flight, the recorded signals were of clinical quality throughout the mission.

Selected examples of the EEG, EOG, and head-motion signals as played back from the onboard tapes are shown in Figs. 55-60. Figs. 55 and 56 illustrate the transition from the awake, alert state through the various stages of sleep for the scientist-pilot on day 6 of the 28-day mission. A similar series for the subject of the 59-day flight is illustrated in Figs. 57 and 58, which were obtained during day 29. Examples from day 3 of the 84-day mission are shown in Figs. 59 and 60.

RESULTS

Sleep Latency

Sleep latency is the amount of elapsed time from the onset of the sleep period (i.e., bedtime) until the first appearance of stage 2 sleep. Sleep-latency characteristics observed during the three Skylab missions are summarized in Fig. 43. Average inflight, preflight, and postflight figures for this parameter are indicated in Tables I, II, and III. Sleep latency varied considerably during the 28-day mission (Fig. 43A), ranging from a low value of 3.6 minutes on day 21 to a maximum value of 45 minutes on day 19. Day 19 (Fig. 11) was, however, the only instance in which the latency exceeded the preflight values, and the average inflight value of 18 minutes actually represents a decrease of 20 minutes as compared to the preflight average of 37.8 minutes. Postflight values were all relatively low but well within the inflight range. Statistically, the inflight and postflight latencies were less than the preflight values ($p < 0.01$)

No statistically significant changes in sleep latency were noted during the 59-day mission, as indicated in Fig. 43B, although on several days the values were somewhat above the preflight average of 12 minutes. This parameter ranged from a low of 4 minutes on day 21 to a maximum of 24 minutes on day 45. A cyclic fluctuation in sleep latency was suggested, with maxima near days 10, 29, 45, and 52. The inflight average value (12.6 minutes), however,

was almost exactly the same as the preflight value. The postflight latencies, averaging 9.6 minutes, are only slightly less than either the pre- or inflight measurements.

Sleep latency during the 84-day mission averaged almost the same inflight (15.6 minutes) as preflight (16.2 minutes), but it dropped to an average of 7.8 minutes postflight (Table III). Although the averages do not reflect a significant change, inspection of Fig. 43C reveals a preponderance of longer latencies in the first half of the mission and a decline as the flight progressed. The average value for the first half (days 3 through 40) was 21.4 minutes, while that for the latter half (days 45 through 82) was 9.7 minutes.

In general then, there was no evidence of difficulty in falling asleep in either the 28- or 59-day mission, while in the 84-day flight, values somewhat above baseline were seen in the first half of the mission but declined to normal or below normal in the final portion.

Sleep Time

A commonly used measure of sleep adequacy is the total sleep time obtained in a given sleep period (i.e., total rest-period time minus total time spent awake). Fig. 44 illustrates the total rest-period length (overall amplitude of vertical bars), total sleep time (solid portion of bars), and total awake time (dashed portion of bars) for each Skylab recording night and for the pre- and postflight baseline studies.

It is apparent that in the 28-day mission (Fig. 44A), there was a reduction of total sleep time throughout the inflight period as compared to the pre- and postflight studies. Postflight, total sleep time was significantly greater than the pre- and inflight values ($p < 0.05$ and 0.01, respectively). As indicated in Table I, the inflight average of 6.0 hours is almost one hour less than the preflight value of 6.9 hours and more than two hours less than the postflight average (8.5 hours). This decrease in sleep time, however, was due not to an unusual amount of time spent in the awake state but to a reduction in the total rest-period time itself. The subject thus slept quite well on most nights while he was in bed; however, he did not spend as much time in bed as he did during studies either before or after the mission.

The postflight average value for total rest-period time (8.9 hours) was significantly higher than the inflight average ($p < 0.01$) but did not differ significantly from the preflight value.

No significant changes in the total sleep/total rest characteristics were obtained during the 59-day mission, as shown graphically in Fig. 44B. The total rest time (overall height of bars, Fig. 44B), which averaged 7.3 hours inflight (Table II), was only slightly lower than either the preflight average of 7.5 hours or the postflight value of 7.8 hours. In terms of total sleep time

(solid bars, Fig. 44B), although there was considerable fluctuation, only one day (52) was below the range established during the preflight series, and the subject obtained in excess of 5 hours' sleep on all other nights. The inflight average value of 6.3 hours (Table II) is nearly the same as the preflight average (6.4 hours) and slightly lower than the postflight results (average, 6.6 hours).

A wide range of variation in the total rest and total sleep times was seen during the 84-day mission (Fig. 44C). Total rest time ranged from a minimum of 6.4 hours on day 10 to a maximum of 9.8 hours on days 24 and 82. This parameter averaged 8.06 hours preflight, dropped by 30 minutes to 7.56 hours inflight, and then rose to 7.67 hours postflight. Although most of the inflight period was marked by considerable variation from one recording session to the next, there was a consistently lowered total rest time during the observations of the first 19 days. The five values of this period averaged 6.86 hours, or 1.2 hours below the preflight average.

Total sleep time tended to parallel total rest time, and thus long periods of time spent awake during the night were, in this mission as in the others, rare. Sleep time ranged from a low of 4.88 hours on day 4 to a high of 9.37 hours on day 24. The inflight average value of 6.69 hours is about 36 minutes below the preflight average of 7.29 hours but is approximately 10 minutes higher than the postflight result of 6.53 hours. As in the case of total rest time, total sleep time also was considerably lower during the first 19-day period. During this time, the average value was 5.87 hours, or 1.42 hours below the preflight average.

Of interest is that while the initial 19-day period was characterized by a reduced time in bed and correspondingly reduced total rest time, it was also marked by a higher value for total awake time (0.99 hours average) compared to either the preflight average (0.77 hours) or the overall inflight average (0.87 hours).

Sleep-Stage Characteristics

Sleep-stage characteristics for the three missions, expressed as percentages of the total sleep time for each recording night, are illustrated in Figs. 45-47. Average percent figures for the various stages in the preflight, inflight, and postflight periods are listed in Tables I, II, and III. Comparisons of individual stage characteristics for the three missions are illustrated in Figs. 48-52.

If the average values are considered, stages 1, 2, 3, and REM were not significantly altered during the inflight period of the 28-day mission (Fig. 45). Stage 1 occupied 5.3% of the total sleep time preflight and averaged 6% inflight and 5.1% postflight. The day-to-day inflight characteristics show a considerable

fluctuation in stage 1 percent, with a tendency toward slightly decreased values in the latter portions of the flight (days 19 through 26). Stage 3, averaging 14.8% in the preflight period, rose slightly to an average of 16.0% inflight and dropped to 12.2% postflight. As seen in Fig. 45, a small increase in the stage 3 percent average was largely a result of moderate increases in this stage on days 24 and 26 at the end of the mission. Stage REM decreased only slightly from a 22.2% preflight average to 17.9% inflight, although again there was considerable variation throughout the flight, with some tendency toward a more marked decrease near the end of the mission. The postflight stage REM average (25.0%) was somewhat higher than either the pre- or inflight values, but it did not attain statistical significance.

Fairly clear-cut changes were seen in stage 2 and stage 4 percentages. In both cases, the most obvious alterations were seen in the last few days of the flight. Stage 2 dropped from an average of 54.8% preflight to 43.4% inflight, returning to 56.6% postflight. These differences, however, were not significant. Similarly, stage 4 rose from 2.9% preflight to 16.7% inflight, then dropped significantly ($p < 0.05$) postflight to 1.1%.

Thus, the 28-day mission was characterized by increased percentages of stages 3 and 4 and corresponding decreases of stages REM, 1, and 2, with the alterations confined primarily to the last few days of the flight.

Sleep-stage features for the 59-day mission are illustrated in Fig. 46, and average values are tabulated in Table II. Stage 1, averaging 8.8% preflight, showed considerable variation inflight but averaged almost the same (8.9%). The postflight average value of 10.2% was only slightly above the inflight result. Stage 2 remained fairly consistent throughout (preflight, 56.3%; inflight, 59.7%; postflight, 57.8%). Thus, neither stage 1 nor stage 2 changed significantly. Stage 3 was similar inflight (17.5%) and preflight (17.4%) and also exhibited a change near the termination of the flight, tending to increase slightly. The postflight average of 10.1%, however, was significantly lower ($p < 0.01$) than either the pre- or inflight values. This subject showed very little stage 4 sleep in his preflight study (2.8%), and this parameter decreased significantly ($p < 0.05$) inflight (1.4%) and postflight (0.4%) ($p < 0.05$). Stage REM showed the greatest alteration, dropping from 14.7% during the preflight baseline series to 12.1% inflight, and then rising significantly ($p < 0.01$) to 21.6% postflight. This postflight increase in REM was also significantly greater than the preflight value ($p < 0.05$). The REM decrease seen inflight was most prominent in the final phase of the study (days 52, 56, and 57).

Sleep-stage characteristics for the 84-day flight are summarized in Fig. 47, and the average values are tabulated in Table III. Stage 1, averaging 8.9% preflight, dropped inflight to 6.8%, then rose postflight to 9.4%, a value slightly higher than the preflight average. There were no clear-cut trends discernible over the inflight course of the mission. The stage 2 values were relatively consistent during the inflight period, and the average value of 58.5% was

identical to the preflight average. Postflight, stage 2 showed a small increase, averaging 66.1% for the three days. As indicated in Fig. 47, the stage 2 values of the first two postflight days were significantly higher than any of the values preflight or inflight. Stage 3 was not significantly different inflight (8.8%) as compared to the preflight value (7.1%). Postflight, however, this parameter fell to an average of 2.7%, with all three values falling well below the pre- and inflight averages. This subject showed very little stage 4 preflight, averaging only 0.2%, and maintained a low level throughout the flight, with the inflight average at 0.5%. There was a further reduction postflight, with the average value less than 0.1%. Stage REM percent averaged 25.3 preflight, and the inflight average remained at 25.3%. There was considerable variation in this parameter over the course of the mission, however, but no definite trends were observed. Although the postflight average of 21.8% was slightly lower than either the preflight or inflight average value, it is obvious (Fig. 47) that this parameter was not stable in the postflight period. The value of 12.1% on the first postflight night is significantly lower than any of the pre- or inflight values for this characteristic. On the other hand, the value of 34.6% seen on the sixth postflight night is considerably higher than any of the values seen preflight or inflight.

REM Latency

REM latency is the elapsed time from sleep onset (i.e., the first appearance of stage 2 sleep) until the onset of the first stage REM period of the night. Because of the relative unreliability of this measurement when derived from the results of automatic analysis, only the values obtained from visual analysis have been reported below.

Compared to preflight values, this measure was shortened during the postflight periods of the 28- and 59-day missions. During the 28-day flight (Fig. 53A and Table I), the REM latency averaged 1.5 hours preflight and 1.1 hours postflight, or a decrease of 24 minutes. Although substantial, this decrease was not statistically significant. The phenomenon was more apparent during the 59-day mission, as illustrated in Fig. 53B. In the preflight baseline period, the values ranged from 1.6 to 2.2 hours, with an average latency of 1.9 hours (see Table II). The inflight values showed considerable fluctuation, but the average of 2.1 hours was not significantly different compared to the preflight results. In the postflight period, however, the latency dropped to 0.9 hours, which represented a decrease of 1 hour below the preflight findings. This postflight REM latency was significantly ($p < 0.01$) less than both pre- and inflight values.

REM latencies during the 84-day mission (Fig. 53C and Table III) showed little change in the inflight period compared to either pre- or postflight studies. The inflight average value of 1.31 hours is not significantly different from the

1.47 hours figure seen preflight, while the value of 1.46 hours seen postflight is almost identical to the preflight result. Note that the first postflight night exhibited a relatively long REM latency, while the latter two postflight nights were marked by much shorter periods.

REM-Period Characteristics

In order to determine the influence of spaceflight upon the cyclical or periodic nature of sleep, the temporal occurrence of REM episodes throughout the night was studied. The length of each REM period was determined, and the average value for the parameters was found for each preflight, inflight, and postflight night for which visually analyzed data was available. Similarly, each REM-cycle length was determined (i.e., the elapsed time between the onset of sleep and the onset of the first REM period and, subsequently, the elapsed time between the onset of one REM period and the onset of the next), and the average value of this measure for each night was calculated. Data for the three missions is presented in Tables IV-VI.

No significant alterations in these parameters were seen during or following the 28-day flight (see Table IV).

During the 59-day mission (Table V) and postflight, there was a small reduction in the average REM-period length (20.7 minutes preflight, 16.0 minutes inflight, and 16.2 minutes postflight), and several inflight daily average values fell considerably below the range seen preflight. A similar trend was seen with respect to the REM-cycle length, which averaged 128.3 minutes preflight, 102.5 minutes inflight, and 73.1 minutes postflight.

The 84-day mission results were similar to those of the 59-day flight in that a small reduction in both the average REM period and REM-cycle length was observed (Table VI). REM-period length, which averaged 31 minutes preflight, was 22.6 minutes inflight and 20.6 minutes postflight. The REM-cycle length, averaging 108 minutes preflight, dropped to 81.8 minutes inflight and was 90 minutes postflight.

Number of Awakenings

The number of awakenings per night was calculated for the data based upon human visual analysis only, and this information is presented comparatively in Fig. 54.

The 28-day flight was characterized in the preflight period by an average of 19.7 awakenings per night, with a range of 16 to 24 (Table I). The postflight average was 22, with a range of 20 to 26. Although only two inflight nights are available for comparison, in both instances the number of awakenings was below

the pre- and postflight levels.

The number of awakenings during the preflight baseline series for the 59-day mission ranged from 34 to 51, with an average of 40.7 (Table II). Inflight a greater range was seen, extending from a low of eight on day 33 to a high of 70 on day 9, with an average of 39.3. Postflight the average number of awakenings dropped to 28.5, with a range of 26 to 31. The number of arousals seen during the inflight portion of this mission peaked at day 9 and tended to decline toward baseline or sub-baseline levels as the flight progressed.

In the case of the 84-day mission (Table III), the number of arousals declined from a preflight average of 20.7 (20 to 21) to an inflight average value of 12, with a range of 6 to 22. Postflight, the level rose to an average of 18.7, with a range of 11 to 24. Although the inflight period was characterized by considerable variation in this measure, there was no consistent trend noticeable.

SUBJECTIVE REPORTS

Although subjective reports of sleep characteristics are often not quantitatively correct when compared to the results of objective sleep monitoring studies utilizing EEG and EOG, in many instances they do reflect an accurate estimate of the overall quality. During Skylab, there were numerous references to sleep made by the crew members in their conversations with Mission Control, and these are preserved in the transcripts of spacecraft-to-ground communications. In addition, comments concerning sleep were made spontaneously and in response to specific questions during the postflight debriefing sessions held after each mission. During the 59- and 84-day missions, sleep logs were kept by all three crewmen, in which they recorded their estimates of the quantity and quality of each night of sleep. Data gathered from these sources is summarized below for each mission. Although the M133 Sleep Monitoring Experiment was performed by the scientist-pilot only, subjective observations made by all three crewmen are included.

28-Day Mission

Subjective sleep logs were not maintained during this mission as they were during the 59- and 84-day flights; in general the crew members felt that sleep was adequate, and no particular problems of a long-term nature were reported. All three astronauts felt that they slept less inflight than they had been accustomed to on the ground, but they did not feel that the reduction in time was detrimental. In fact, they did not feel that they required

more sleep than they actually obtained. The extra time was utilized for reading or other personal recreation, and the eight-hour total rest period was felt to be beneficial even though not always used for sleep.

The sleep-restraint system was considered to be quite functional, and according to the CDR it was a significant improvement over the methods utilized in prior spacecraft.

The occasional periods of elevated temperature present in Skylab were considered to have interfered with sleep to some extent, and the sporadic noise generated by certain equipment on board occasionally resulted in brief arousals from sleep.

The M133 system caused no particular problems, although the SPT felt that the recording cap resulted in some mild discomfort, and this may have occasionally influenced sleep characteristics.

59-Day Mission

The crewmen were satisfied with the functioning of the sleep-restraint system and felt that it, in some respects, simulated the pressure sensations of 1 g. In general, they felt that sleep was better when the Skylab temperature was cooler. There were complaints about the lack of soundproofing and light-proofing in the individual sleep compartments: Sleep was difficult if one crewman was active while the others attempted to sleep.

The SPT commented on how pleasant it was to sleep in space, and he felt that he was receiving approximately the same amount of sleep as he was accustomed to on the ground. He also commented that on the few nights when he did not sleep well, or long enough, the lack of sleep seemed to affect him more the next day than a comparable sleep loss would have on the ground. A similar comment was made by the CDR, who noted that on the ground he might miss considerable sleep during the week and yet make it up on the weekends without its affecting his performance, but in space it seemed to affect him immediately the next day.

All crewmen, in general, felt that they slept well. Falling asleep was not a problem, and the SPT commented that he almost enjoyed waking up because he then had the pleasure of returning to sleep. The Skylab equipment noises were somewhat bothersome during the first few nights in space.

It was noted that the M133 cap was more bothersome in the postflight period due to the pressure on the head. The SPT felt that he lost perhaps an hour of sleep during the R+1 study due to the discomfort.

The SPT commented that he rarely felt as tired at the end of a day in space as he might have after a comparable day on Earth. He went to bed because he felt that he needed the sleep, but he usually had the impression that he could easily have stayed awake longer. The CDR, however, stated that he did feel tired at the end of the day, and he had not noticed a difference in this aspect peculiar to spaceflight.

The subjective reports of sleep estimates for each day of the mission, as recorded in the crew logs, are presented in Table VII for all three crewmen. Medication used during the 24 hours preceding the sleep period is also indicated in this table. A comparison of the objective (M133) data with the SPT's estimates is illustrated graphically in Fig. 61.

84-Day Mission

The three crew members were unanimous in their opinions that sleep quality was greatly enhanced by the sleeping bag restraint systems. Attempts were made by at least two of the astronauts (SPT and CDR) to sleep without restraints on several occasions while drifting freely. Although they felt that they did sleep to some extent under this condition, sleep was intermittent and was not considered to be sound. The restraints apparently produced a sensation somewhat similar to gravity, and this contributed to the ability to fall asleep and remain asleep. In addition, when drifting freely there was intermittent contact with various items which apparently served as arousal stimuli.

The SPT reported no difficulty in operation of the M133 system and expressed the opinion that the recording cap did not interfere with his sleep. He found the cap more comfortable in zero g than he had under 1 g conditions. The only significant problem noted with respect to the M133 Experiment was the necessity to clean excess electrolyte gel out of his hair each morning following use of the cap, a job requiring approximately five minutes. He experienced some difficulty in plugging the cap umbilical cable back into the control unit when it was necessary to get up during the night.

Occasional and intermittent bouts of insomnia were reported by all three astronauts, especially during the first 28 days of the mission. The crew members attributed this, in part, to unusually long working hours (several 18-hour workdays) in the early days of the mission, with insufficient time in the presleep period to relax and "wind down." No specific problems were delineated, and they experienced at various times difficulty in falling asleep, arousals from sleep, with a prolonged time necessary to return to sleep, and early awakenings. The SPT apparently experienced the most-pronounced difficulty, primarily during the first 28 days; then he began to sleep fairly well, with only sporadic problems for the remainder of the flight. However, he felt strongly that the problems encountered were "man made" (i.e., due to overscheduling problems), and he did not feel that the zero g environment per se was a factor. Dalmane and

promethazine/ephedrine were occasionally utilized to promote sleep, with the promethazine/ephedrine providing the best subjective response.

All crewmen were asked to report any changes in their sleep characteristics which had occurred postflight as opposed to pre- and inflight. The SPT felt that he had been much more conscious of dreaming postflight, and he felt that he did not dream noticeably inflight. The CDR noted that during the first two-thirds of the mission his dreams were 1 g but changed to zero g during the last third of the flight. The PLT did not routinely recall dreams preflight and noted no change in this characteristic either inflight or postflight.

During this mission, each crew member routinely reported his own estimate of his sleeping quantity and quality upon arising each morning. These results are presented in Table VIII for the CDR, Table IX for the PLT, and Table X for the SPT. In addition to sleeping characteristics, each table indicates the medication taken by each crewman over the course of the mission. The information shown in Table VIII (CDR) is summarized graphically in Fig. 62, while that of Table IX (PLT) is plotted in Fig. 63. A similar graphic representation for the SPT (Table X and Fig. 64) also includes, for ease of comparison, the actual sleep and rest times as determined objectively from the M133 data. It is apparent that in almost every instance, on days when M133 data was available, the subject's estimates of total sleep time corresponded closely to the subjective measure of total bed time. In a few instances (e.g., days 72, 77, 80, etc.), his estimate of "heavy sleep" coincided with the objective measure of total sleep time, but in most cases there was no correlation.

DISCUSSION

Overview

Sleep Latency

The three Skylab flights differed with respect to sleep-latency characteristics. No significant changes in this parameter were noted during the course of the 59-day mission. During the 28-day mission, the inflight and postflight latencies were significantly lower than the preflight values. The 84-day flight was characterized by relatively long sleep latencies in the early portion of the flight, with a return to values typical of the preflight and postflight periods in the latter half of the mission.

The alterations seen during the 28-day mission are apparently explainable, at least in part, by a difference in the subject's routine rather than by a direct

environmental influence. This individual typically spent a few minutes reading in bed prior to falling asleep during the preflight studies in his own home. However, he did not continue this practice either during the flight or in the postflight period.

In only the initial portion of the 84-day mission was a degradation in sleep latency seen. As illustrated in Fig. 43C, even in this case the magnitude of the alterations seen was not great, and on only two nights were the values outside the range seen during the preflight studies. In addition, it is significant that these alterations occurred in the early portion of the study and thus cannot be attributed to the longer duration of this mission. Consequently, it appears reasonable to conclude that spaceflight and the associated weightless condition do not significantly interfere with the process of falling asleep, although in some individuals there may be an adaptive period during which some difficulty is experienced.

Sleep Time

The greatest overall change in total sleep time occurred during the 28-day mission when a decrease of approximately one hour was seen inflight compared to preflight. As indicated previously, this was a voluntary reduction in sleep time by the subject himself and thus cannot be considered as insomnia. The subject did not complain of sleep loss and apparently was sleeping as much as he actually required. No significant changes in sleep times were noted during the 59- or 84-day mission. If the initial portion of the 84-day flight is considered separately, however, it is evident that the subject experienced some difficulty in sleeping during this time. Sleep was also subjectively more of a problem to this individual, and he indicated on several occasions that his sleep was not adequate. Sleeping medication was occasionally used by the subject, although not on the nights which were monitored.

Of the three subjects, then, only the one studied during the 84-day flight experienced real difficulty in terms of total sleep time. In this case the problem diminished with time, although sleeping medication was used sporadically throughout the flight. Regarding sleep loss in terms of any possible adverse effect upon performance capability, it seems likely only during the initial period of the 84-day mission. This cannot be precisely assessed because of the long sample intervals; however, even generalizing the worst case (4.9 hours on day 4), a severe influence upon performance would not be expected during this period.

Sleep-Stage Characteristics

Several changes in sleep-stage characteristics were common to all three flights. Stage 3 (Fig. 50), which was significantly elevated during the inflight portion of the 28-day mission, also rose inflight, though not significantly, in the 59- and 84-day flights. Postflight, the stage 3 and stage 4 (Fig. 51) values

were below the preflight average in all three flights, although statistical significance was achieved in only the 28- and 59-day missions. A consistent elevation of stage REM (Fig. 52) was seen in the late postflight period of all flights and was accompanied by a shortening of REM latency. In the 59- and 84-day missions, a slight decrease in the average REM-period length and the average REM-cycle length was noted inflight and postflight.

Number of Awakenings

Although this measure was highly variable, in general the inflight period of all missions was characterized by no overall increases in number of arousals, and in the case of the 84-day mission, there were significantly fewer awakenings.

Significance of Results

The results obtained during the three Skylab missions suggest that prolonged spaceflight, with its accompanying weightless state, is not directly associated with major adverse changes in sleep characteristics. The alterations in sleep patterns that were observed to occur were not of sufficient magnitude to result in significant degradation of performance capability. These conclusions were somewhat unsuspected, particularly in view of the pre-Skylab reports of sleeping difficulty that were frequently recorded during the Gemini and Apollo flights. At that time, the suspicion arose that the zero-g state might, itself, in some way disrupt the normal sleep-wakefulness mechanisms. It had been suspected that the altered sensory input to the central nervous system associated with weightlessness might interfere with sleep onset, result in prolongation of the sleep-latency increase, and lead to long periods of wakefulness following arousals from sleep. The Skylab results, however, show that in none of the missions was sleep latency a significant problem over the course of the flight, and in only one case (the 84-day flight) was it even a temporary difficulty. Furthermore, there was no evidence of consistently increased amounts of time spent awake during the night; in fact, the number of awakenings tended to decrease inflight. The results indicate that during spaceflight of long duration it is possible to obtain adequate amounts of sleep during regularly scheduled eight-hour rest periods.

The most consistent and significant changes were actually observed in the postflight period of all flights, and they pertained to sleep-stage characteristics. Thus, stages 3 and 4 tended to be decreased in the postflight period as compared to both pre- and inflight results while stage REM was elevated in the late postflight period (after day R+3) and was accompanied by a shortening of REM latency.

The postflight changes in stage REM are worthy of further consideration. Since such findings are typical of the rebound effect seen following periods of relative deprivation of stage REM, the question of a significant deprivation inflight arises. This question is, however, somewhat difficult to accurately

assess. When the overall averages are considered, there appears to be no significant decrease in REM inflight. However, when the individual data points are considered (Fig. 52), there is a suggestion that perhaps REM percent did decline in the terminal portion of the flights. This tendency is most prominent in the case of the 28-day mission, in which a relatively steady decline in stage REM percent is evident after day 17. Such a trend is less obvious in the case of the 59-day mission, although the last two days are below the preflight average value. In the case of the 84-day flight, the latter portion of the mission shows only a slight indication of a decrease in stage REM. Even though the results appear to argue against a prior period of REM deprivation inflight as a contributing factor, it must be emphasized that recordings were not made during the last two nights of each mission, and consequently this situation cannot be fully assessed.

A shortening of REM latency was observed in the late postflight period of all missions and accompanied the increase in REM percent noted during that time. This phenomenon has also been reported as a manifestation of a prior period of REM deprivation. Arguing against REM deprivation as a causative agent of this change is that no lessening of the effect was evident even on the sixth night following recovery of the 59- and 84-day missions nor after the eighth night following the 28-day mission. Similarly, it seems unlikely that the changes in stage REM can be attributed to alterations in the astronauts' sleep schedules (i.e., the advances in bedtime near the termination of each mission). It has been reported that delaying sleep periods by four hours results in a shortening of REM latency, but such findings have not been reported with comparable advances in sleep onset. Furthermore, while delaying sleep periods has been found to increase REM percent, advancing sleep periods resulted in a decrease in REM percent (Taub and Berger, 1973).

The data from the postflight period of the 84-day mission further suggests that the increase in REM percent seen late postflight is actually a delayed phenomenon and follows a period of relative REM suppression in the immediate recovery period. In fact, the REM percent value of 12.1% on the first night following recovery is well below any REM percent value seen either preflight or inflight. The value seen on day R+5 in the late postflight period is correspondingly well above any value seen either pre- or inflight. Delayed REM rebound is not a typical finding in experimental situations involving REM deprivation. It has been reported following periods of total sleep deprivation, in which case there is an elevation of stages 3 and 4 in the first recovery night and a later elevation of stage REM. However, in none of the three Skylab flights was a postflight elevation of stages 3 and 4 noted, and in fact these parameters tended to decline. Consequently, in these cases a delayed REM rebound appears to argue against prior sleep deprivation as the cause of the postflight REM changes.

In view of these findings, it seems plausible that the decreased REM latency and increased REM percent represent a true influence of the reinstated 1-g condition and that this signifies a basic alteration in the sleep-wakefulness mechanism

of the central nervous system.

It has been postulated that sleep, and in particular the REM stage, may be of importance in the organization and maintenance of memory (Gaarder, 1966; see also reviews by Dewan, 1970, and Greenberg, 1970). According to this view, REM may be involved in consolidation or reprogramming of short-term memory into a more permanent or long-term form. If this hypothesis is correct, then it might be predicted that tasks associated with acquisition of new motor skills and coordinated motor activity might be associated with an increased need for stage REM sleep.

In support of this conclusion, Zimmerman et al. (1970) have found that during the period of adaptation to an inverted visual field, REM time was increased. Following a decline to relatively normal levels after adaptation, reinverting the visual field to normal was again accompanied by an increase in REM-sleep amount. The situation in spaceflight may be analogous, since the withdrawal of gravitational cues and the decrease in proprioceptive input and altered vestibular input place a considerable burden upon the visual system as the sole means of maintaining spatial orientation. Following the mission, the return to Earth similarly required a period of adaptation to the 1-g condition. It might be speculated, then, that the increase in REM time seen postflight was a manifestation of this hypothesized mechanism. There is no evidence in the Skylab data that adaptation to zero g is accompanied by an increase in REM time, and in fact the inflight values were either the same or lower than preflight values. However, the hypothesis cannot be adequately evaluated, since no sleep data was obtained prior to day 3 in any of the flights, and thus pertinent changes could conceivably have been missed. If such inflight changes were present, however, they evidently were of shorter duration than those seen postflight, in which case changes were seen out to day R+8.

CONCLUSIONS

The objective results of these sleep monitoring experiments indicate that man is able to obtain at least adequate sleep over a prolonged time in space and that this can be accomplished during regularly scheduled eight-hour sleep periods. The alterations in sleep patterns that were observed during these missions were not of the type nor of sufficient magnitude (with the possible exception of the initial portion of the 84-day mission) to result in significant degradation of performance capability. The most notable changes seen actually occurred in the postflight period, and this suggests that perhaps the readaptation to 1 g is somewhat more disruptive to sleep than is the adaptation to zero g. Yet, even in this case, the alterations seen were those of sleep quality and not quantity. It is also worthy of emphasis, particularly with respect to the results seen during prior spaceflights, that none of the Skylab

crewmen complained excessively of sleeping difficulties. In fact, most reported no problems with respect to sleep, and some expressed the opinion that sleep was perhaps better in space. Viewed overall, these results are somewhat surprising because of the frequent complaints of insomnia during pre-Skylab missions. Apparently, the problem encountered during earlier spaceflights was not due simply to the imposed zero-g environment. The Skylab orbiting laboratory differed considerably from spacecraft of the Apollo and Gemini types, although the gravitational and atmospheric factors were the same in all cases. The working volume of the spacecraft is the most likely influencing factor in terms of sleep. Skylab provided adequate room for separate eating, exercising, working, and sleeping areas in 12 763 ft^3 of living area. The Apollo spacecraft measured only approximately 3% of this volume, while the Gemini contained less than 1%. In these smaller spacecraft, all daily tasks were made more difficult, and the astronauts undoubtedly had a greater sense of confinement. In addition, Skylab allowed the establishment of a daily routine which was, in most respects, directly comparable to ground-based, everyday activity. The subjects maintained their Houston-based time reference throughout the flight and worked during conventional hours for the most part. The individual sleeping compartments were a definite improvement over the prior spacecraft systems, and undoubtedly interference with sleep caused by activity of other crewmen was greatly minimized or eliminated. In general, the element of risk or danger, which is present in all spaceflights, seemed to be minimized in Skylab by the presence of an established daily routine, and this also may have contributed to the improvement in sleeping conditions.

The results also suggest areas for future study with respect to the acquisition of scientific data and in terms of man's overall adaptation to life in space. As indicated previously, the changes in sleep-stage characteristics seen postflight possibly represent a direct influence of the altered gravitational factors upon the sleep-wakefulness mechanisms. Future experiments, if properly designed, could provide information of basic importance to our understanding of sleep. In terms of human capabilities, we feel confident that flights of two to three months will not be jeopardized by sleeping difficulties, but beyond this point we must continue to carefully evaluate sleep and ensure proper work-rest scheduling.

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FIGURES

DEVELOPMENT AND APPLICATIONS OF THE SLEEP MONITORING SYSTEM
NASA CONTRACT SUPPORT

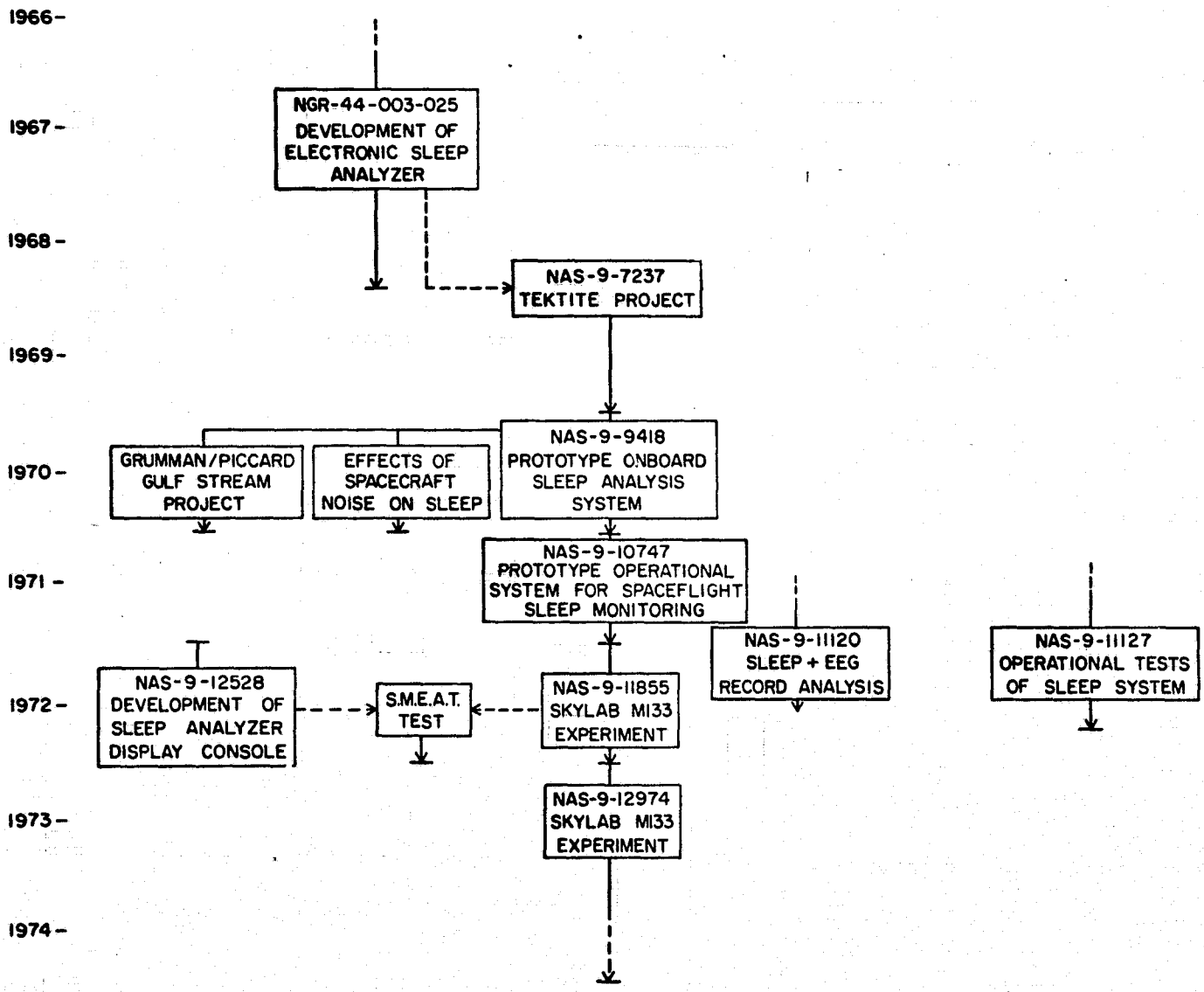


FIG. 1

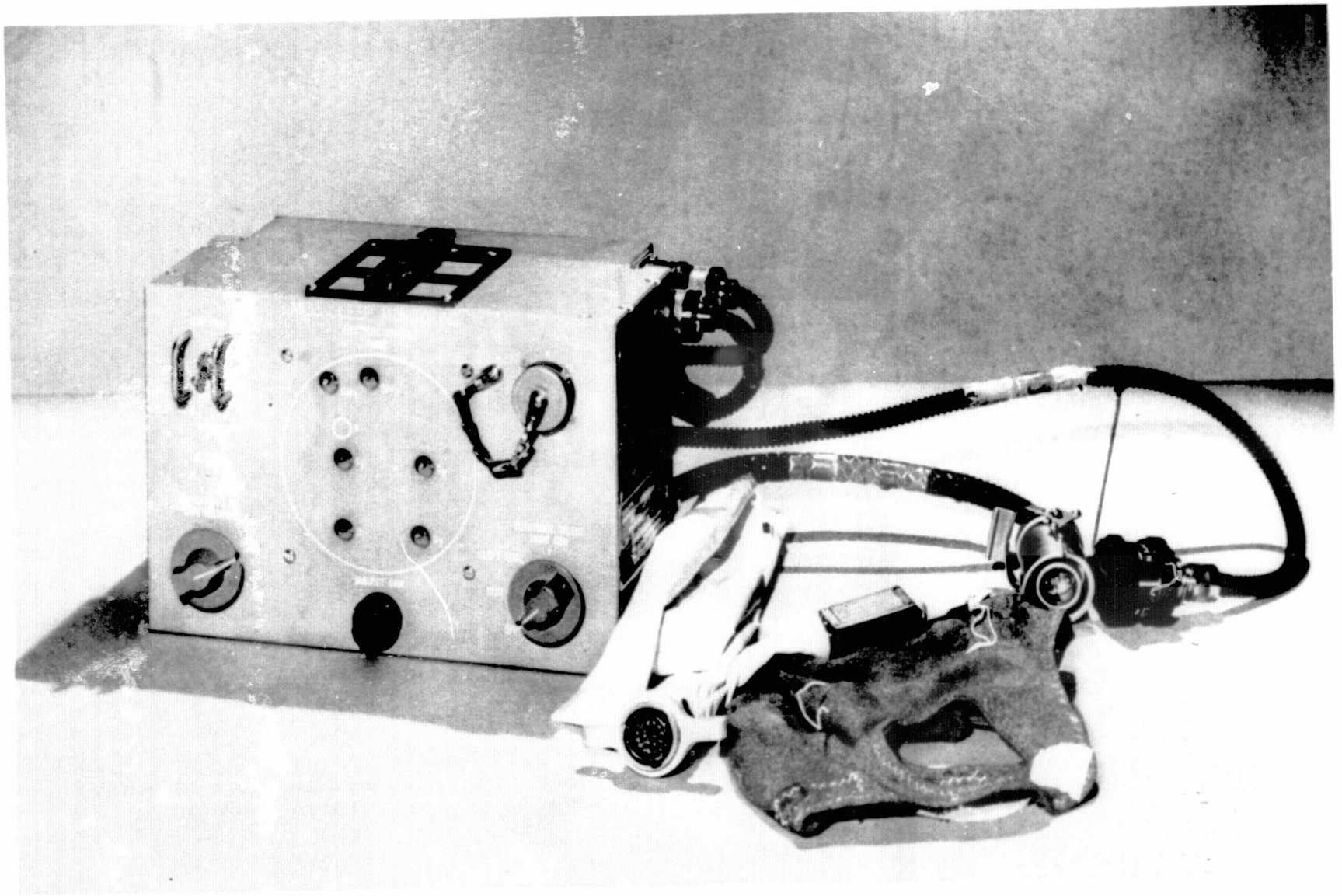


FIG. 2

FIG. 3

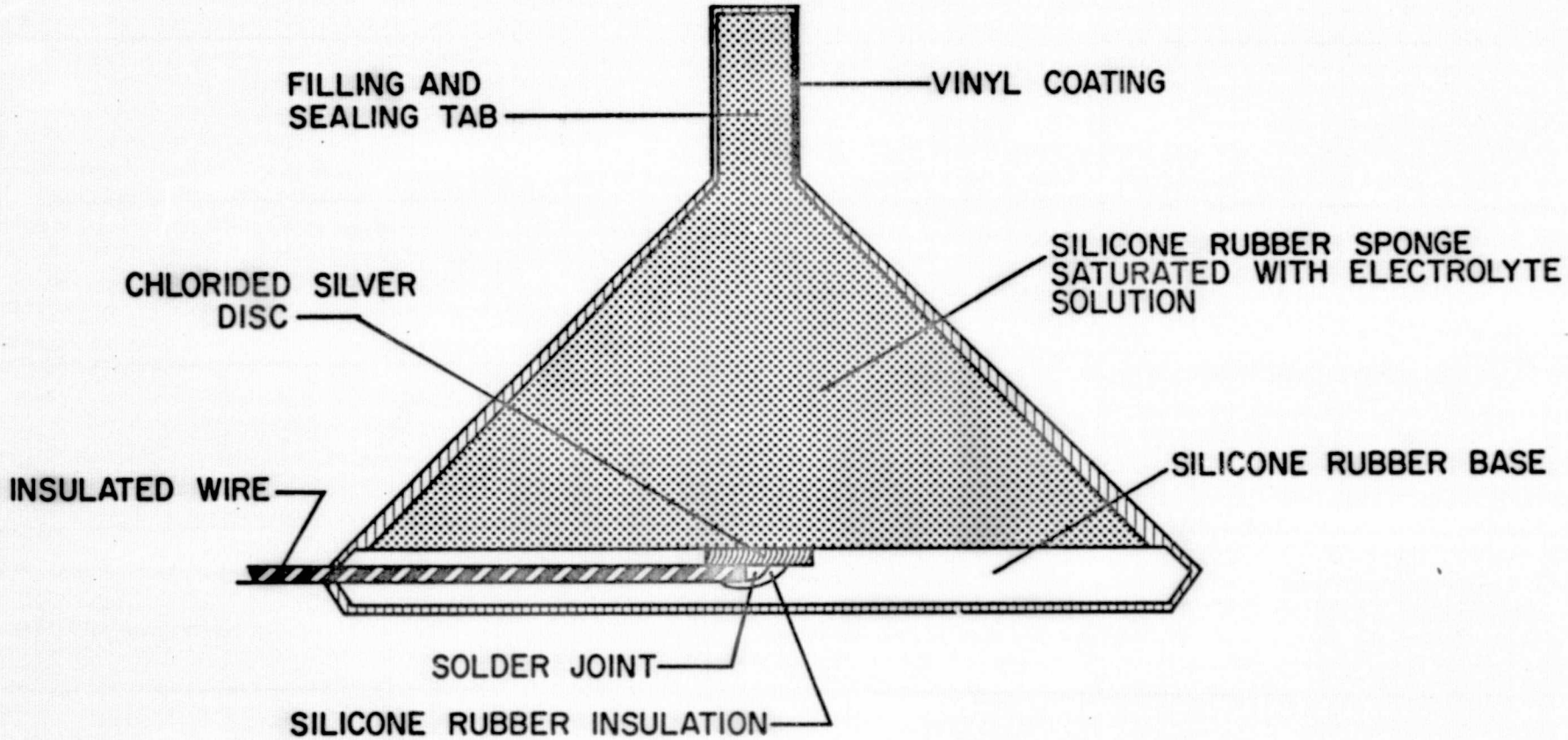


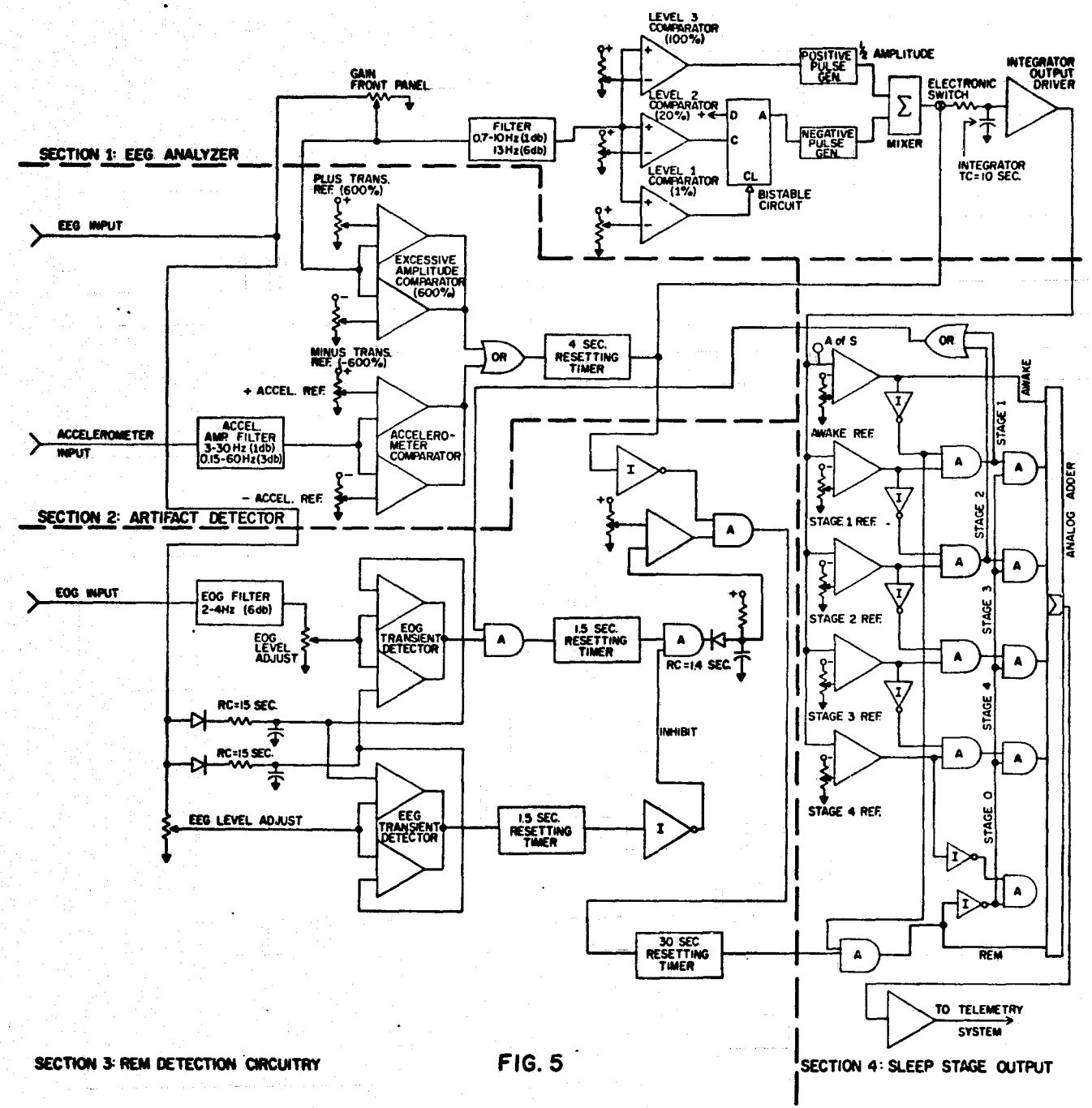
FIG. 4A

CROSS SECTION OF

PREFILLED SPONGE ELECTRODE

FIG. 4B

FIG. 4C



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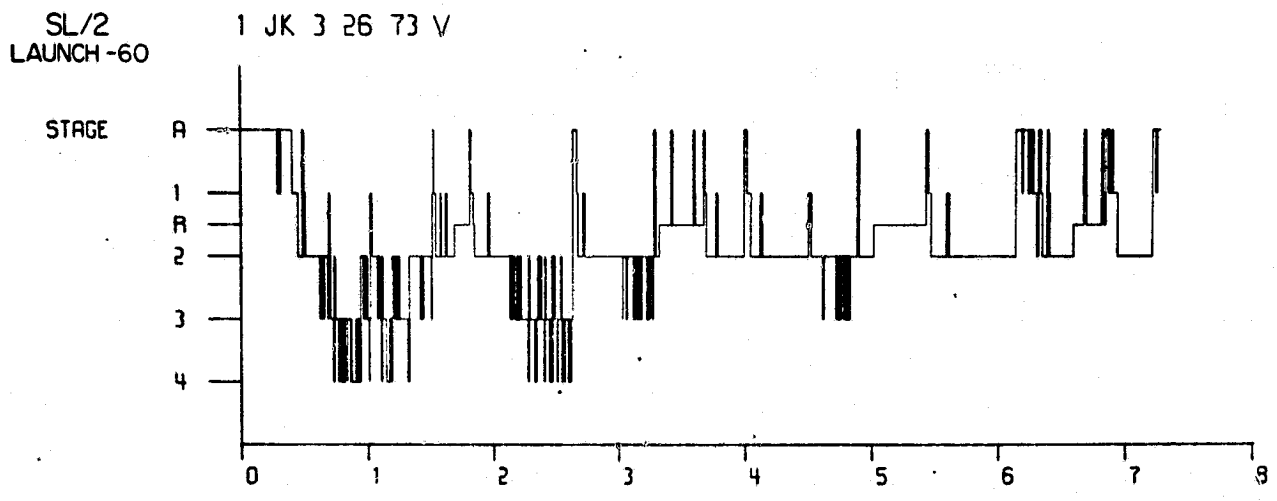

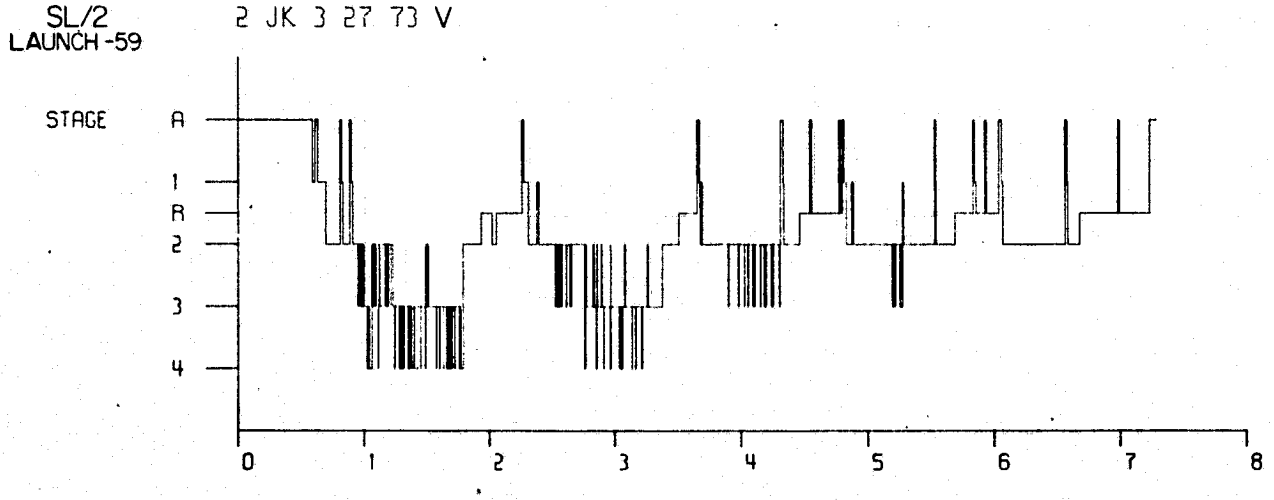

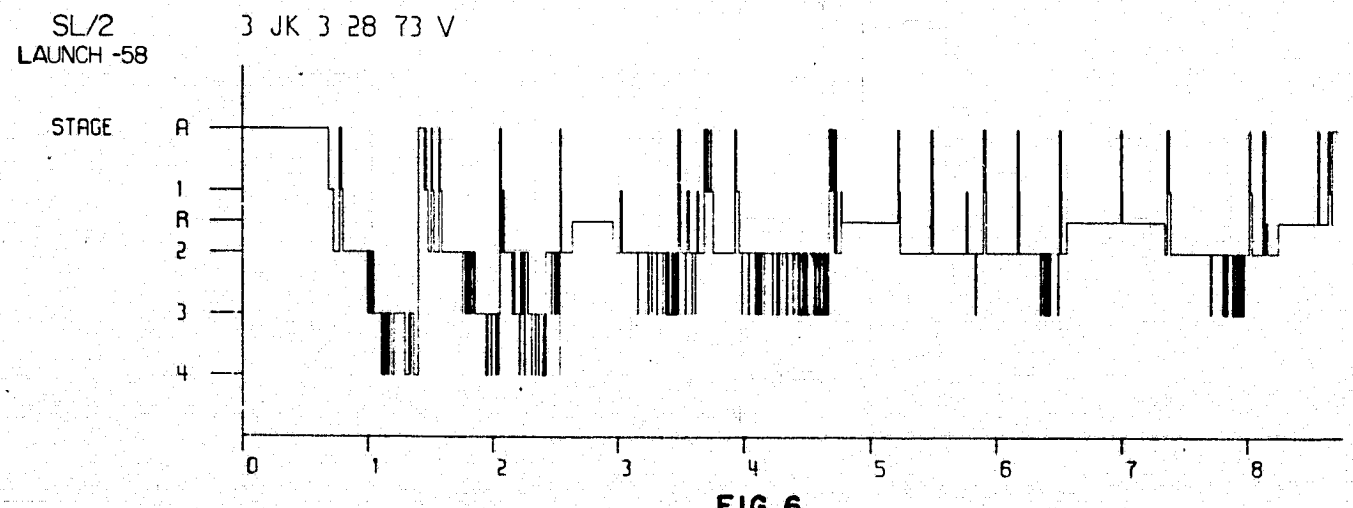

FIG. 6

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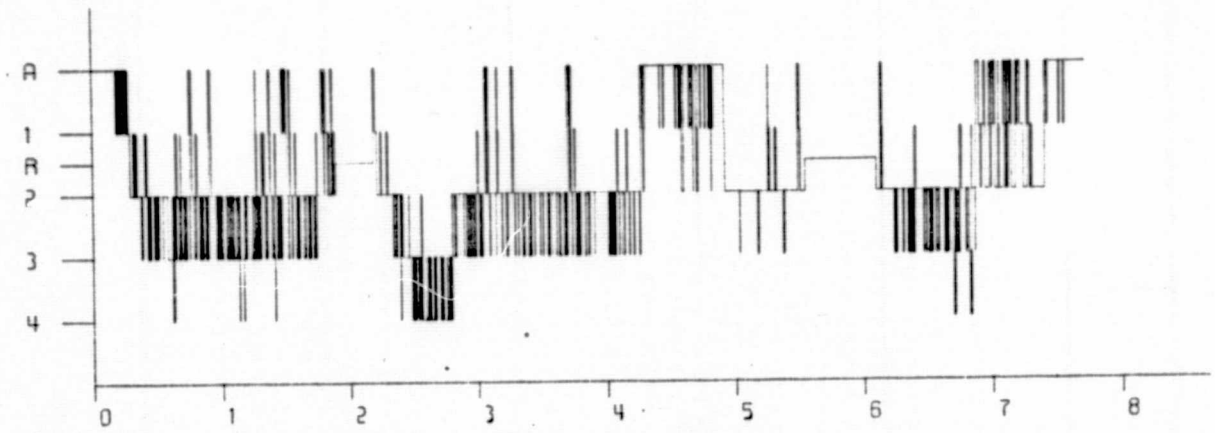

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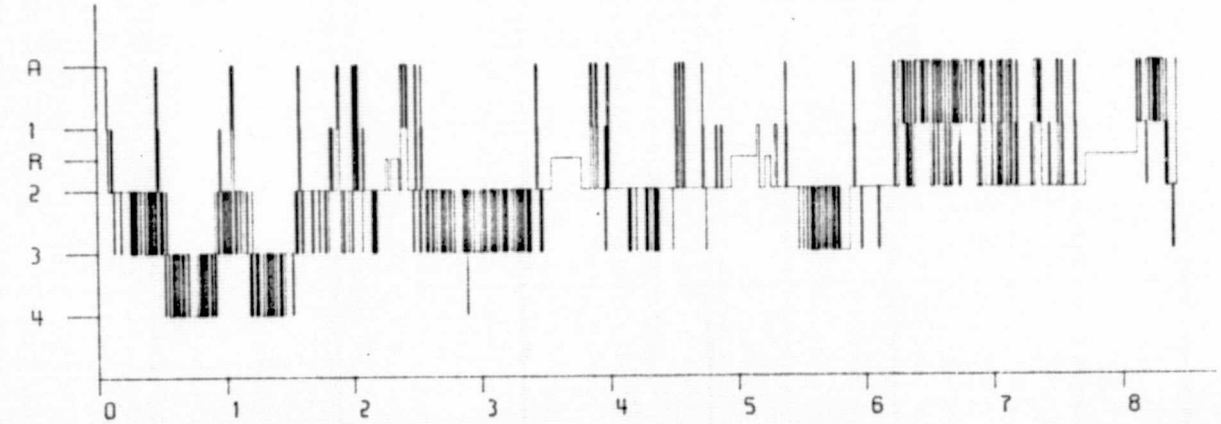

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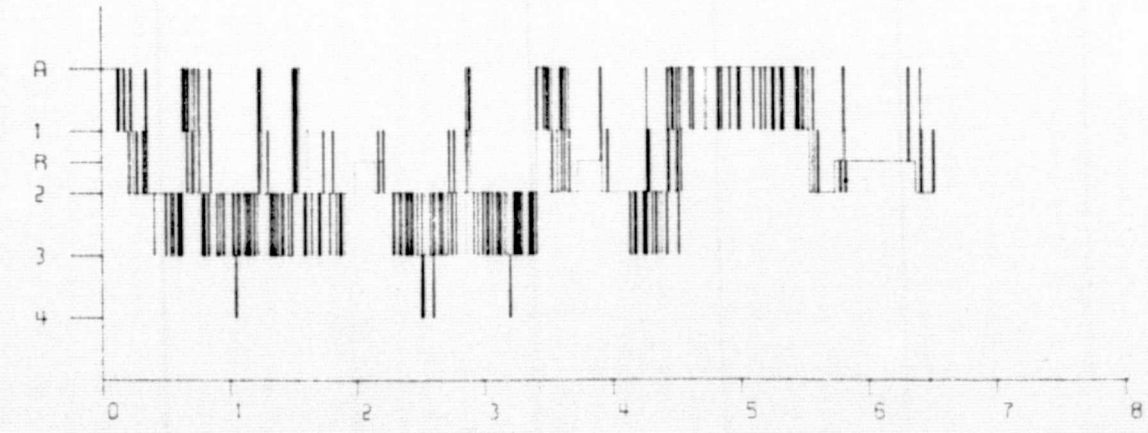

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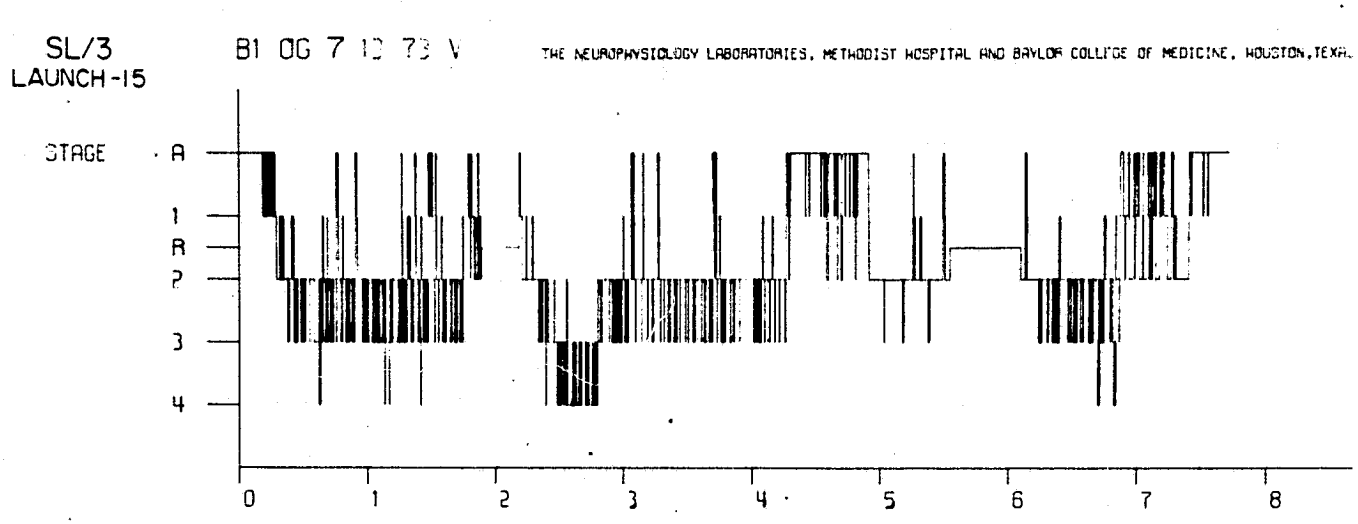
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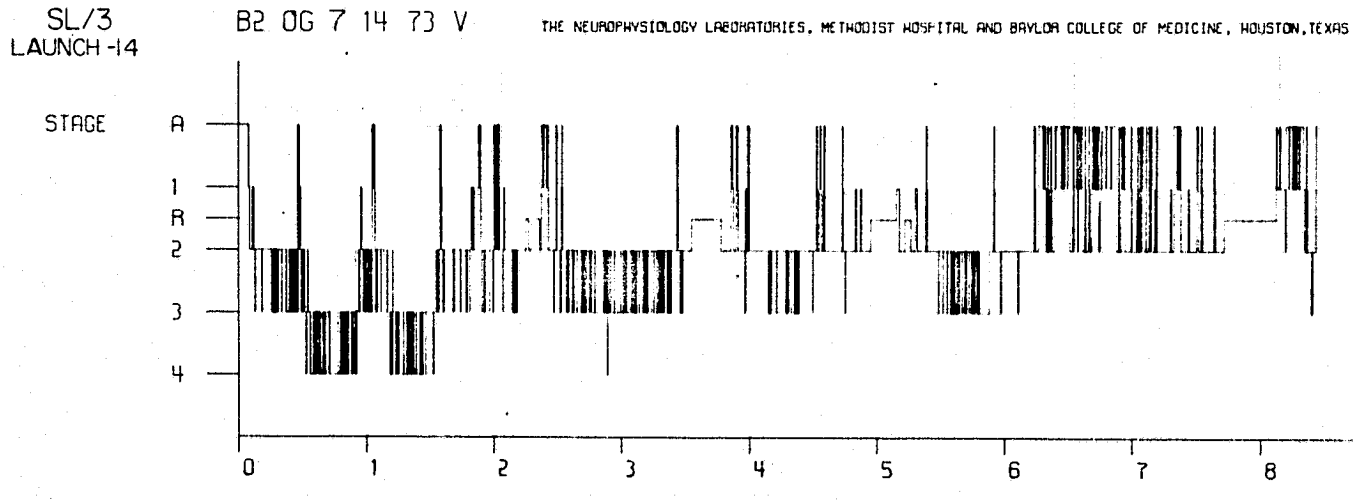
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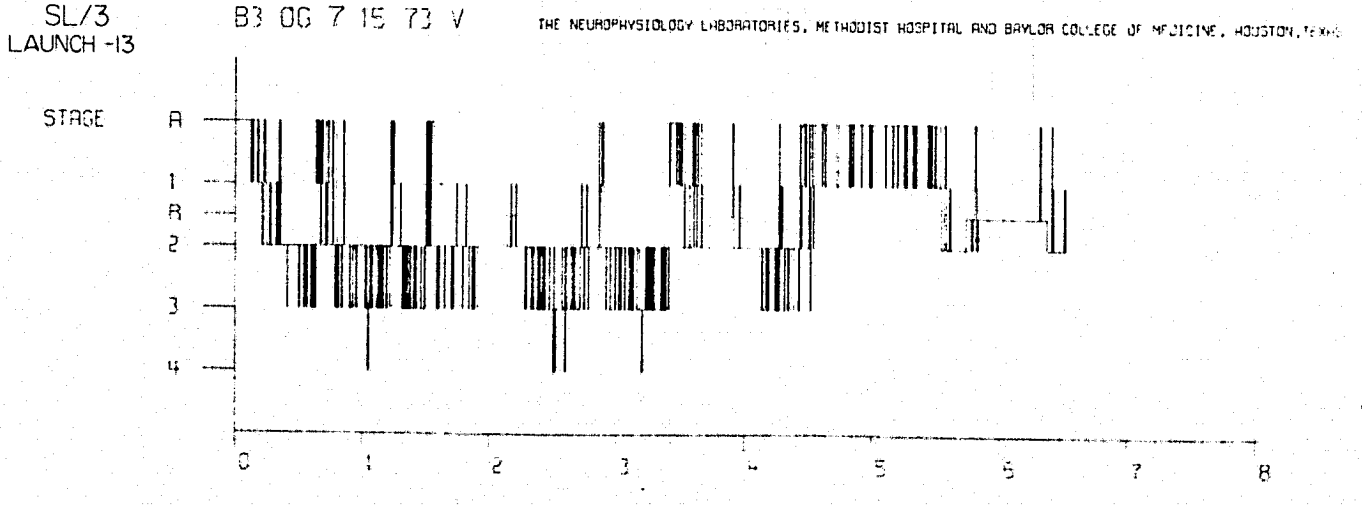
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FIG. 7

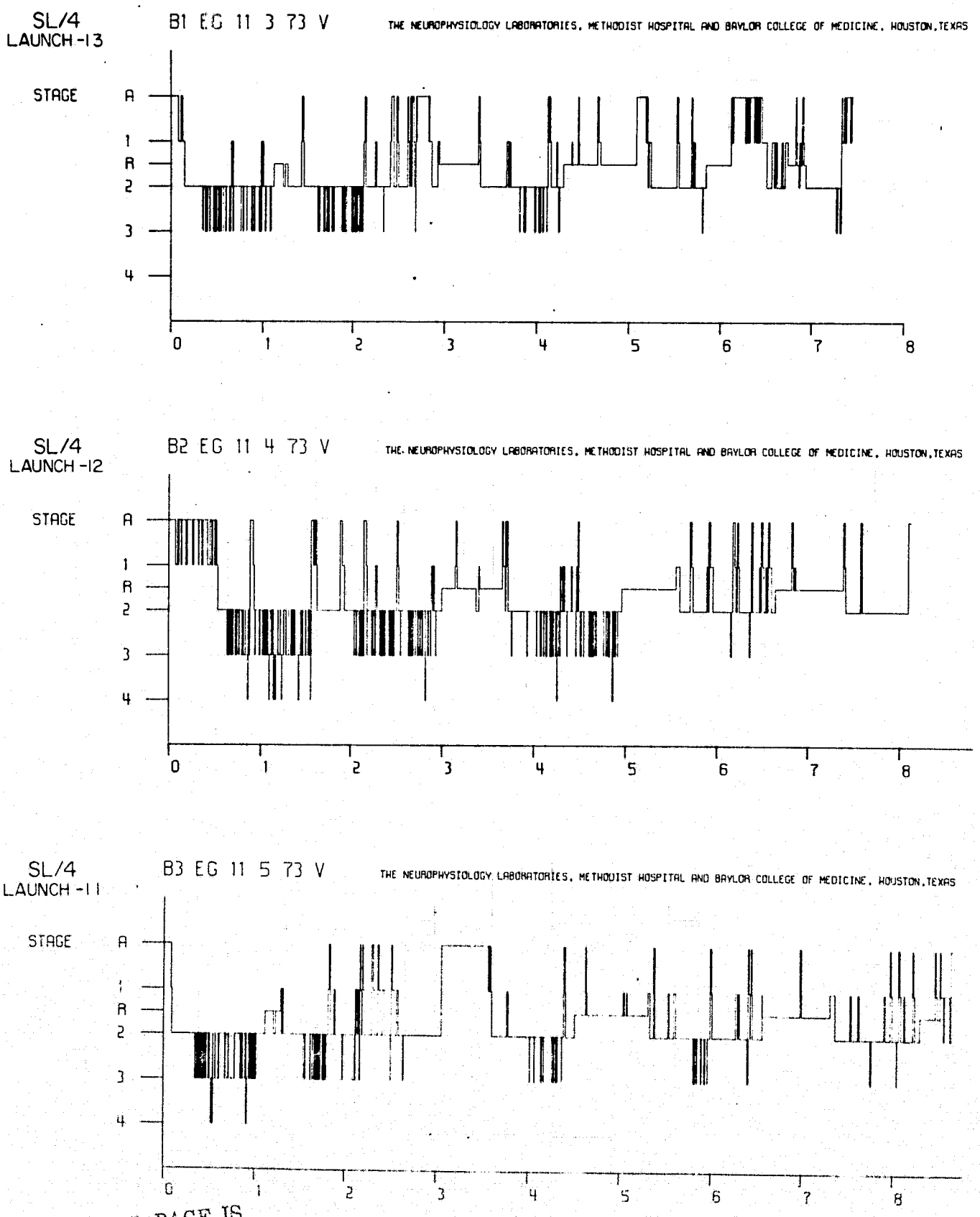

FIG. 8

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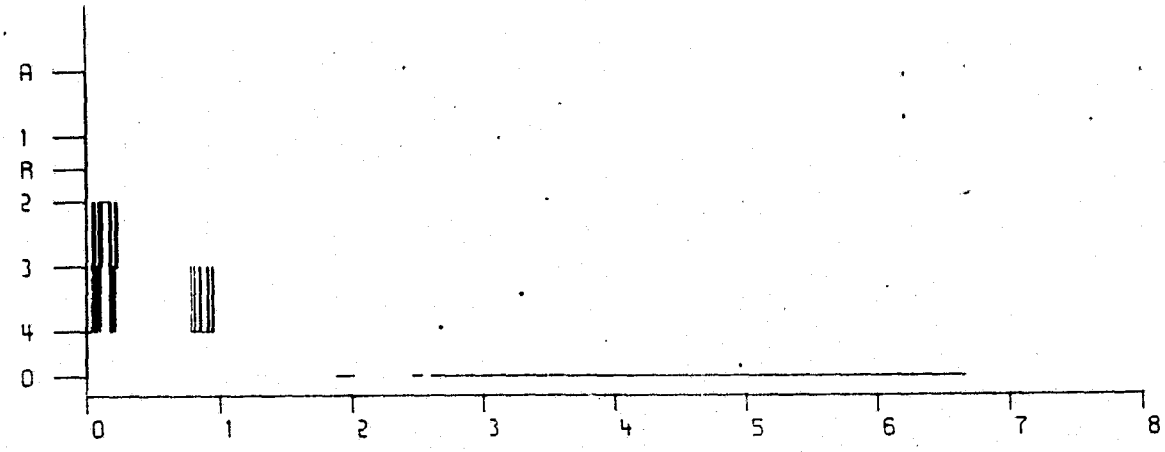

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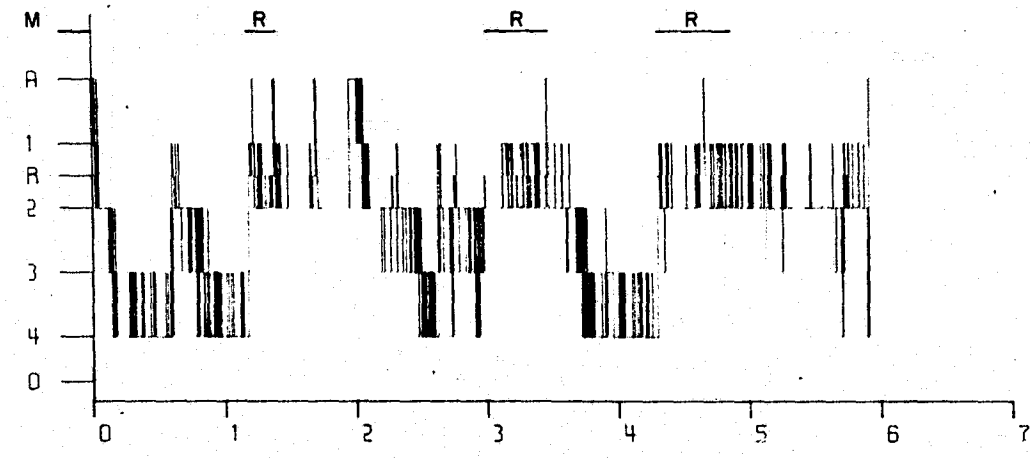

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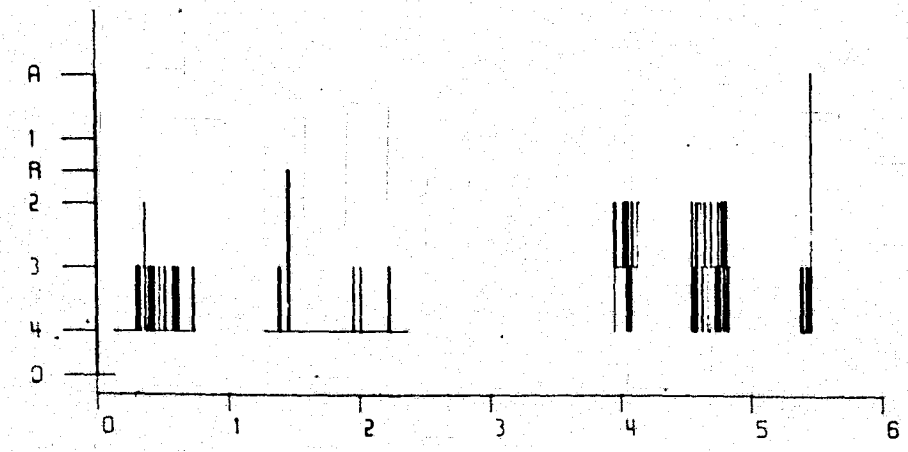
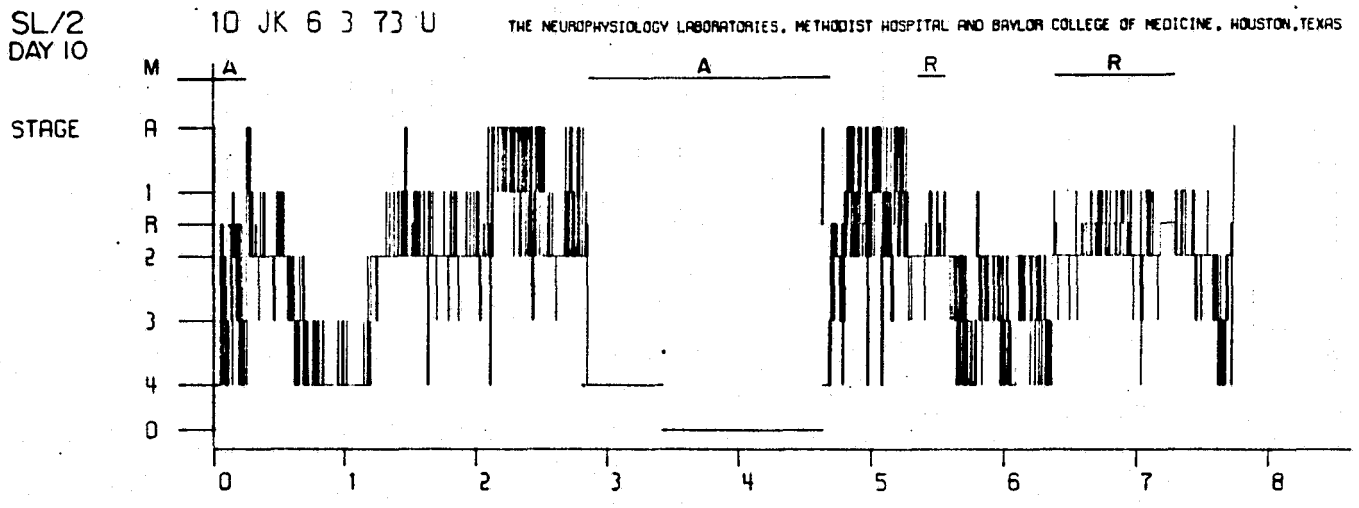


FIG. 9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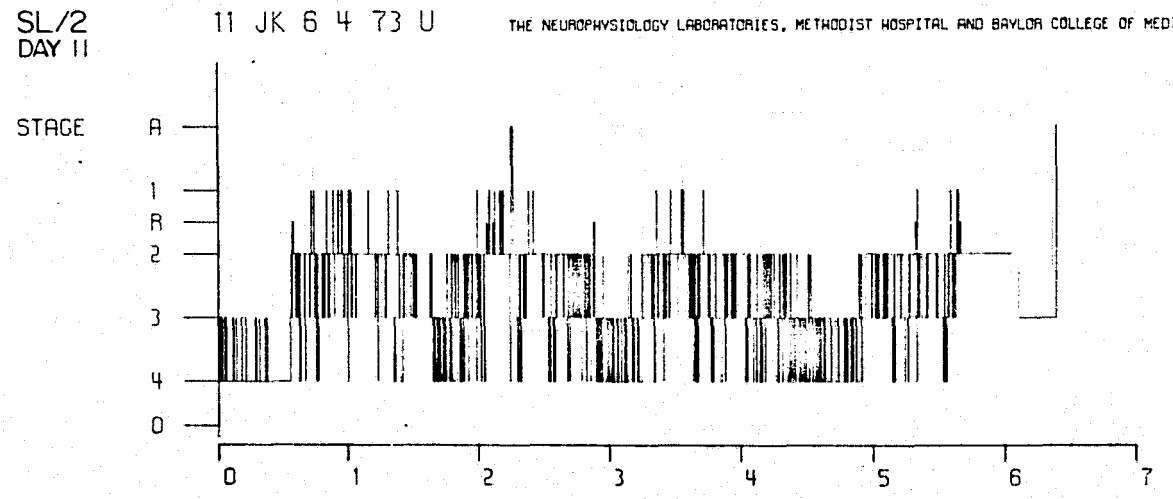
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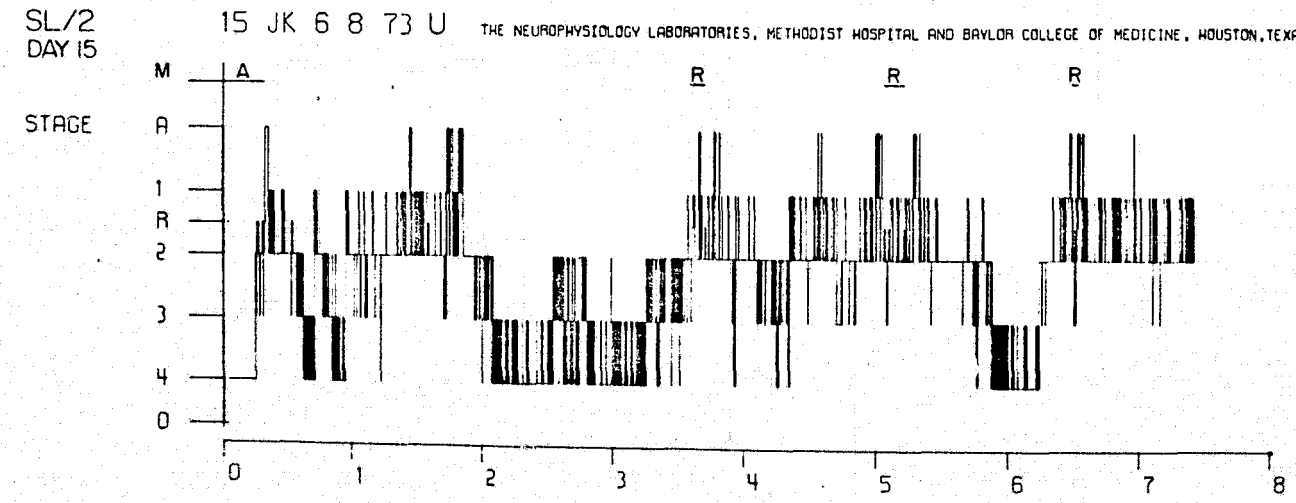
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FIG. 10

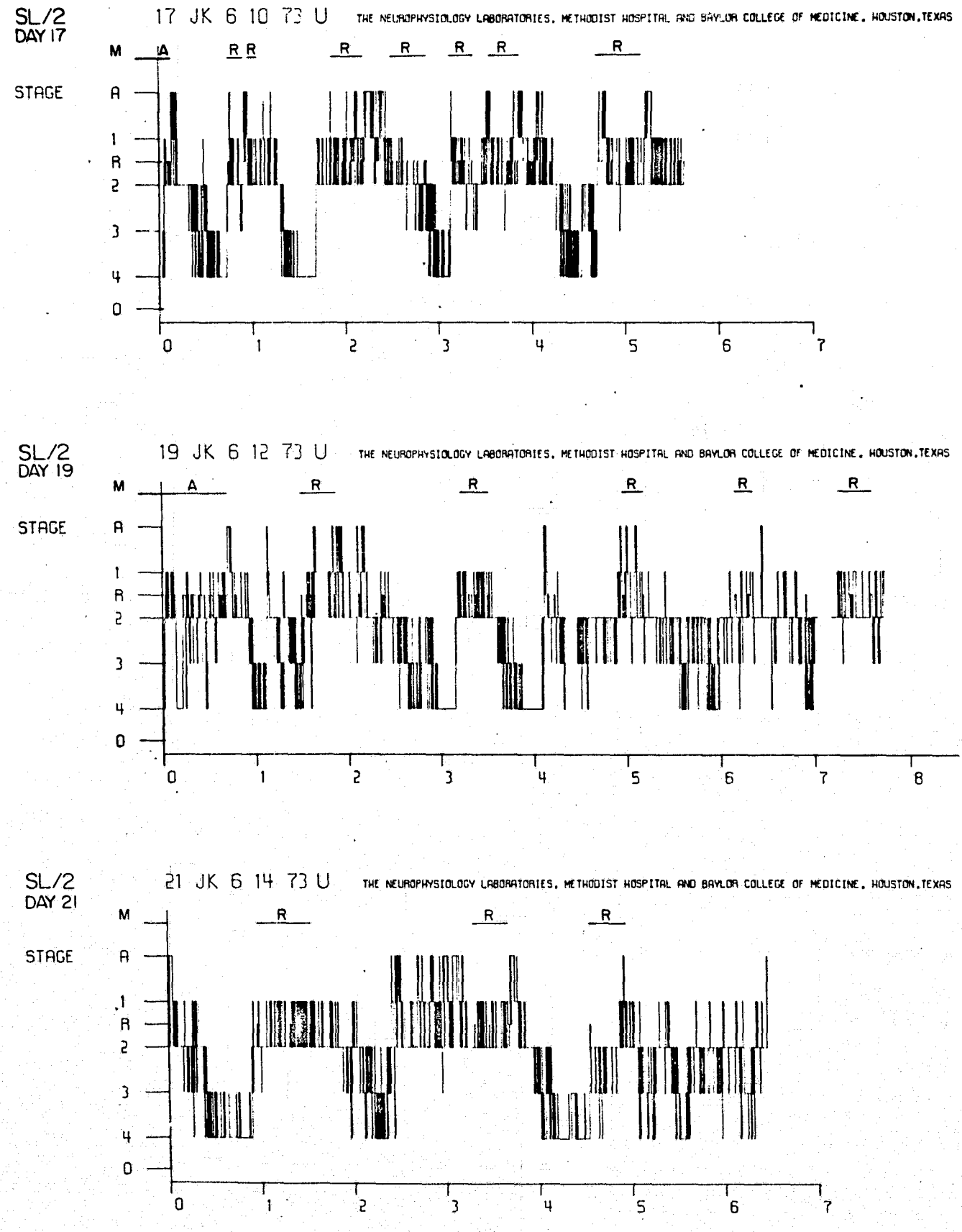
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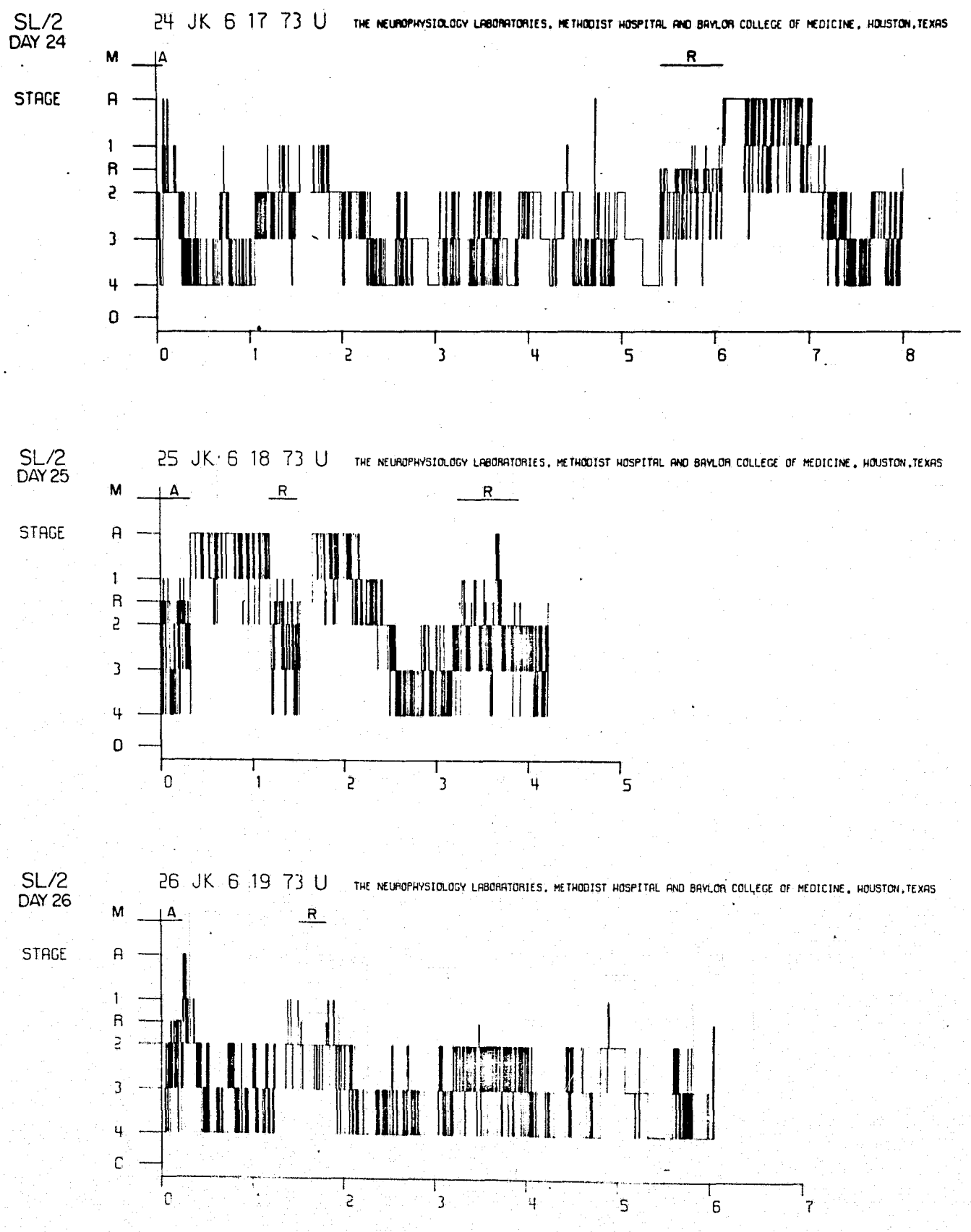
FIG. 11


SL/2
DAY 24
24 JK 6 17 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
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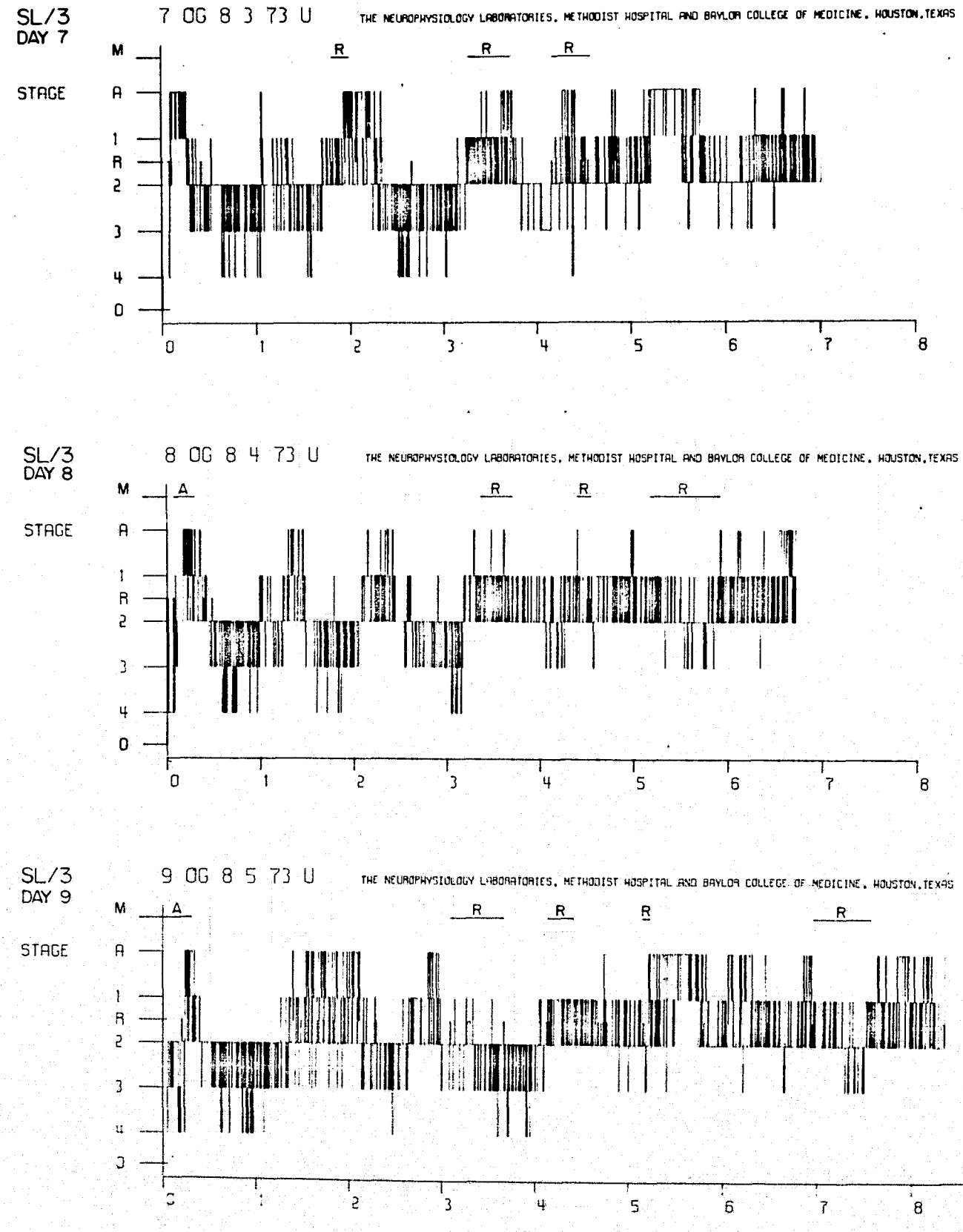
0 1 2 3 4 5 6 7 8
SL/2
DAY 25
25 JK 6 18 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
0 1 2 3 4 5
SL/2
DAY 26
26 JK 6 19 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
0 2 3 4 5 6 7

FIG.12


SL/3
DAY 7
7 OG 8 3 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
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R
0 1 2 3 4 5 6 7 8
SL/3
DAY 8
8 OG 8 4 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
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4
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R
R
0 1 2 3 4 5 6 7 8
SL/3
DAY 9
9 OG 8 5 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
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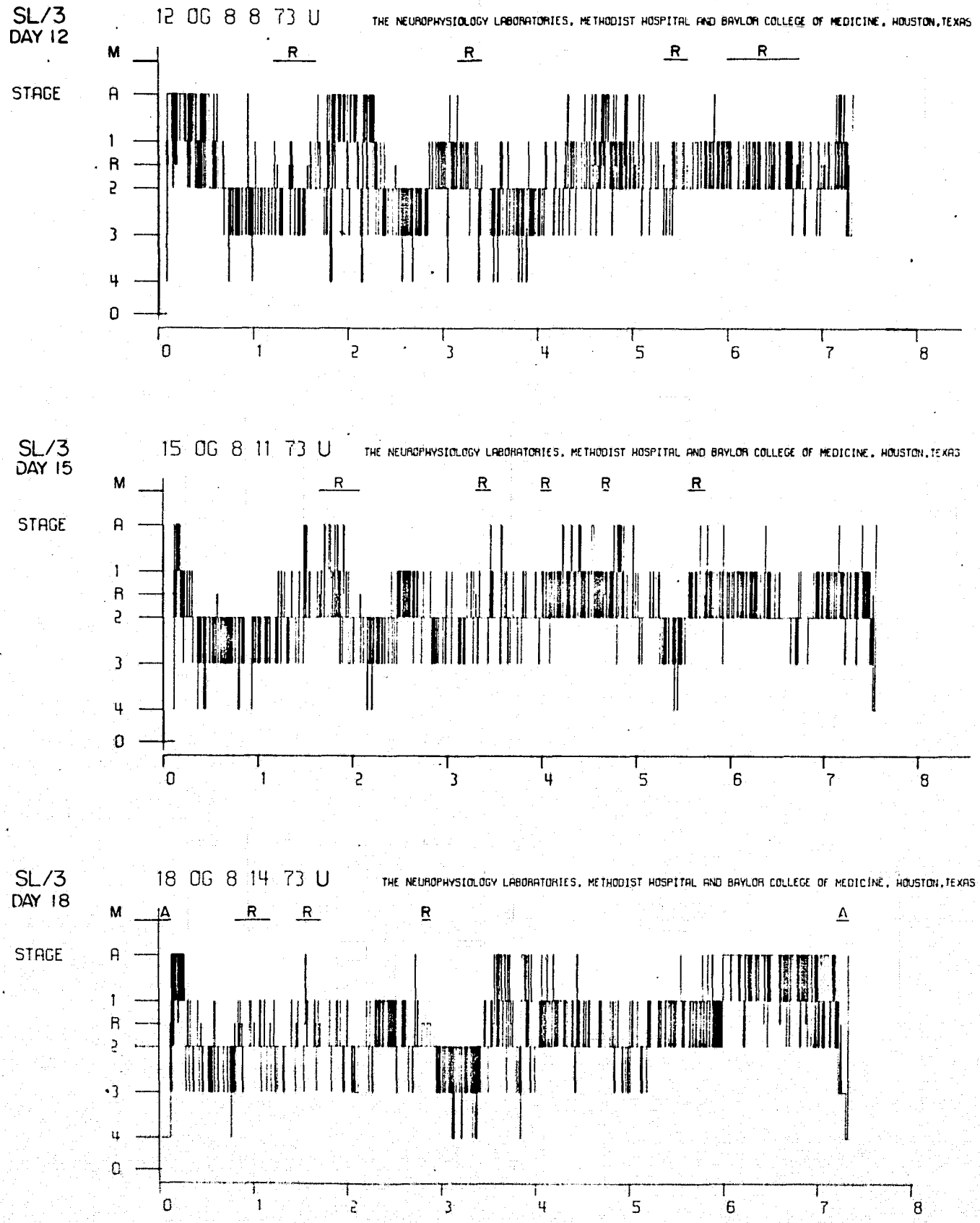
4
0
A
R
R
R
R
0 1 2 3 4 5 6 7 8

FIG. 13


SL/3
DAY 12
12 00 8 8 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
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3
4
0
R
R
R
R
0 1 2 3 4 5 6 7 8
SL/3
DAY 15
15 00 8 11 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
R
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4
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R
R
R
R
R
0 1 2 3 4 5 6 7 8
SL/3
DAY 18
18 00 8 14 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
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2
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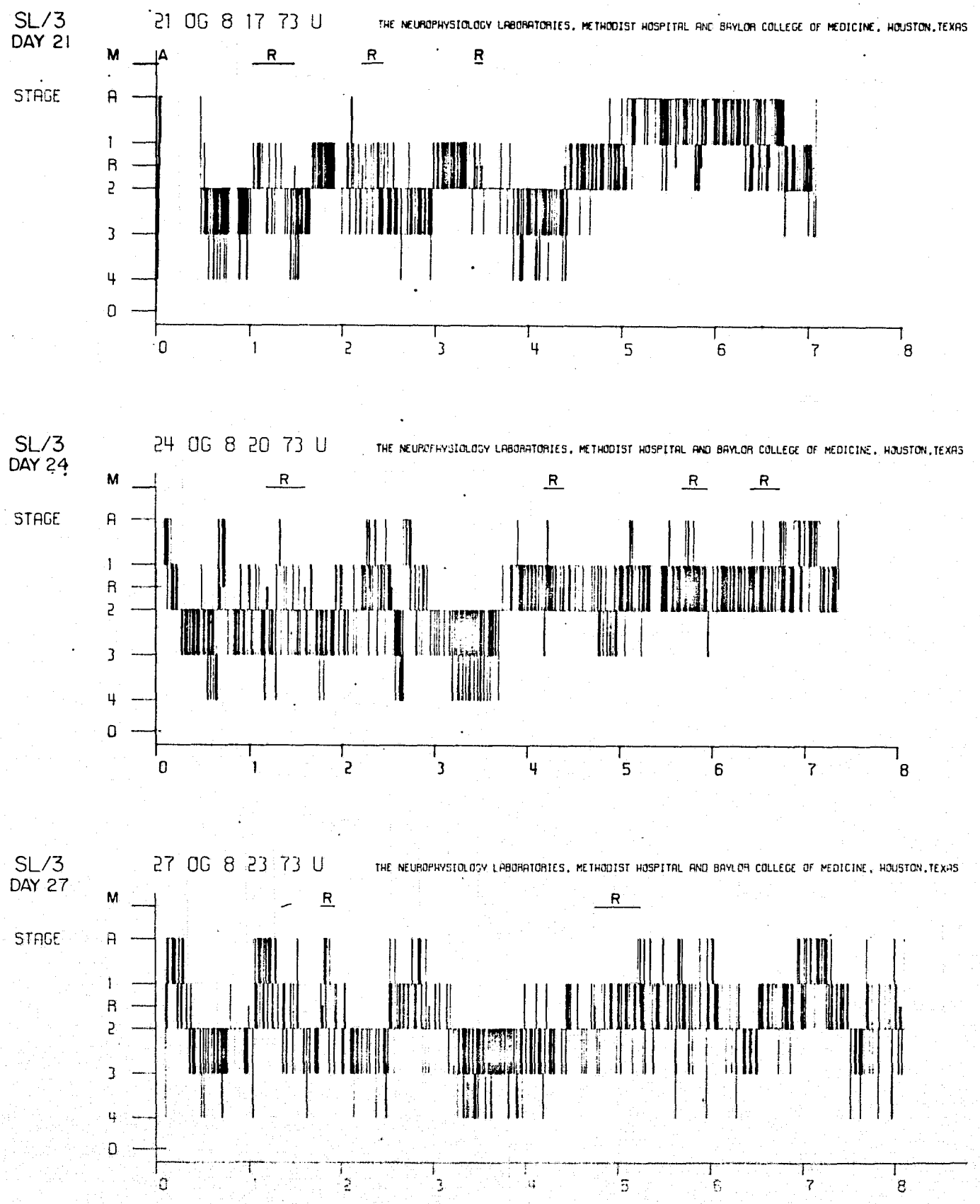
4
0
A
R
R
R
A
0 1 2 3 4 5 6 7 8

FIG. 14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DAY 21
21 OG 8 17 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
R
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4
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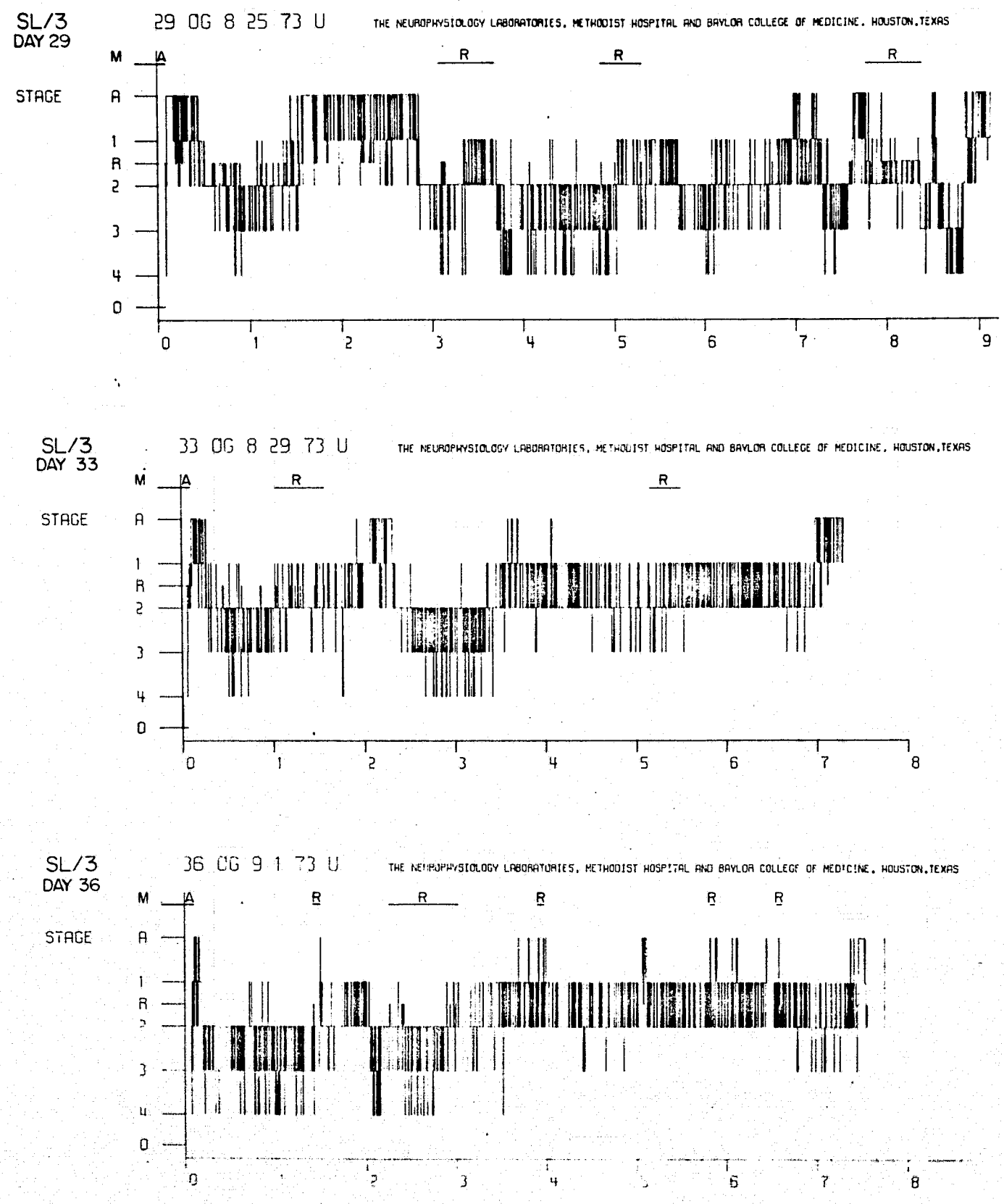
0 1 2 3 4 5 6 7 8
SL/3
DAY 24
24 OG 8 20 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
SL/3
DAY 27
27 OG 8 23 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE

FIG. 15


SL/3
DAY 29
29 OG 8 25 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON,TEXAS
M
A
R
R
R
STAGE
A
1
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4
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1
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4
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6
7
8
9
SL/3
DAY 33
33 OG 8 29 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON,TEXAS
M
A
R
R
STAGE
A
1
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6
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8
SL/3
DAY 36
36 OG 9 1 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON,TEXAS
M
A
R
R
R
R
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STAGE
A
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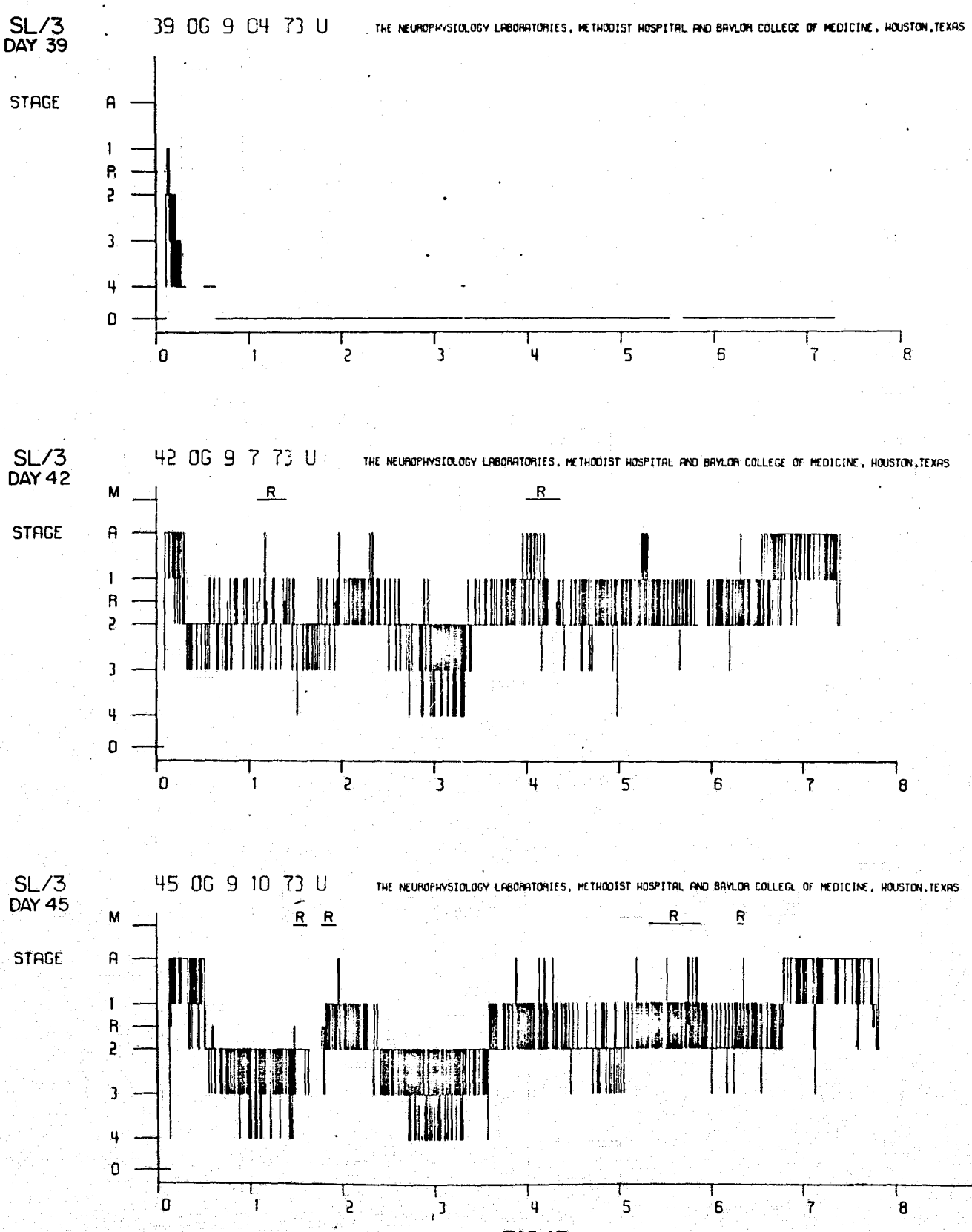
FIG. 16


SL/3
DAY 39
39 OG 9 04 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
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4
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0 1 2 3 4 5 6 7 8
SL/3
DAY 42
42 OG 9 7 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
M
R
R
STAGE
A
1
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0 1 2 3 4 5 6 7 8
SL/3
DAY 45
45 OG 9 10 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
M
R R
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STAGE
A
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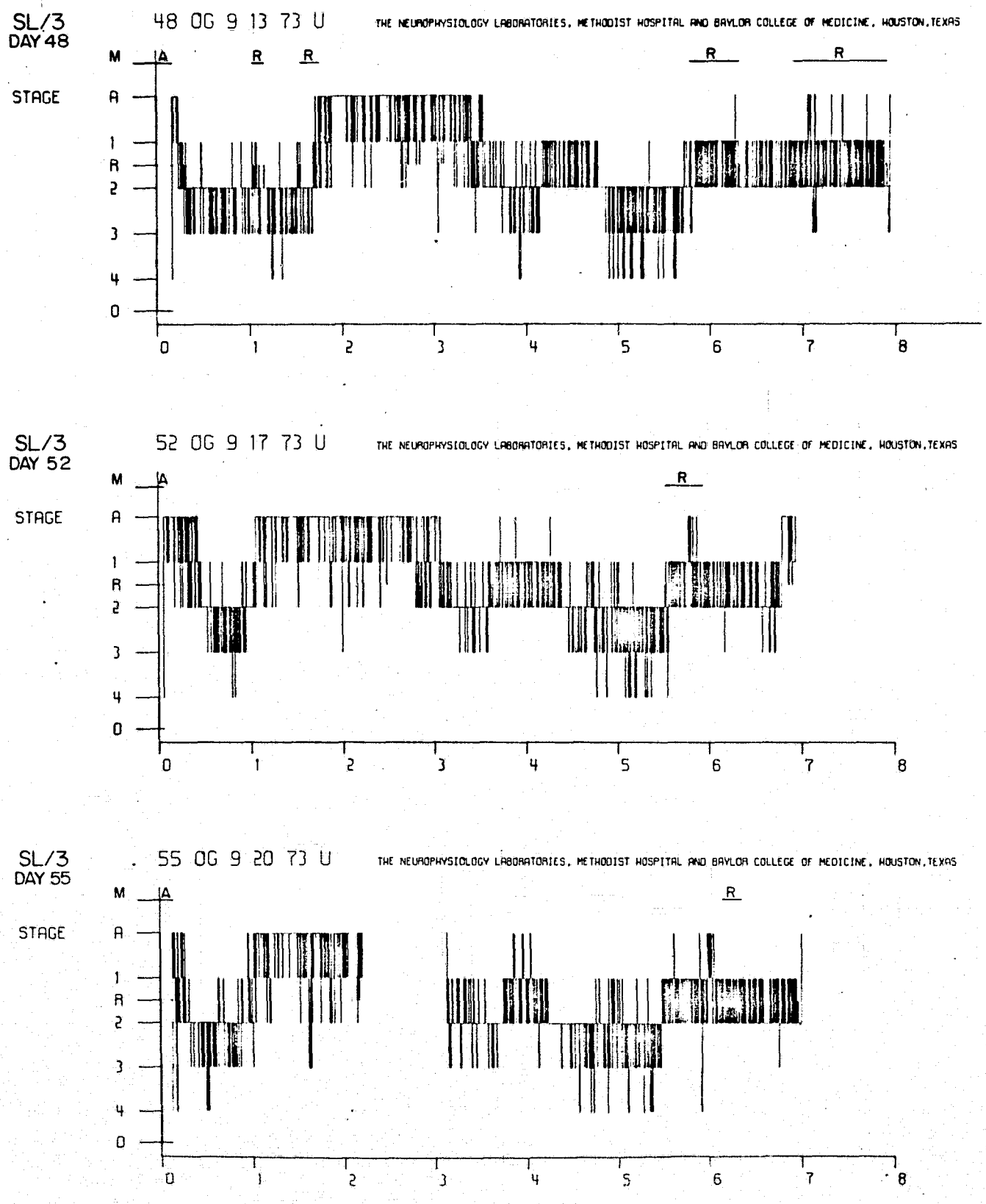
0 1 2 3 4 5 6 7 8

FIG. 17


SL/3
DAY 48
48 OG 9 13 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
M
A
R
R
R
R
STAGE
A
1
R
2
3
4
0
0 1 2 3 4 5 6 7 8
SL/3
DAY 52
52 OG 9 17 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
M
A
R
STAGE
A
1
R
2
3
4
0
0 1 2 3 4 5 6 7 8
SL/3
DAY 55
55 OG 9 20 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
M
A
R
STAGE
A
1
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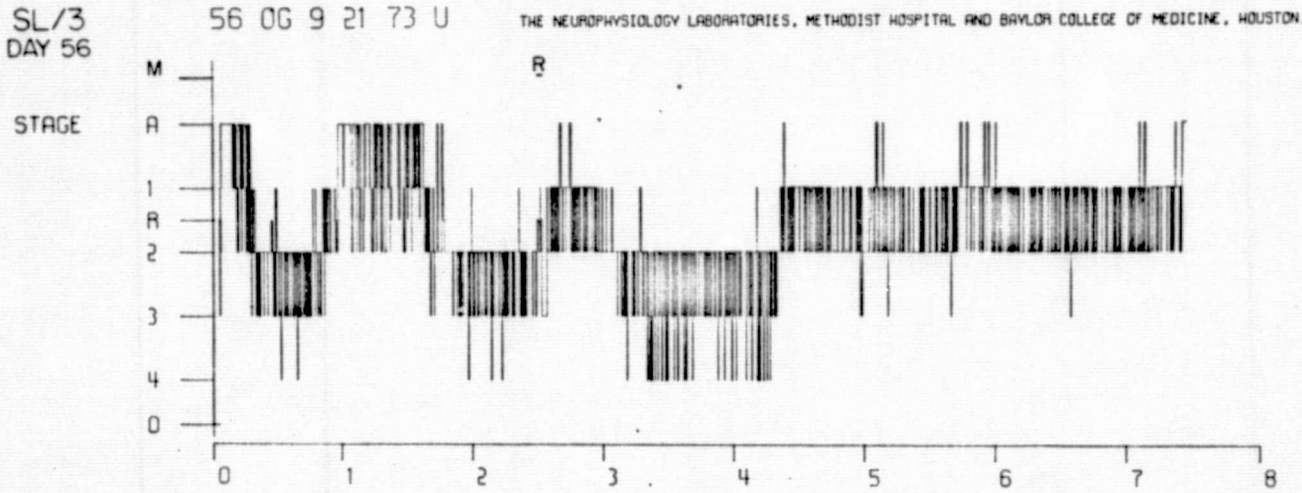
0 1 2 3 4 5 6 7 8

FIG.18


SL/3
DAY 56
56 06 9 21 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
R
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R
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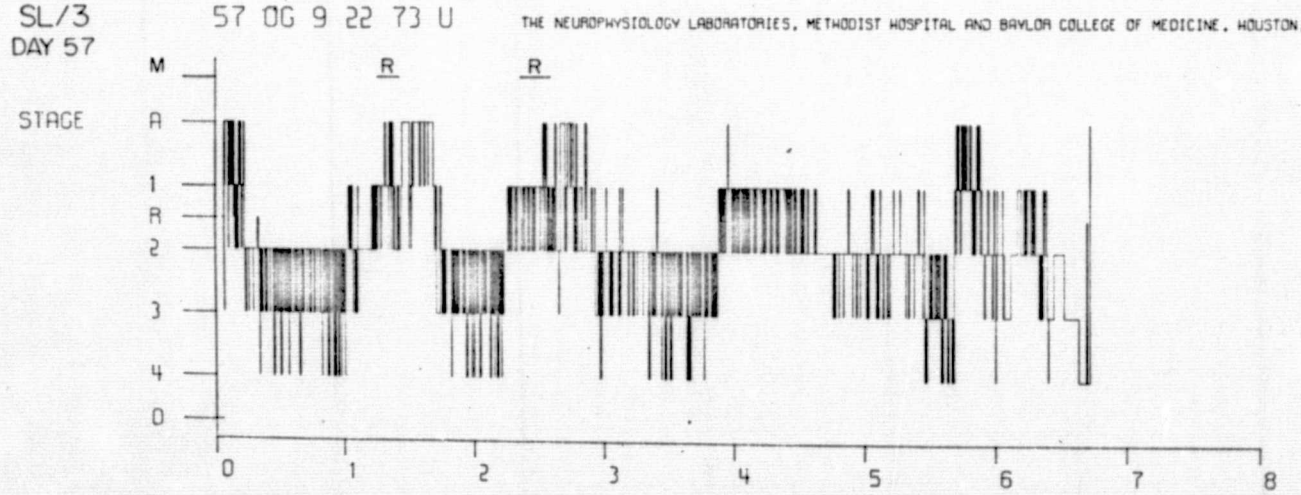
SL/3
DAY 57
57 06 9 22 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
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1
R
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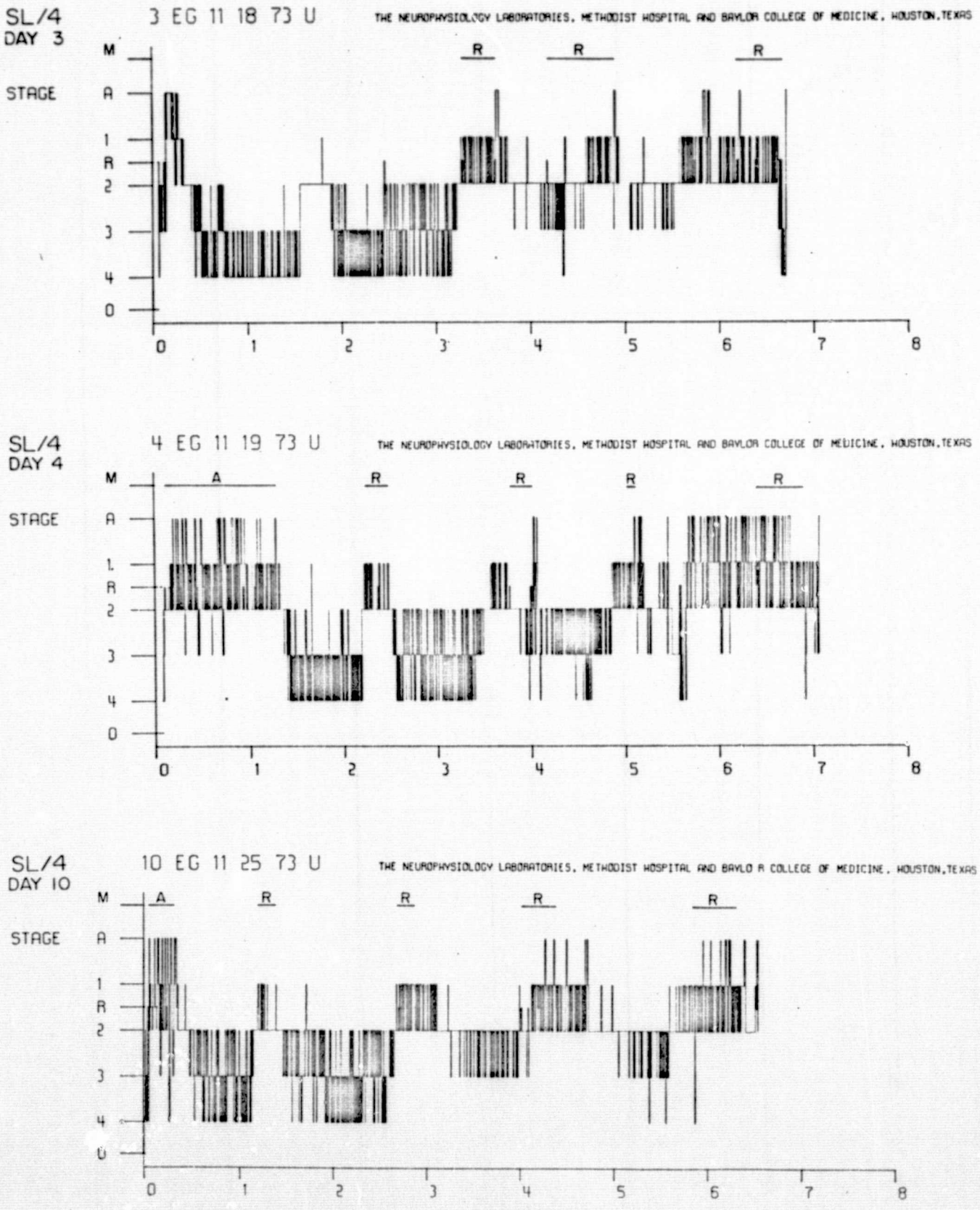
FIG. 19


SL/4
DAY 3
3 EG 11 18 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
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R
R
0 1 2 3 4 5 6 7 8
SL/4
DAY 4
4 EG 11 19 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
R
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4
0
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R
R
R
R
0 1 2 3 4 5 6 7 8
SL/4
DAY 10
10 EG 11 25 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
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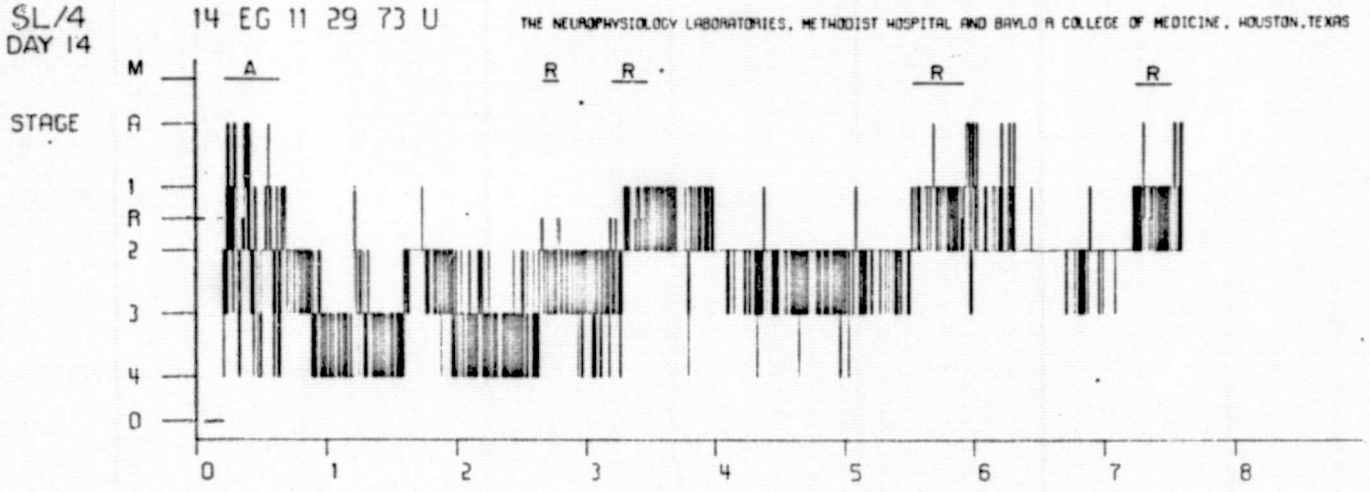
R
R
R
R
0 1 2 3 4 5 6 7 8

FIG. 20


SL/4
DAY 14
14 EG 11 29 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
R
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4
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A
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R
R
R
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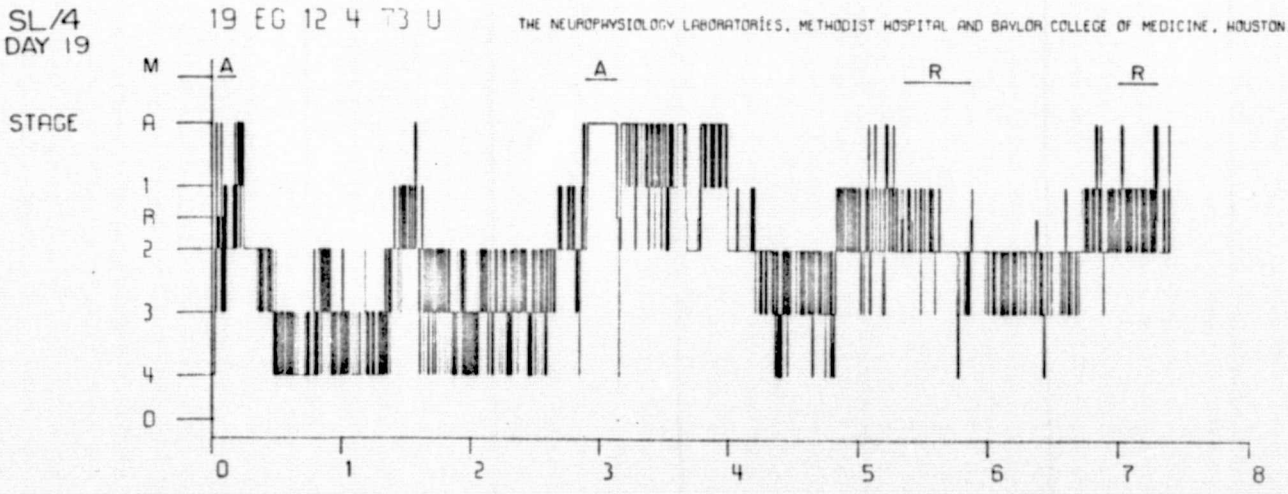
7
8


SL/4
DAY 19
19 EG 12 4 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
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R
R
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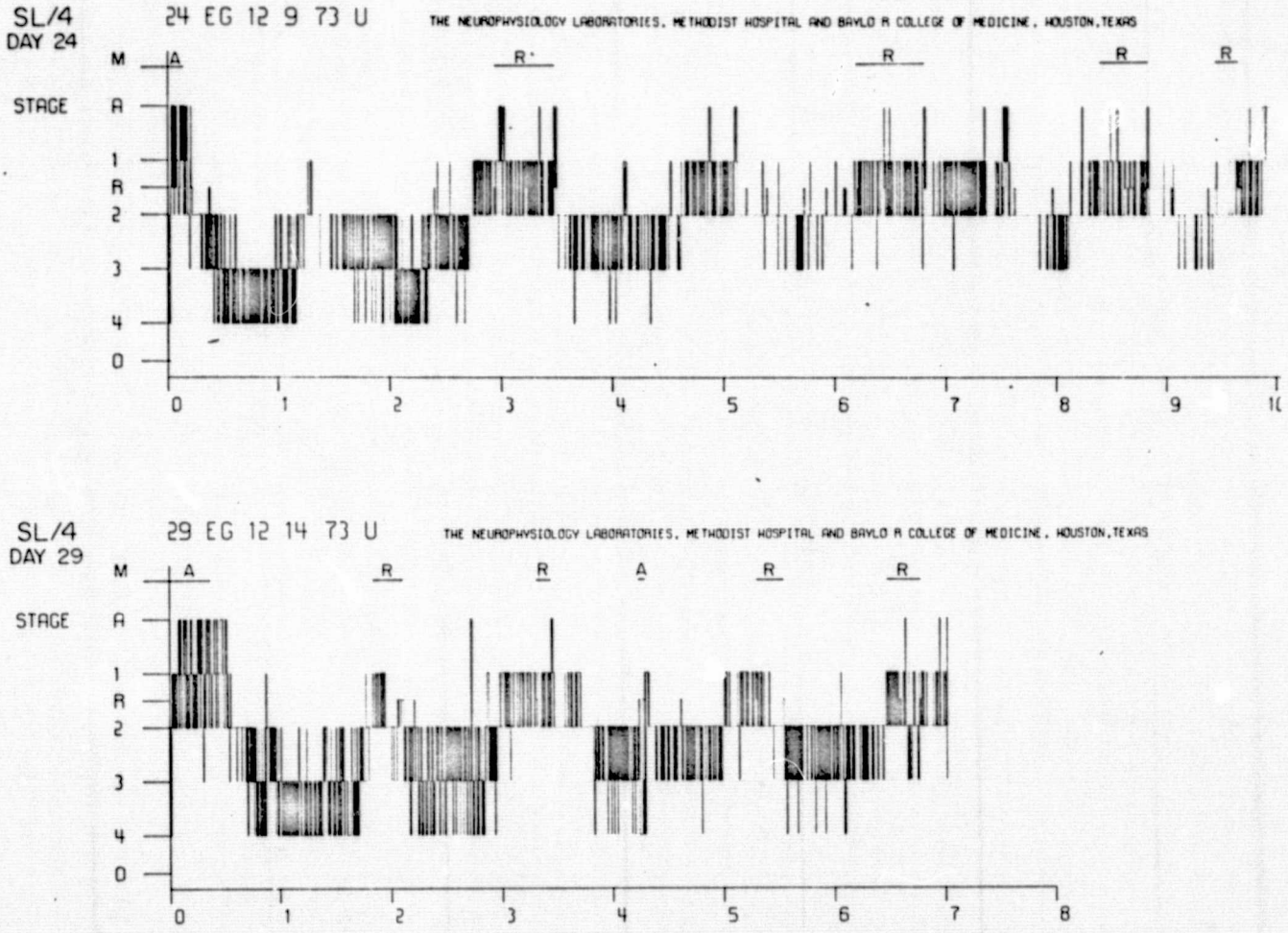
FIG. 21


SL/4
DAY 24
24 EG 12 9 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
R
1
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0
0 1 2 3 4 5 6 7 8 9 10

SL/4
DAY 29
29 EG 12 14 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
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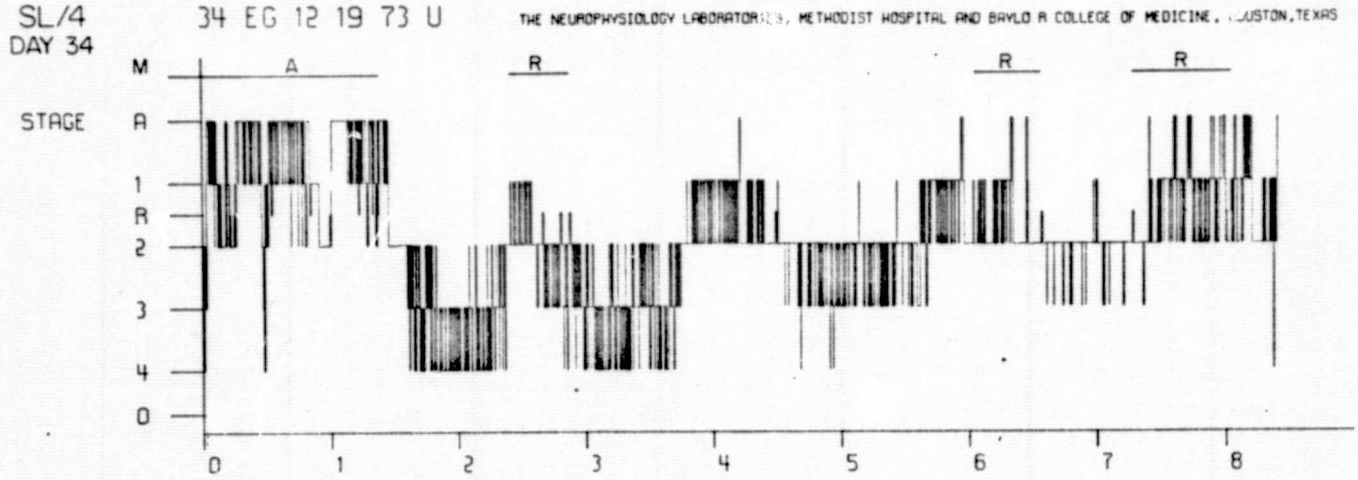
0 1 2 3 4 5 6 7 8

FIG. 22


SL/4
DAY 34
34 EG 12 19 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
M
A
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R
R
STAGE
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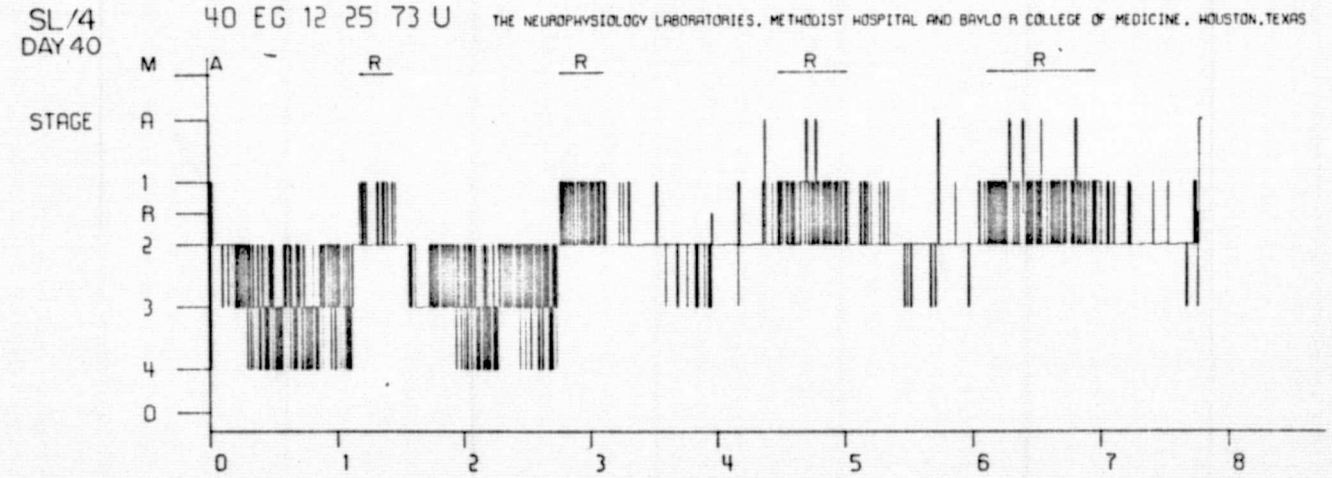
7
8


SL/4
DAY 40
40 EG 12 25 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
M
A
R
R
R
R
STAGE
A
1
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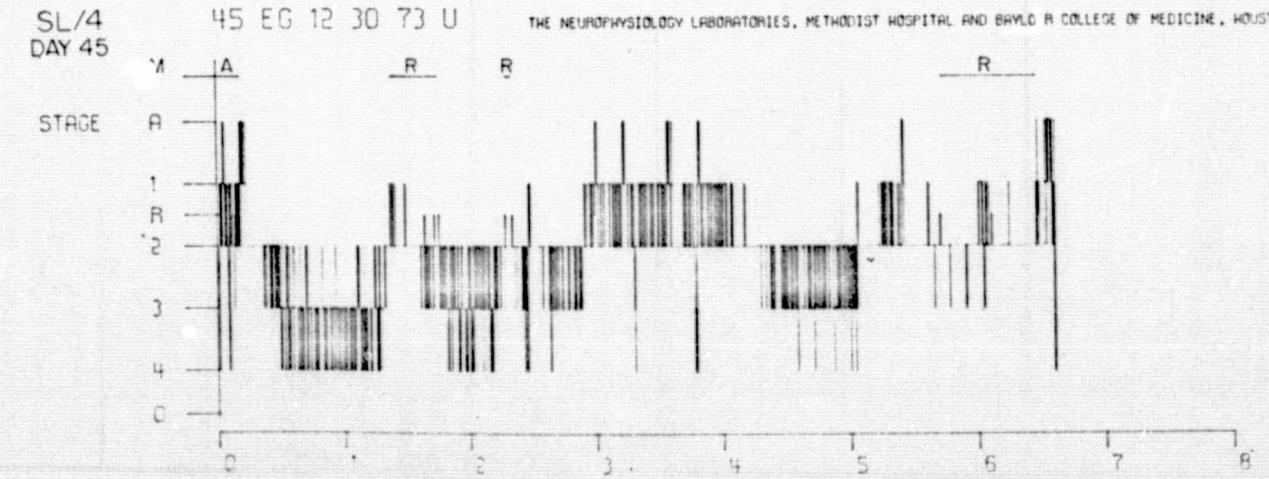
SL/4
DAY 45
45 EG 12 30 73 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
M
A
R
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STAGE
A
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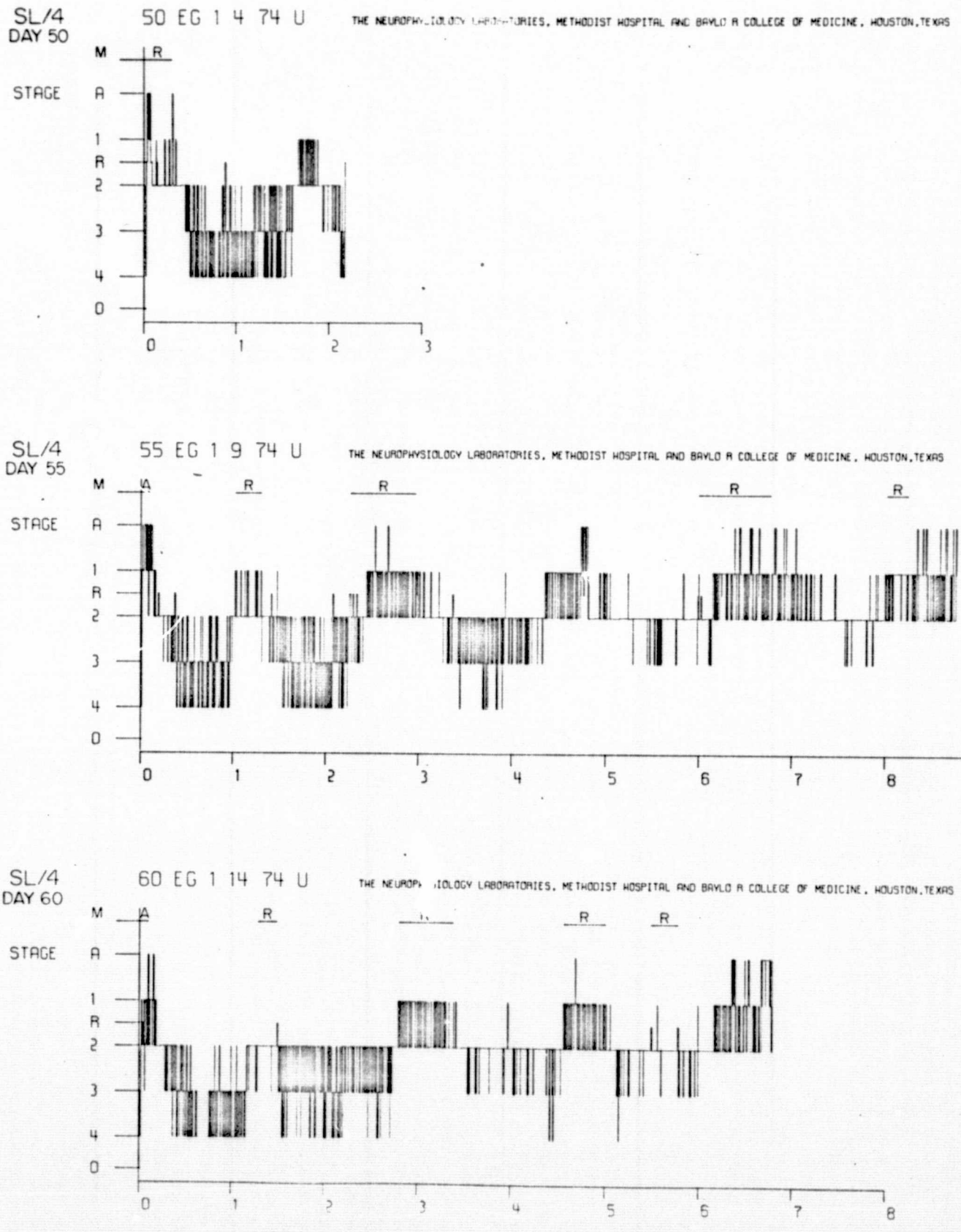
FIG. 23


SL/4
DAY 50
50 EG 1 4 74 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
R
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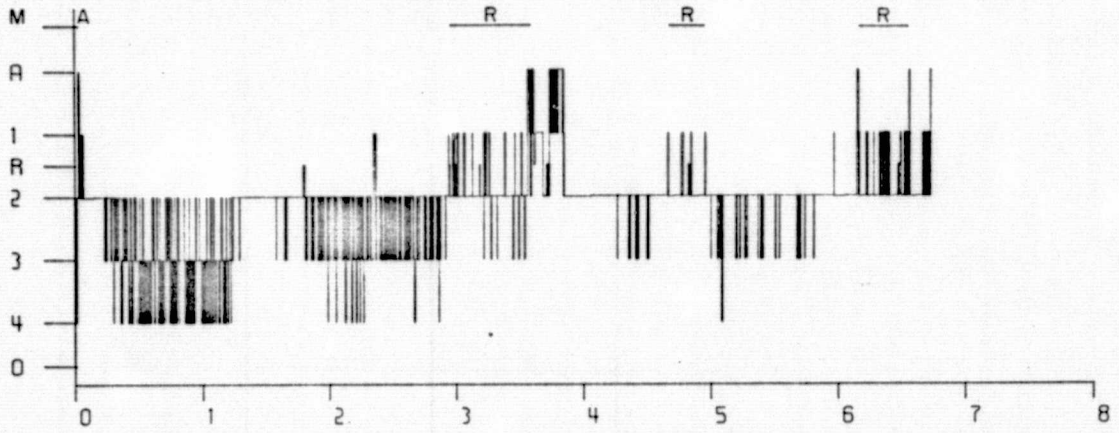
3
4
0
R
0 1 2 3
SL/4
DAY 55
55 EG 1 9 74 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
R
2
3
4
0
A
R
R
R
R
0 1 2 3 4 5 6 7 8
SL/4
DAY 60
60 EG 1 14 74 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
1
R
2
3
4
0
A
R
R
R
0 1 2 3 4 5 6 7 8

FIG. 24

SL/4
DAY 72

72 EG 1 26 74 U

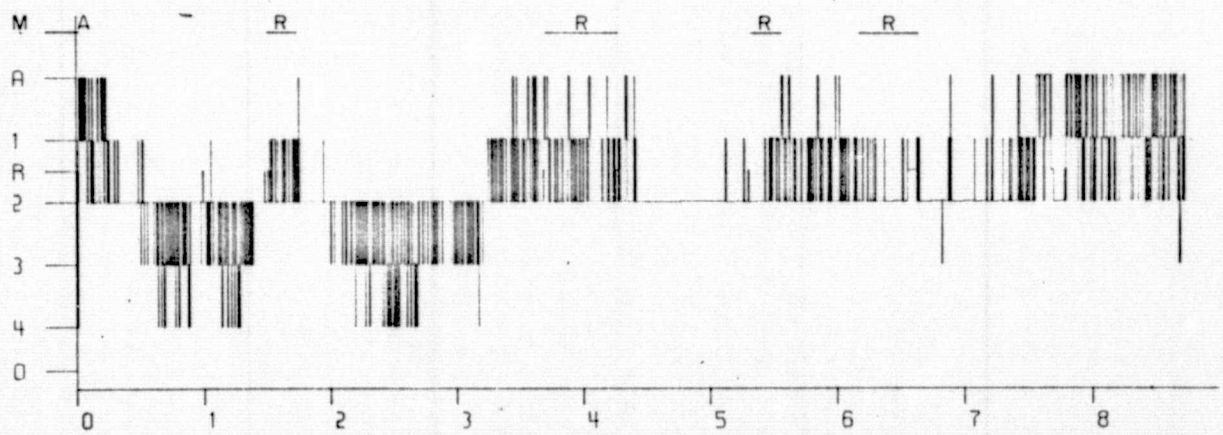
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/4
DAY 77

77 EG 01 31 74 U

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/4
DAY 80

80 EG 2 3 74 U

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS

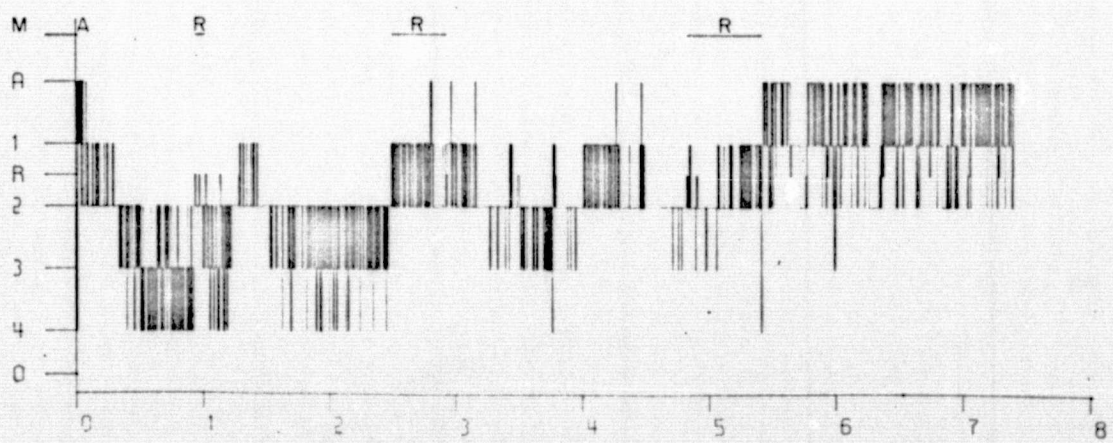
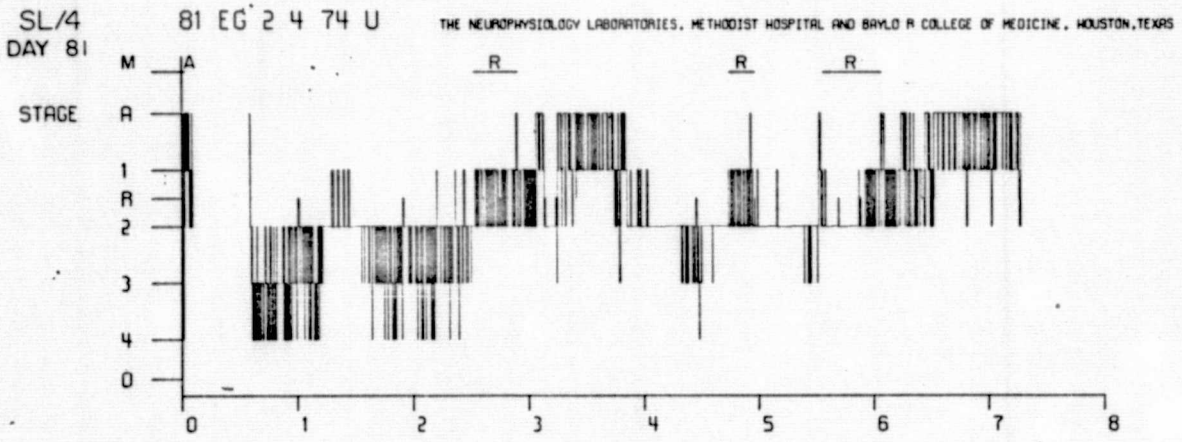


FIG.25


SL/4
DAY 81
81 EG 2 4 74 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
A
R
1
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0 1 2 3 4 5 6 7 8

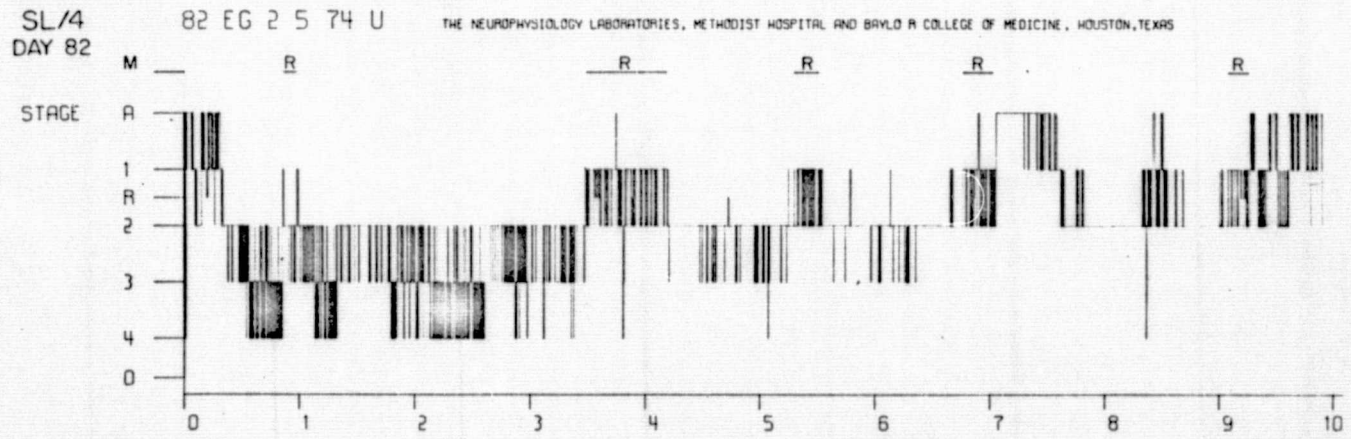
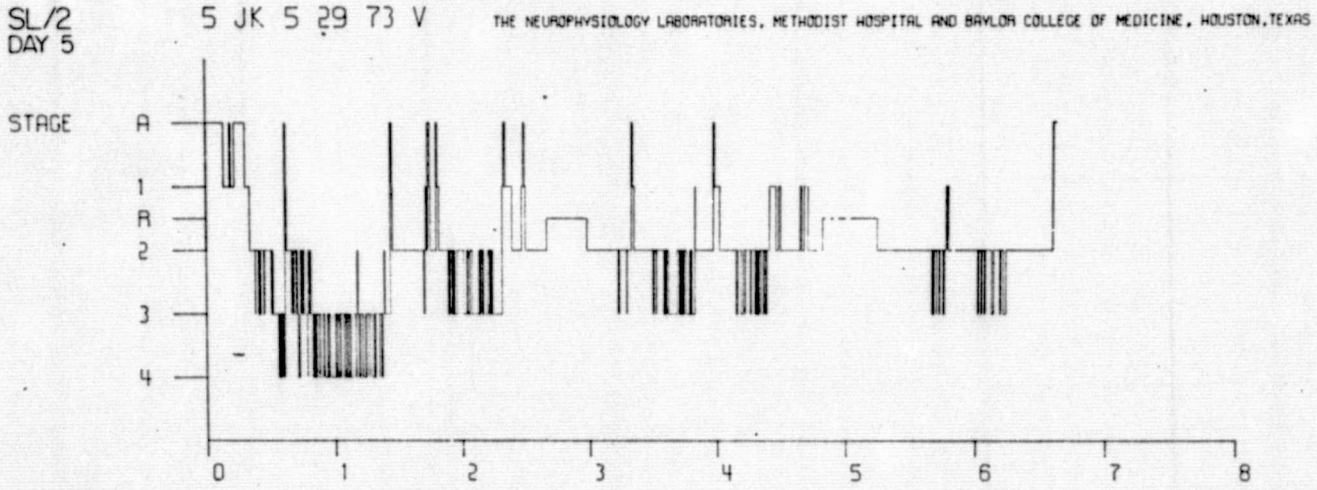

SL/4
DAY 82
82 EG 2 5 74 U
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
M
R
1
2
3
4
0
0 1 2 3 4 5 6 7 8 9 10

FIG. 26


SL/2
DAY 5
5 JK 5 29 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
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4
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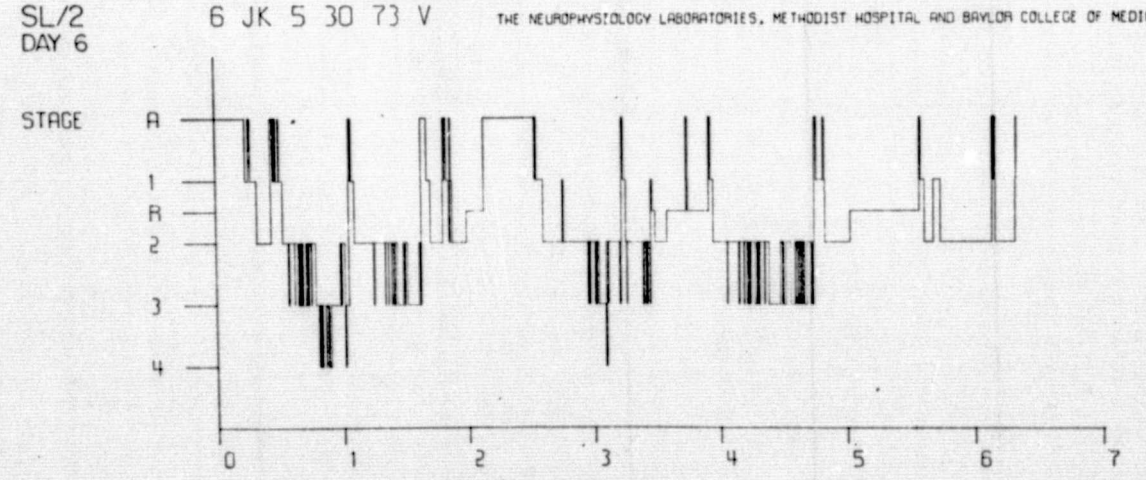
6
7
8


SL/2
DAY 6
6 JK 5 30 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
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0
1
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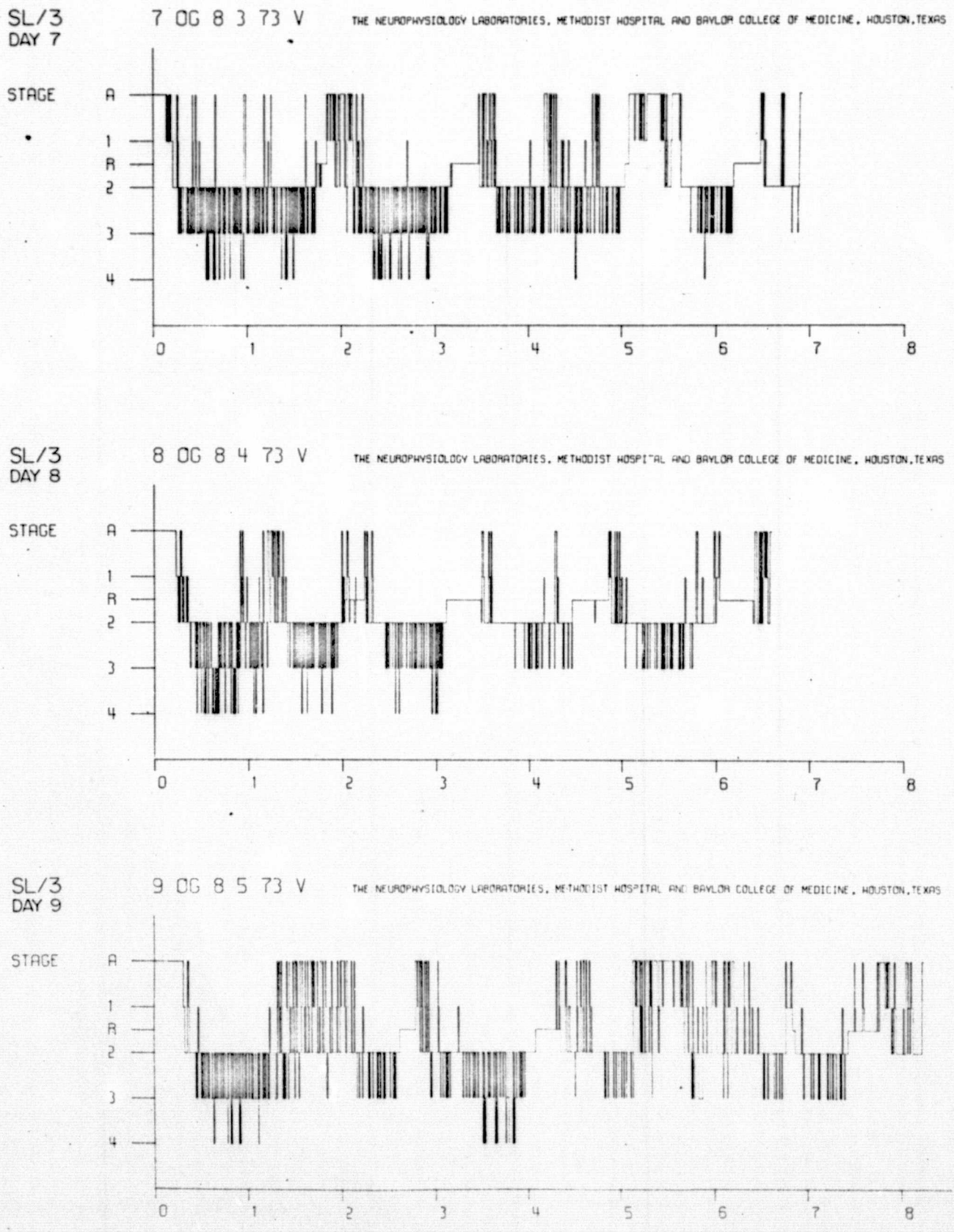
FIG. 27


SL/3
DAY 7
7 OG 8 3 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
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3
4
0
1
2
3
4
5
6
7
8
SL/3
DAY 8
8 OG 8 4 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8
SL/3
DAY 9
9 OG 8 5 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
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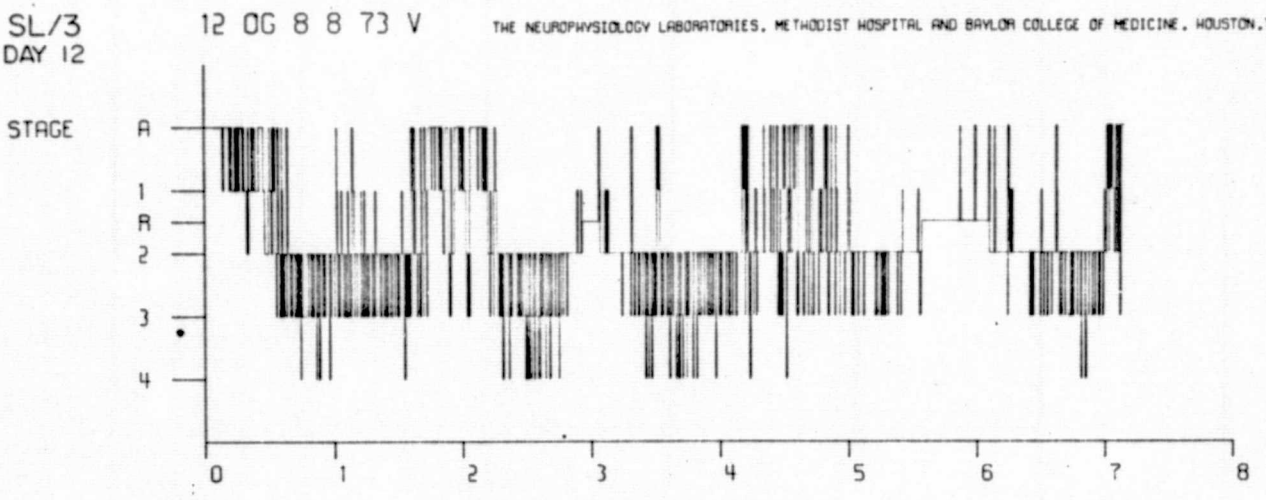
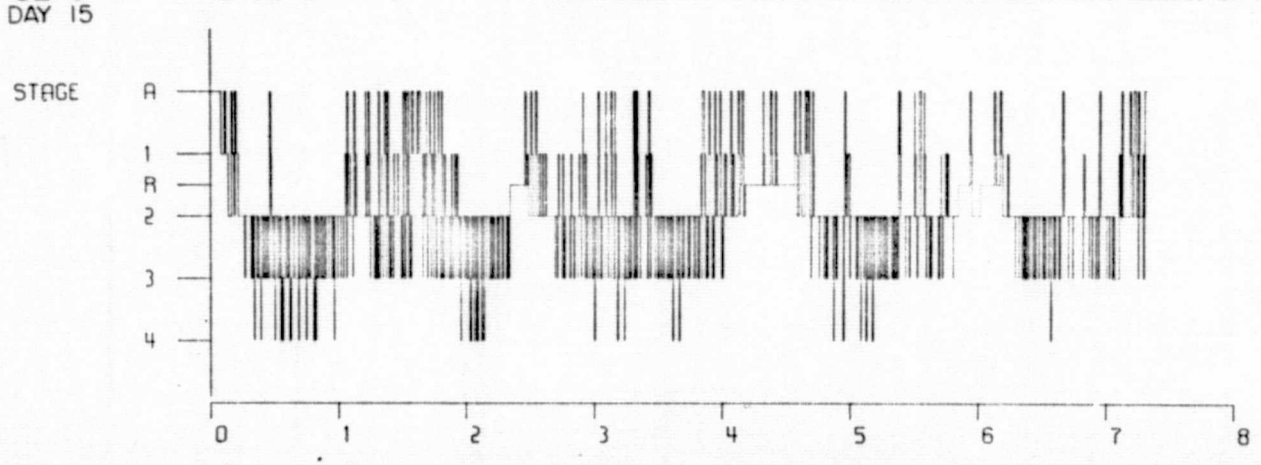
7
8

FIG. 28


SL/3
DAY 12
12 OG 8 8 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8


SL/3
DAY 15
15 OG 8 11 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

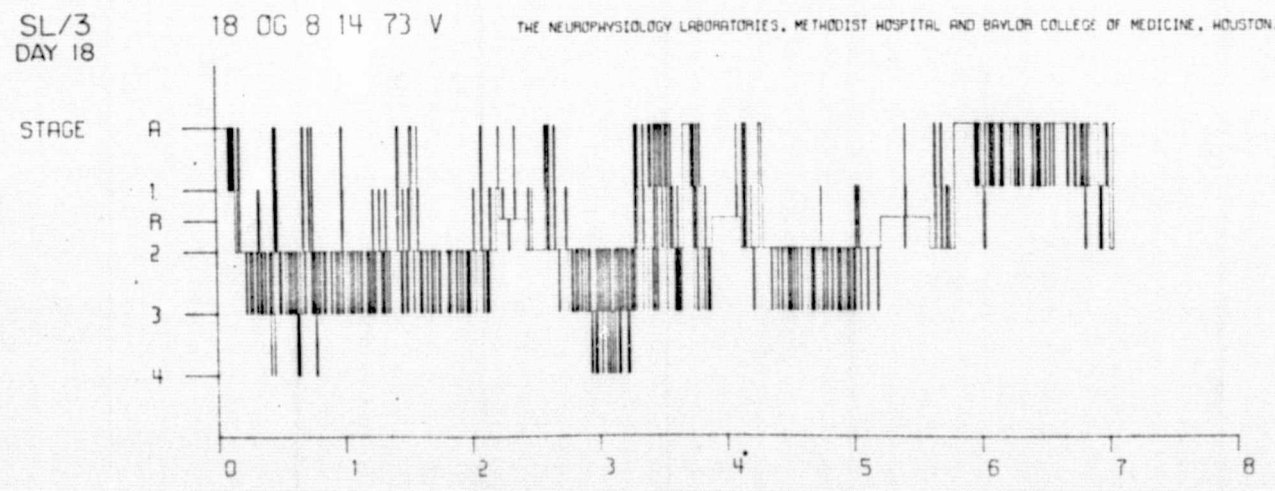
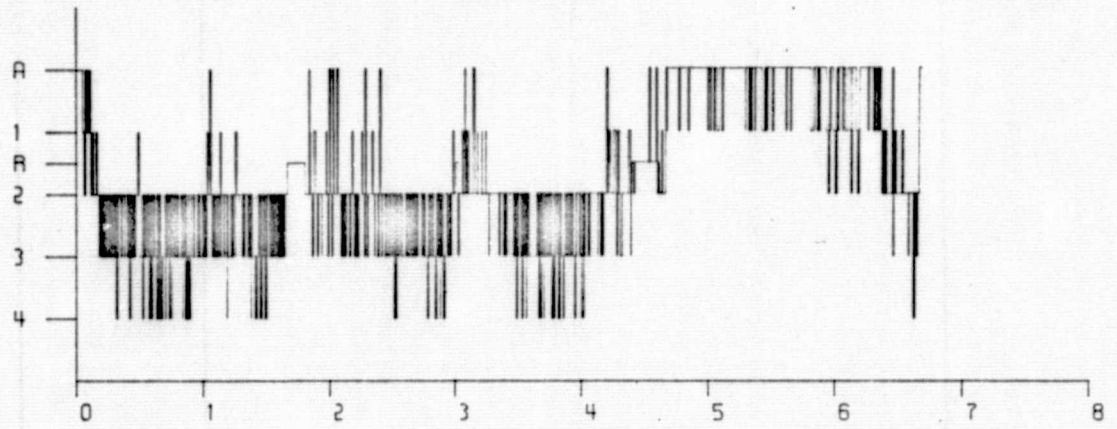

SL/3
DAY 18
18 OG 8 14 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

FIG. 29

SL/3
DAY 21

21 OG 8 17 73 V

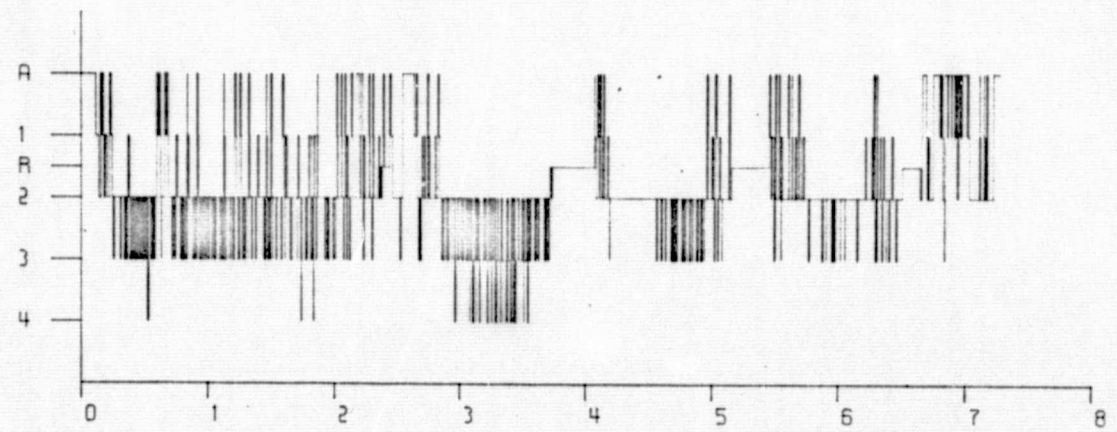
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/3
DAY 24

24 OG 8 20 73 V

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/3
DAY 27

27 OG 8 23 73 V

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS

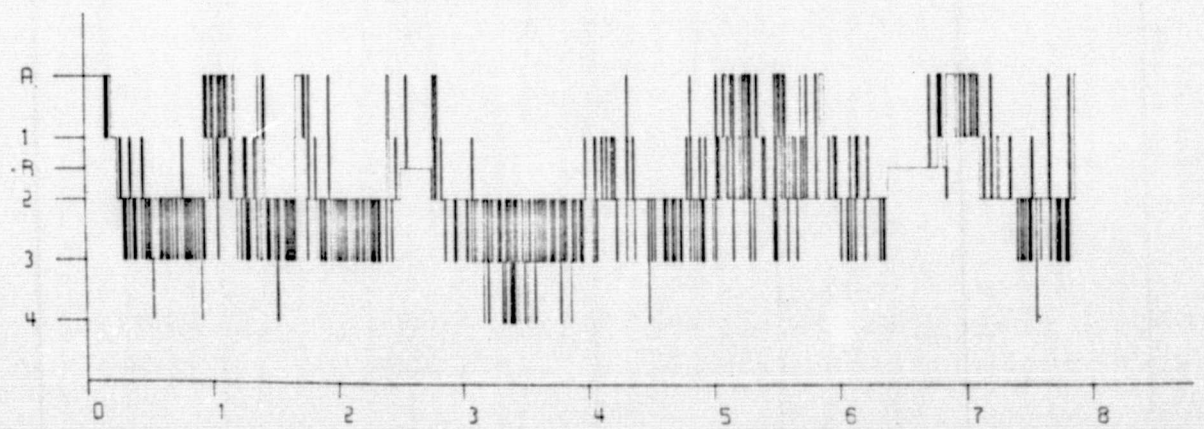


FIG. 30

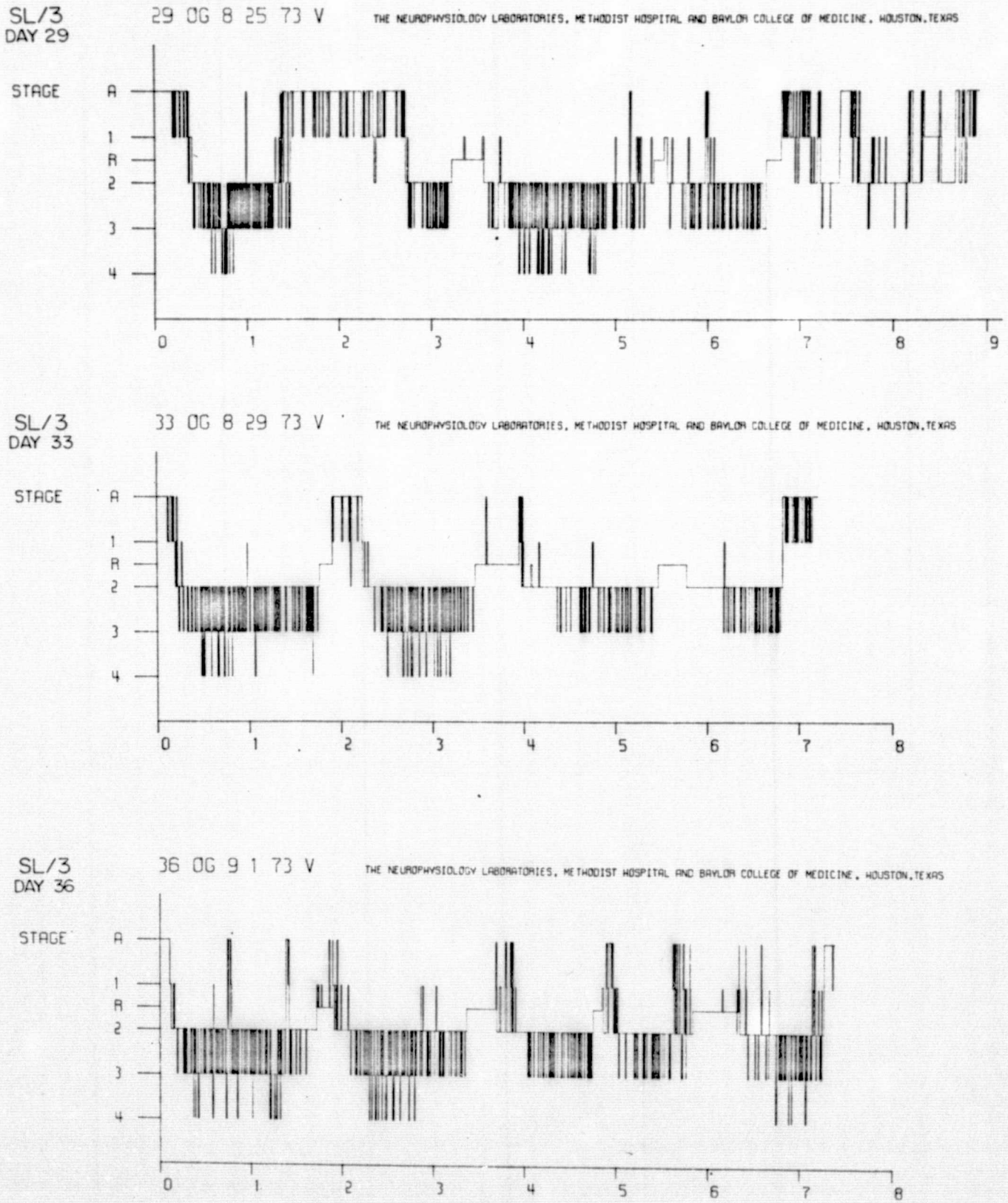

SL/3
DAY 29
29 OG 8 25 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0 1 2 3 4 5 6 7 8 9
SL/3
DAY 33
33 OG 8 29 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0 1 2 3 4 5 6 7 8
SL/3
DAY 36
36 OG 9 1 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0 1 2 3 4 5 6 7 8

FIG. 31

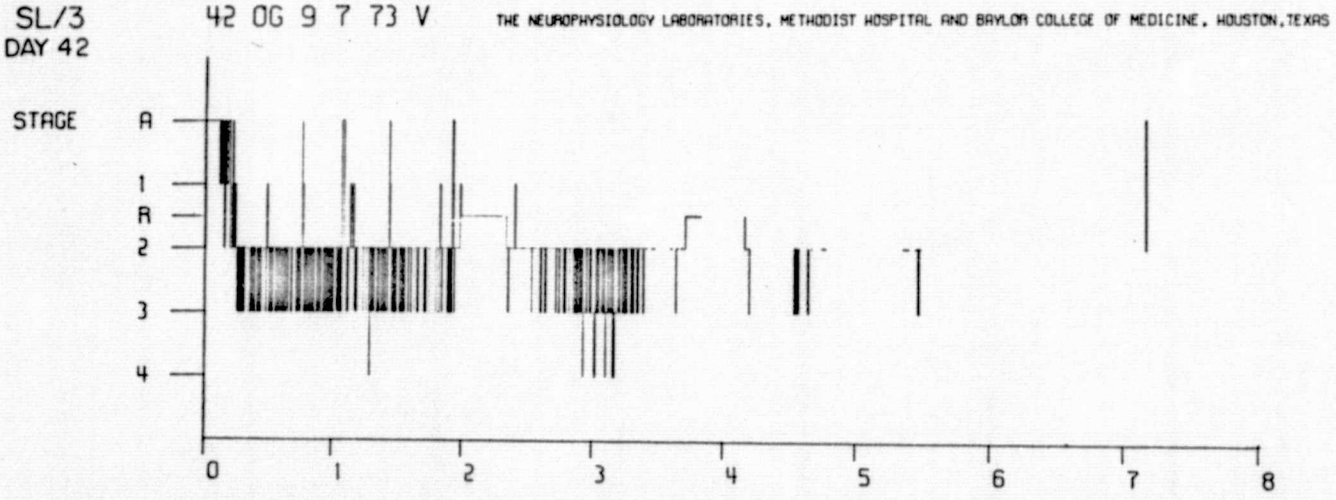

SL/3
DAY 42
42 OG 9 7 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

FIG. 32

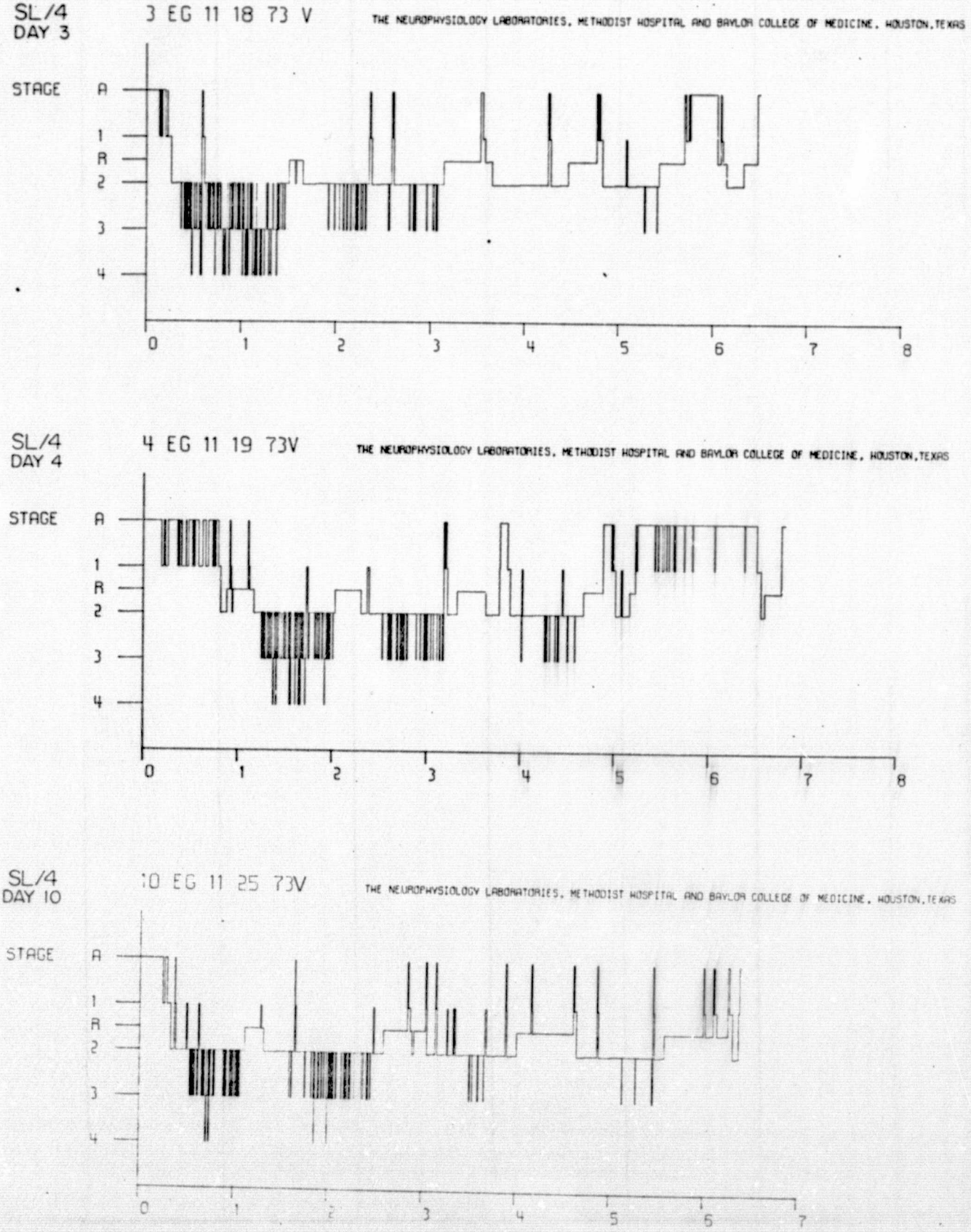
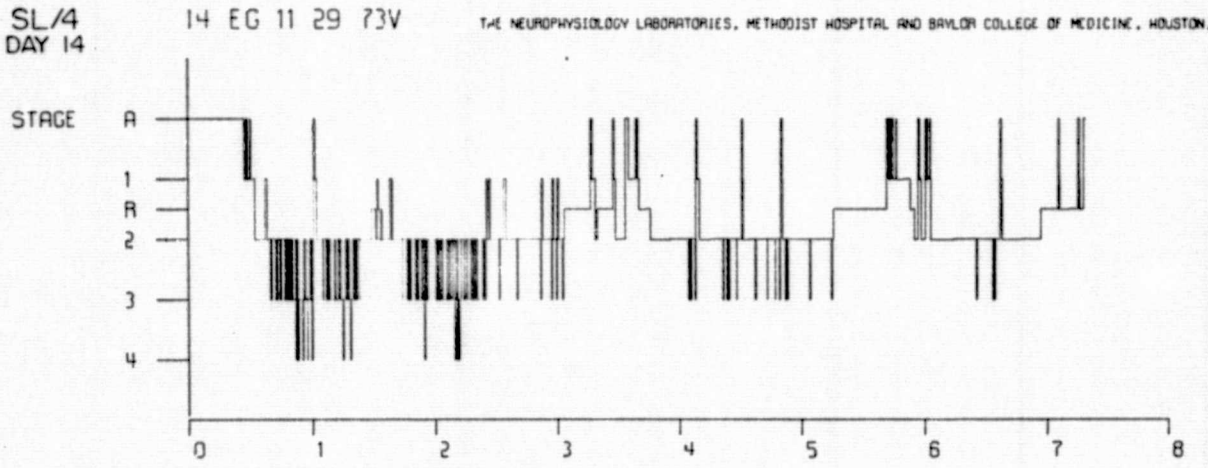

SL/4
DAY 3
3 EG 11 18 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8
SL/4
DAY 4
4 EG 11 19 73V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8
SL/4
DAY 10
10 EG 11 25 73V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7

FIG. 33


SL/4
DAY 14
14 EG 11 29 73V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

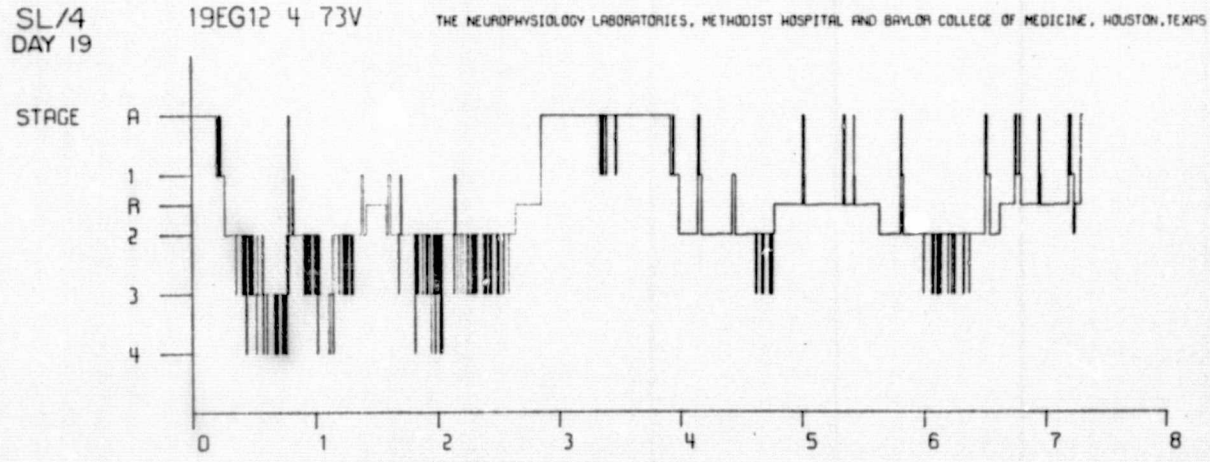
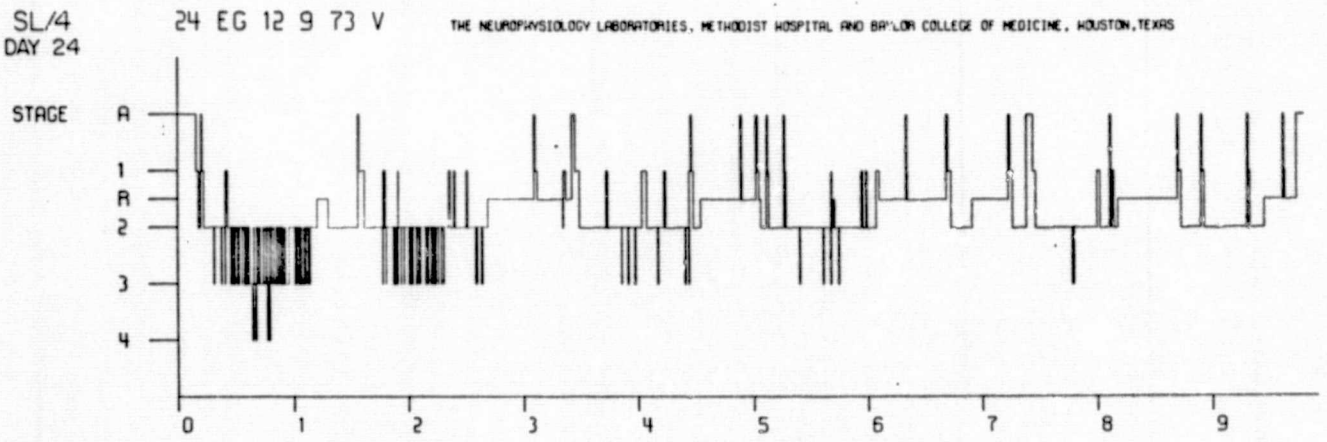

SL/4
DAY 19
19EG12 4 73V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

FIG. 34


SL/4
DAY 24
24 EG 12 9 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8
9

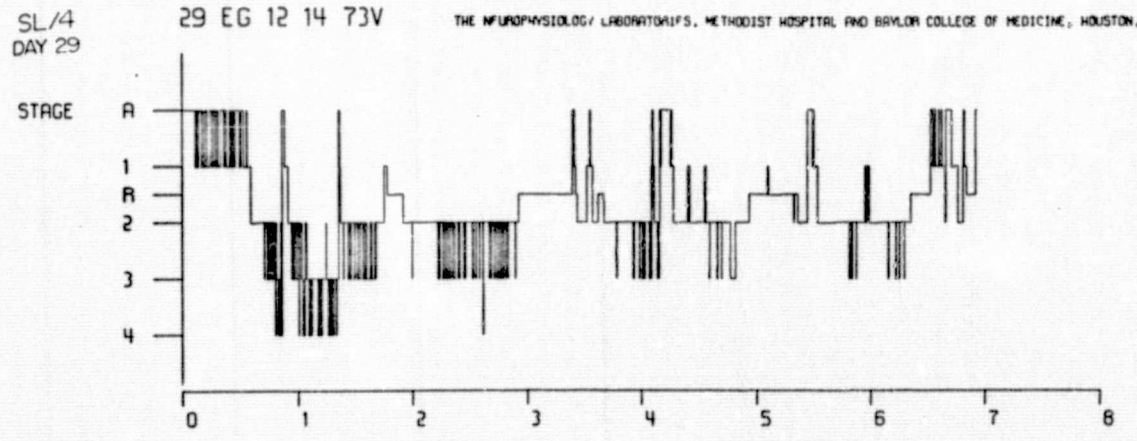
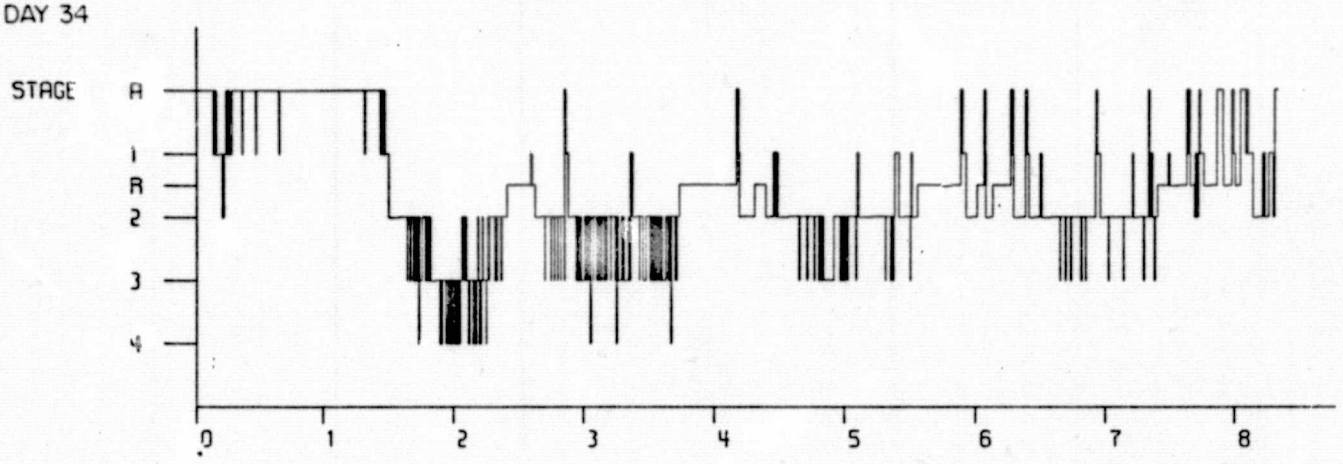

SL/4
DAY 29
29 EG 12 14 73V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

FIG. 35

SL/4
DAY 34

34 EG 12 19 73V

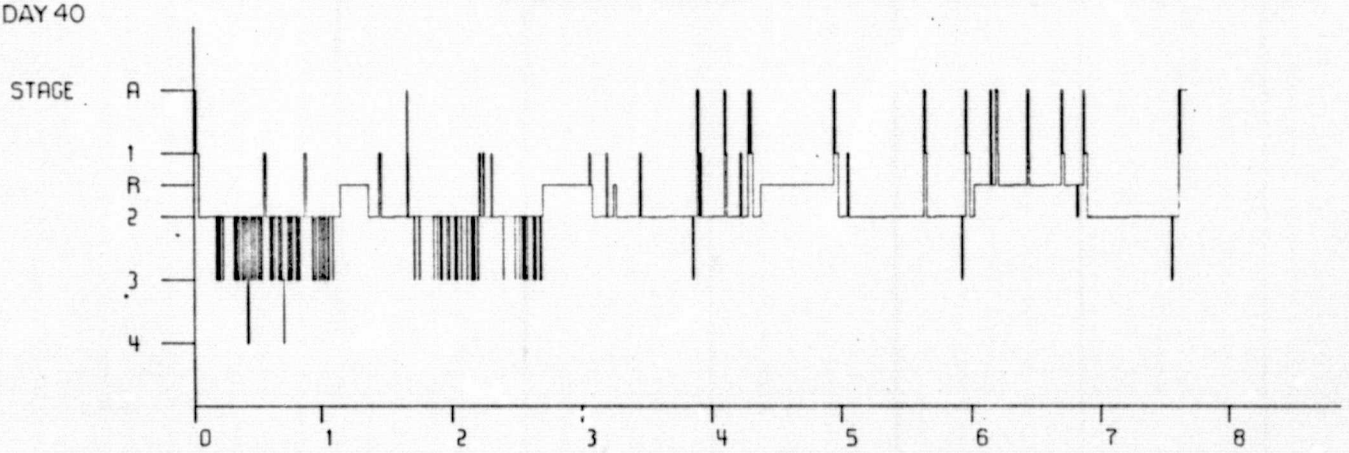
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/4
DAY 40

40 EG 12 25 73V

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/4
DAY 45

45 EG 12 30 73V

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS

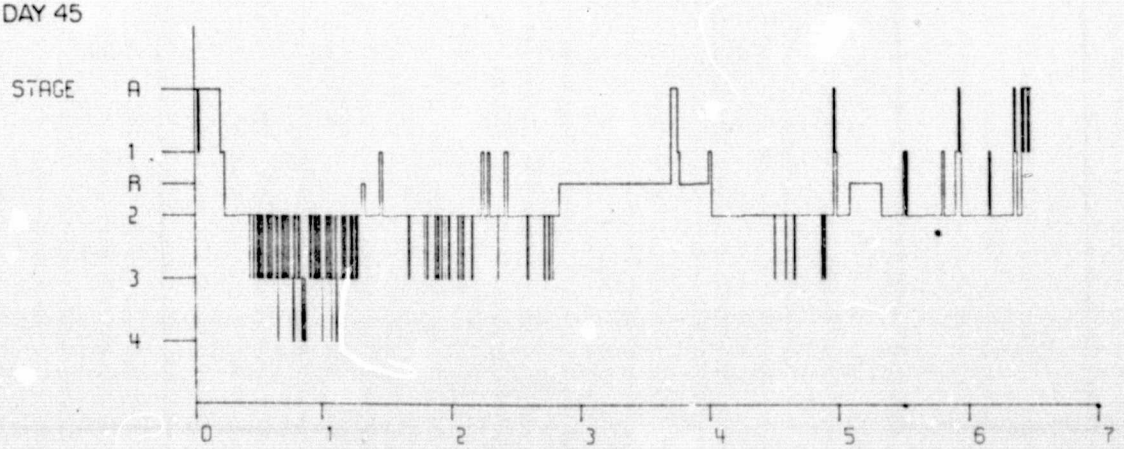


FIG. 36

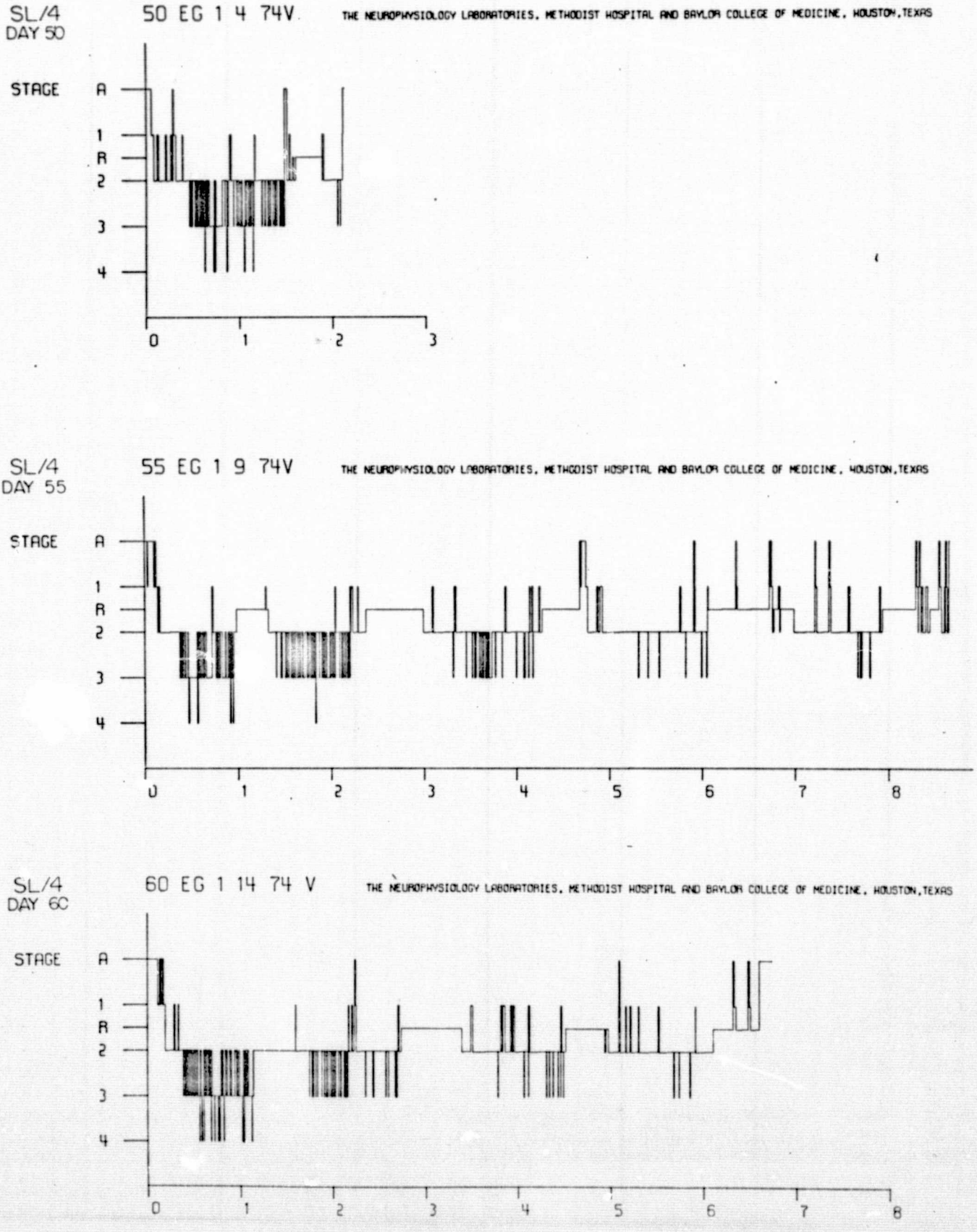
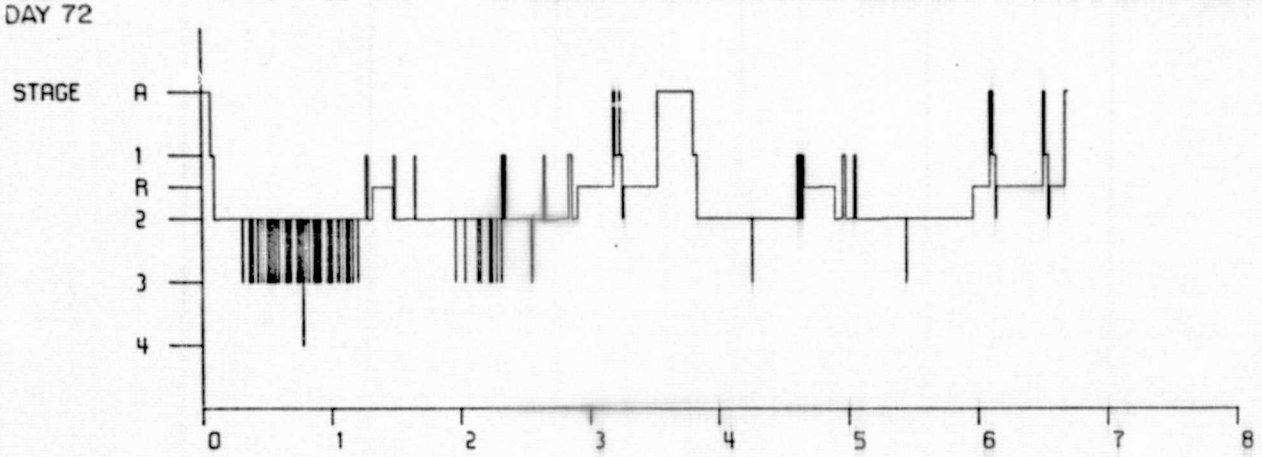

SL/4
DAY 50
50 EG 1 4 74V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
SL/4
DAY 55
55 EG 1 9 74V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8
SL/4
DAY 60
60 EG 1 14 74 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

FIG. 37

SL/4
DAY 72

72 EG 1 26 74V

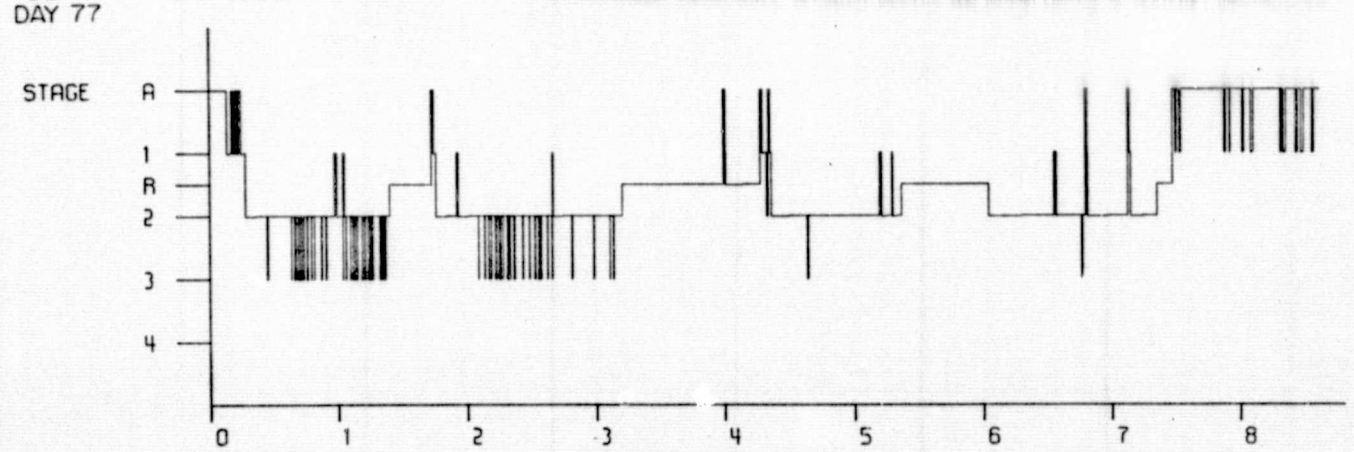
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/4
DAY 77

77 EG 1 31 74 V

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/4
DAY 80

80 EG 2 3 74V

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS

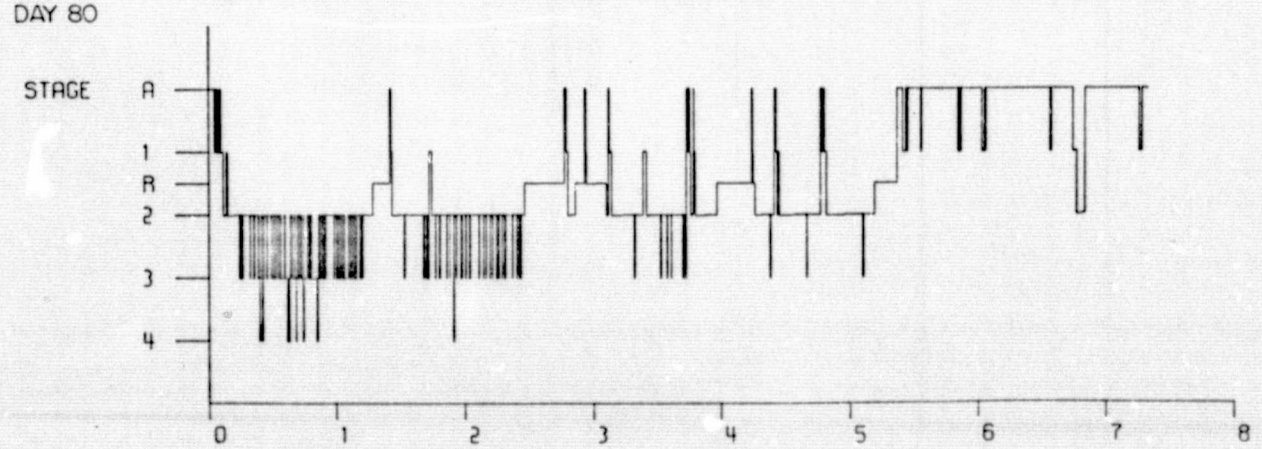
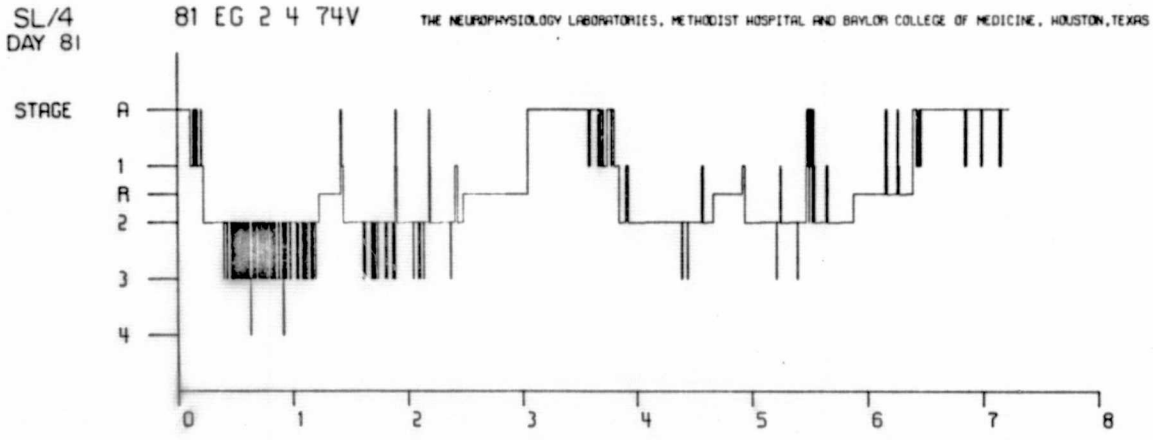


FIG. 38


SL/4
DAY 81
81 EG 2 4 74V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

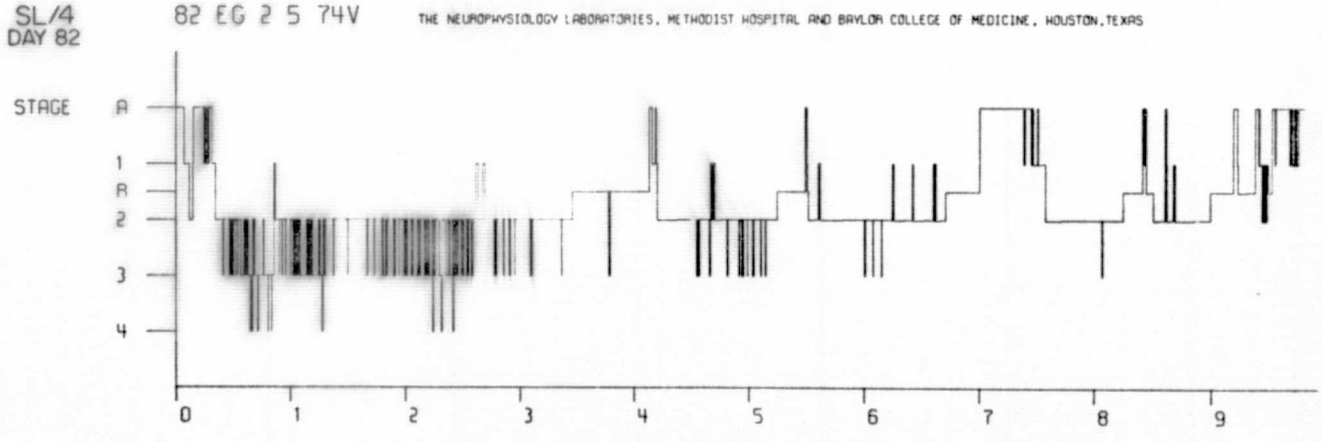

SL/4
DAY 82
82 EG 2 5 74V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8
9

FIG. 39

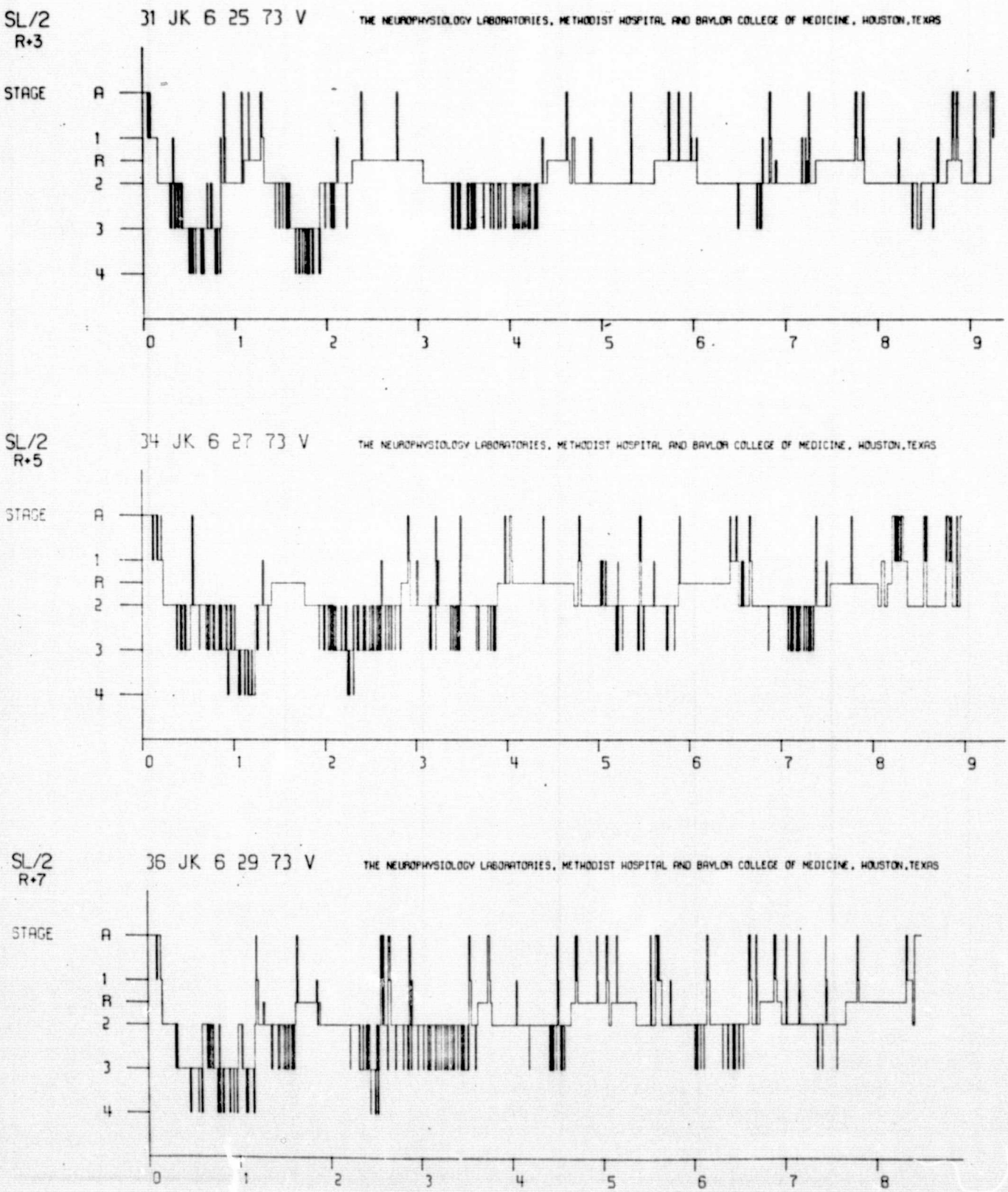
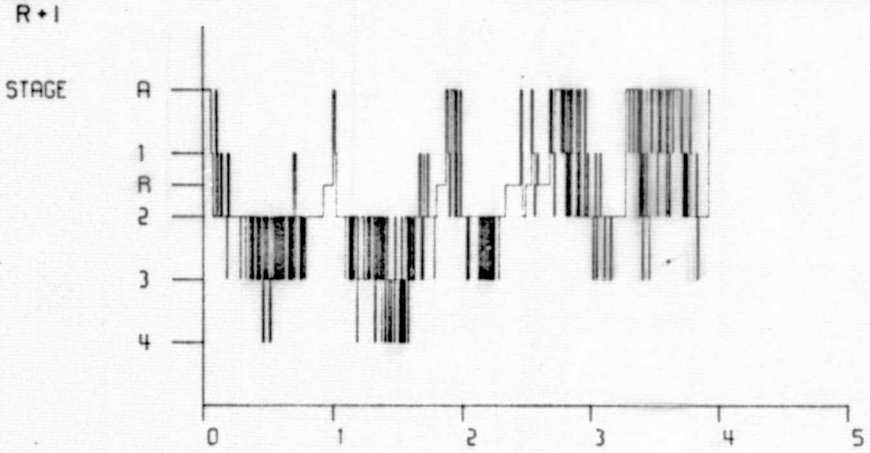

SL/2
R+3
31 JK 6 25 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0 1 2 3 4 5 6 7 8 9
SL/2
R+5
34 JK 6 27 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0 1 2 3 4 5 6 7 8 9
SL/2
R+7
36 JK 6 29 73 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0 1 2 3 4 5 6 7 8

FIG. 40

SL/3
R+1

R1 OG 9 26 73 V

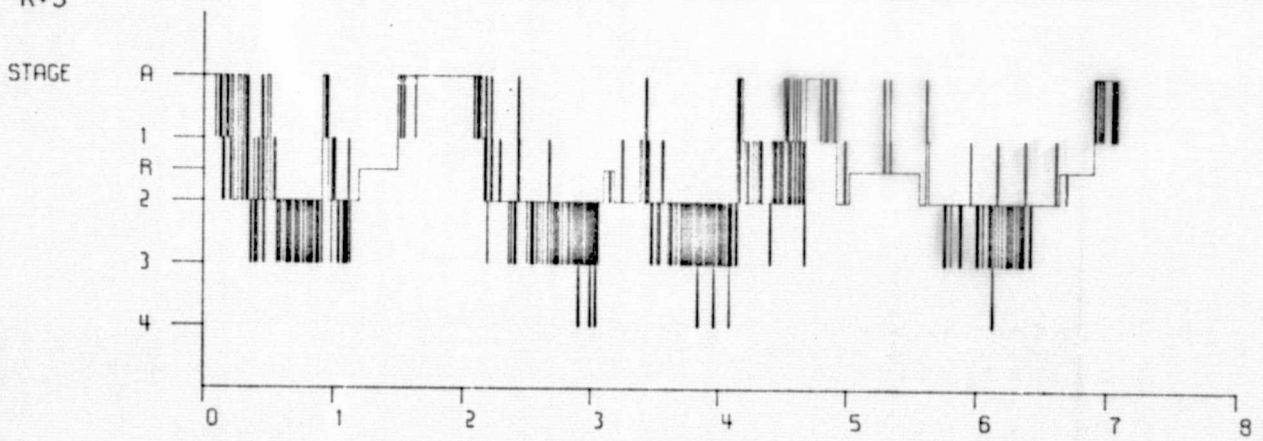
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/3
R+3

R3 OG 9 28 73 V

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS



SL/3
R+5

R5 OG 9 30 73 V

THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS

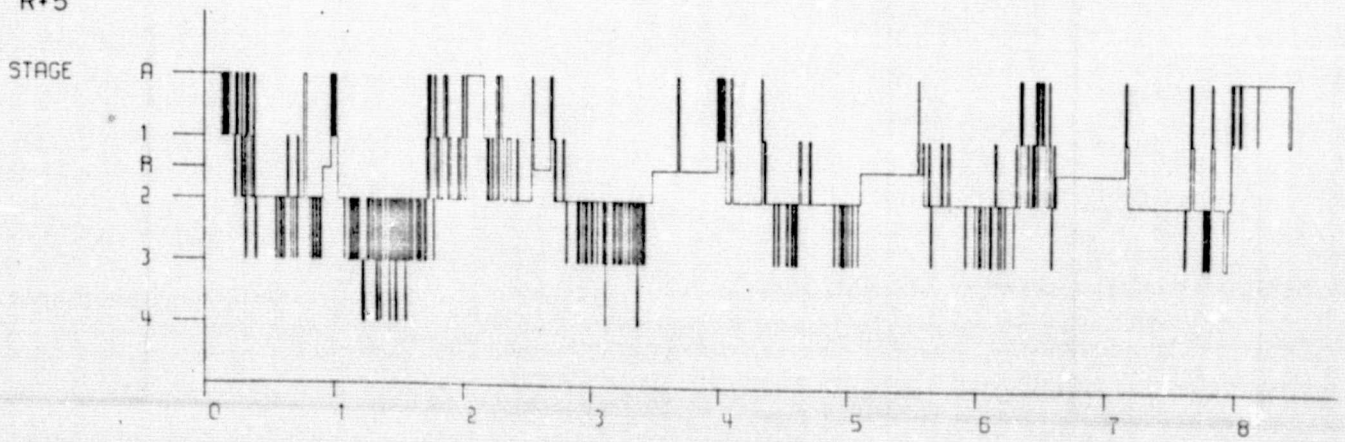
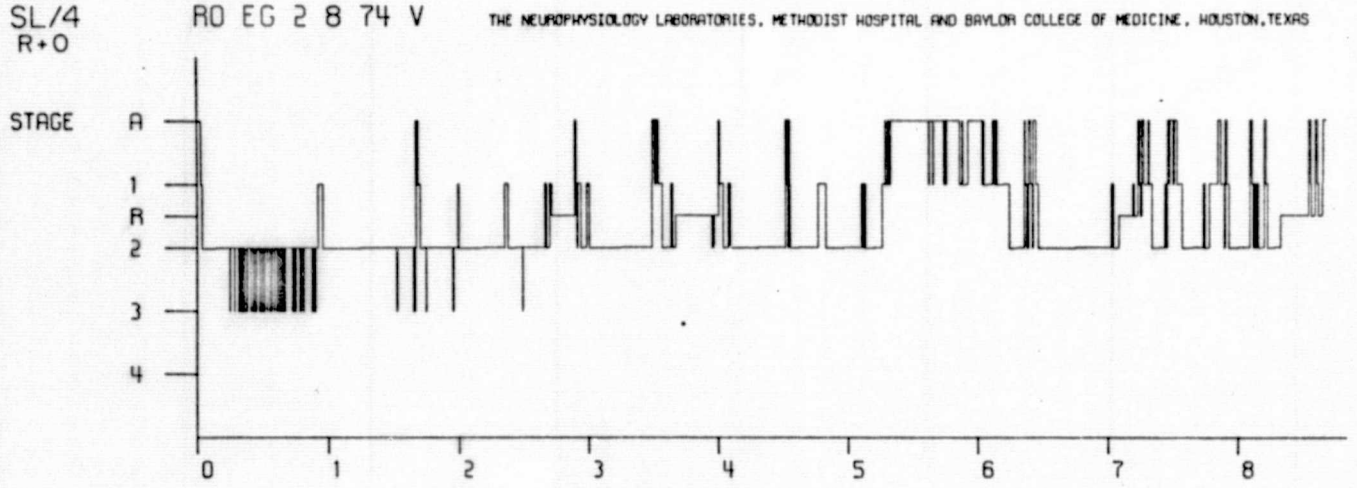
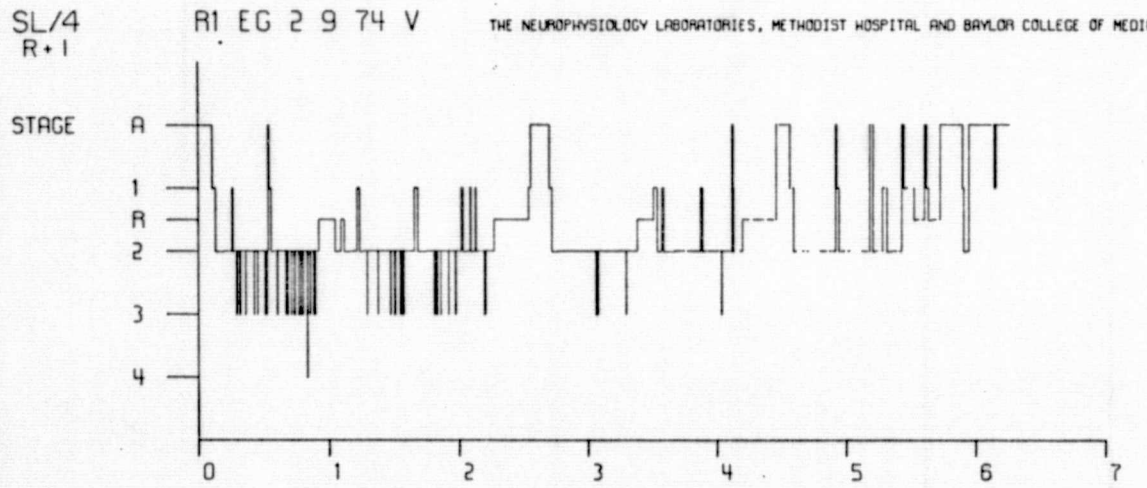


FIG. 41


SL/4
R+0
R0 EG 2 8 74 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8


SL/4
R+1
R1 EG 2 9 74 V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7

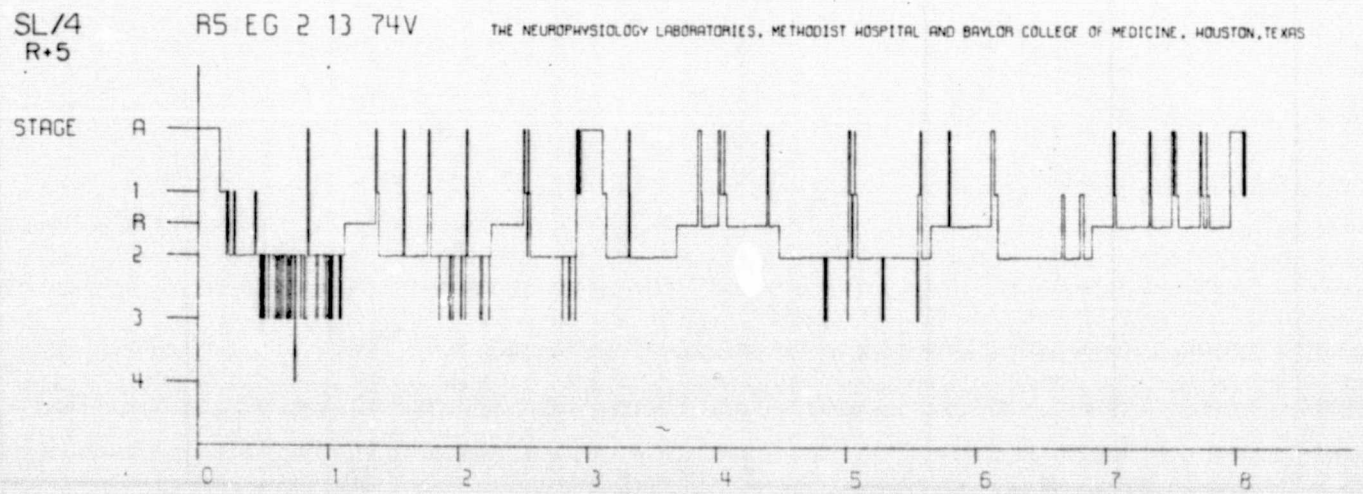

SL/4
R+5
R5 EG 2 13 74V
THE NEUROPHYSIOLOGY LABORATORIES, METHODIST HOSPITAL AND BAYLOR COLLEGE OF MEDICINE, HOUSTON, TEXAS
STAGE
A
1
R
2
3
4
0
1
2
3
4
5
6
7
8

FIG. 42

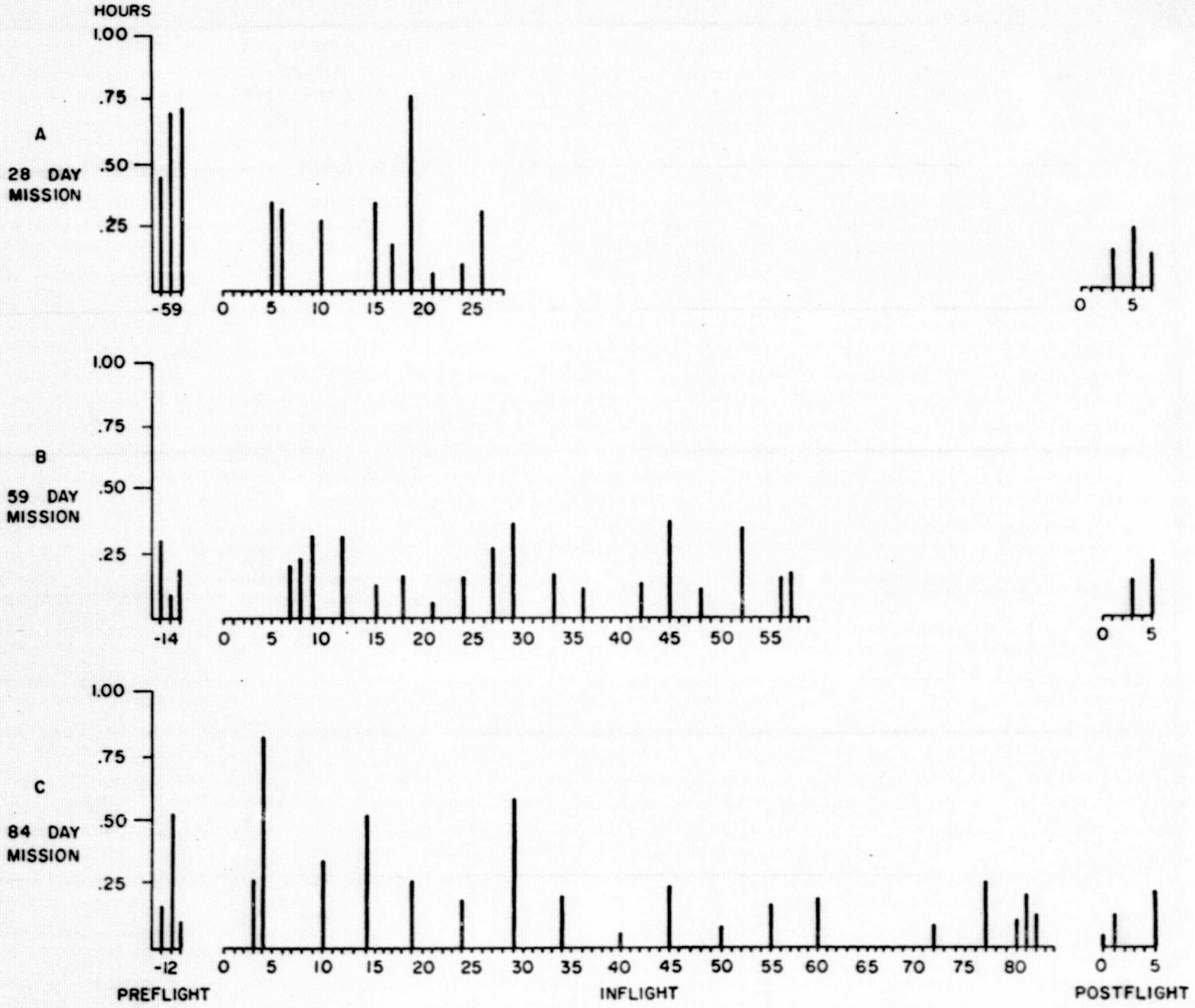

HOURS
1.00
.75
.50
.25
A
28 DAY
MISSION
-59
0 5 10 15 20 25
0 5
B
59 DAY
MISSION
-14
0 5 10 15 20 25 30 35 40 45 50 55
0 5
C
84 DAY
MISSION
-12
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
0 5
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 43

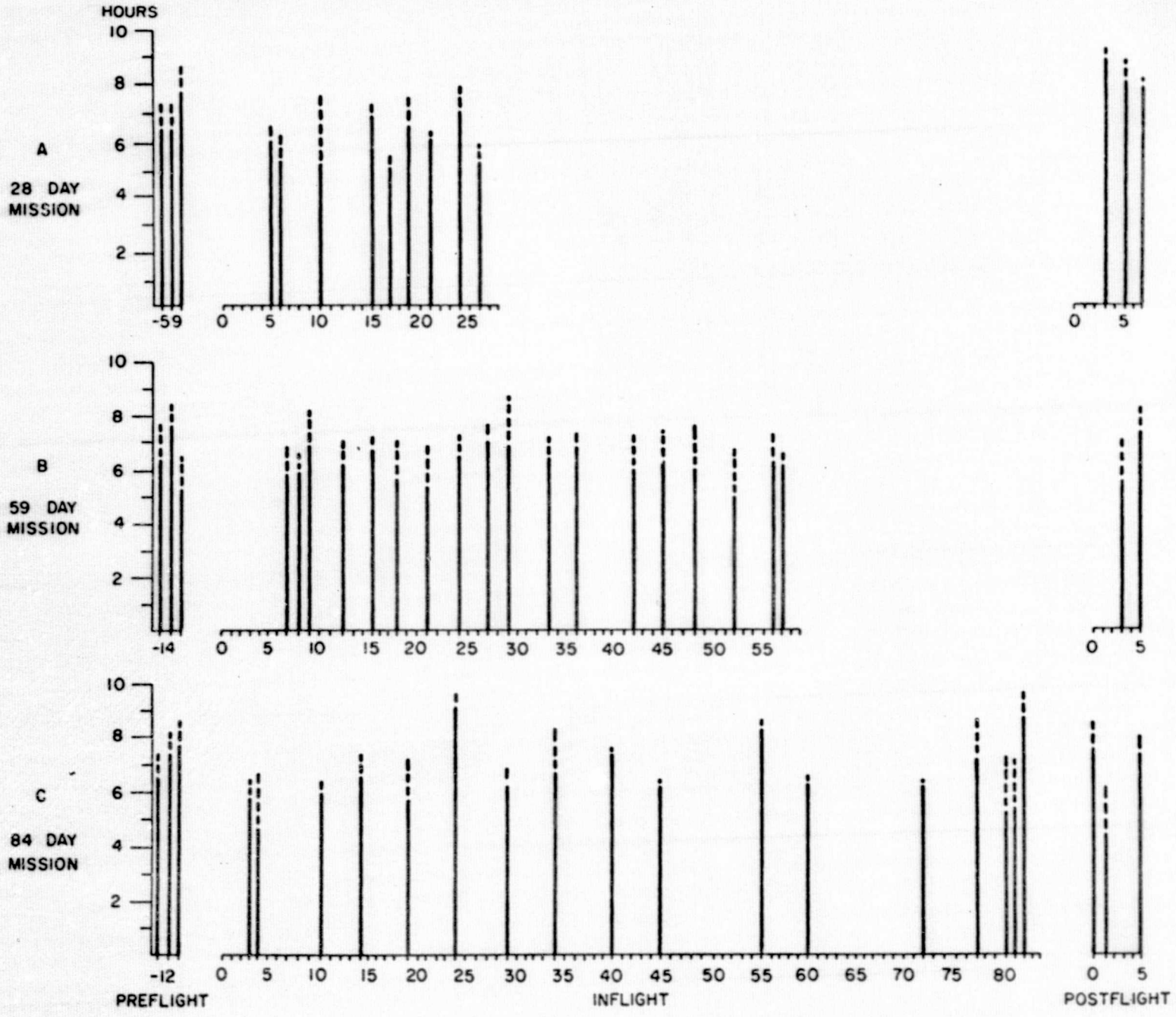

HOURS
A
28 DAY
MISSION
B
59 DAY
MISSION
C
84 DAY
MISSION
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 44

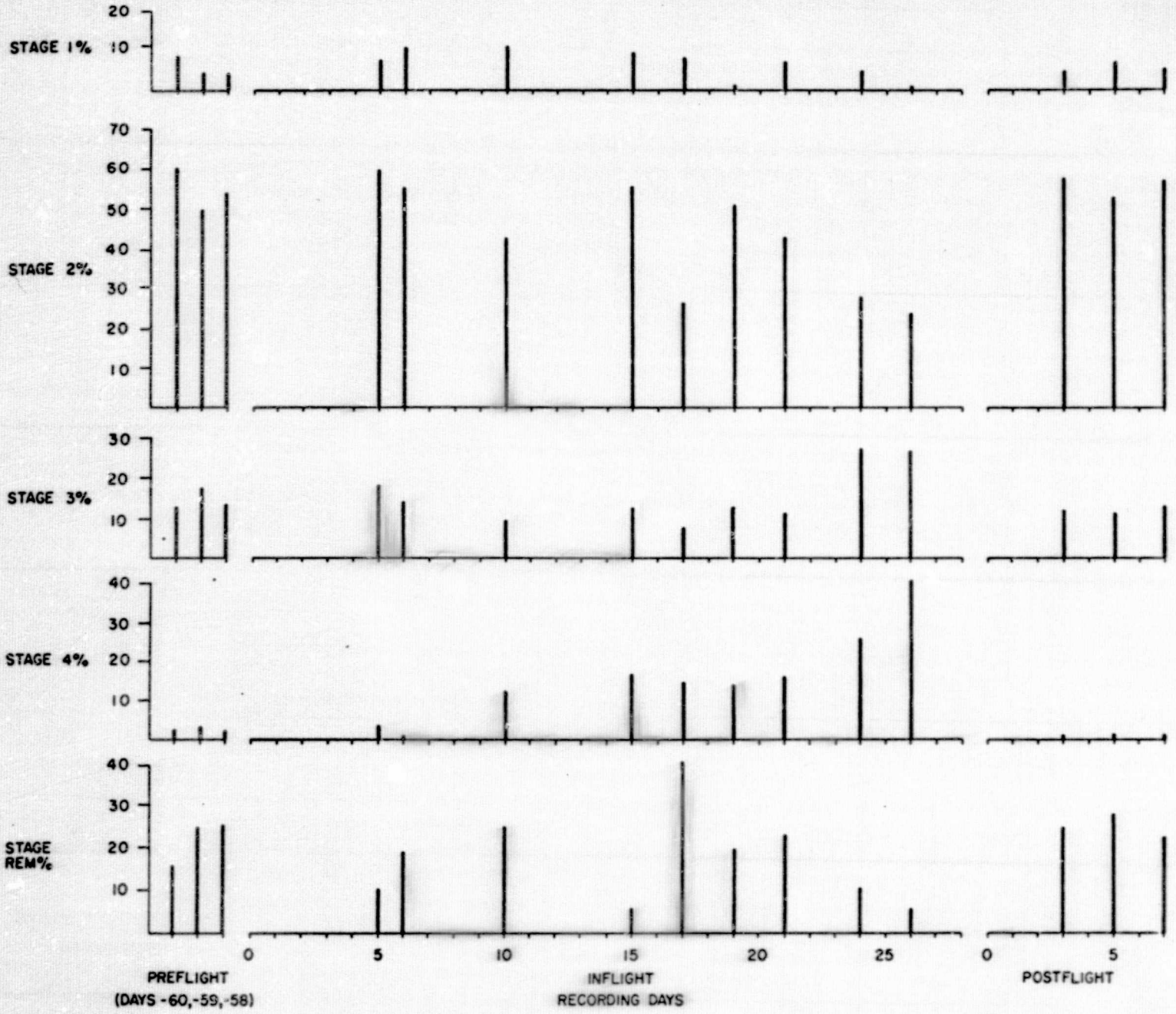

STAGE 1%
20
10
STAGE 2%
70
60
50
40
30
20
10
STAGE 3%
30
20
10
STAGE 4%
40
30
20
10
STAGE REM%
40
30
20
10
0
5
10
15
20
25
0
5
PREFLIGHT
(DAYS -60,-59,-58)
INFLIGHT
RECORDING DAYS
POSTFLIGHT

FIG. 45

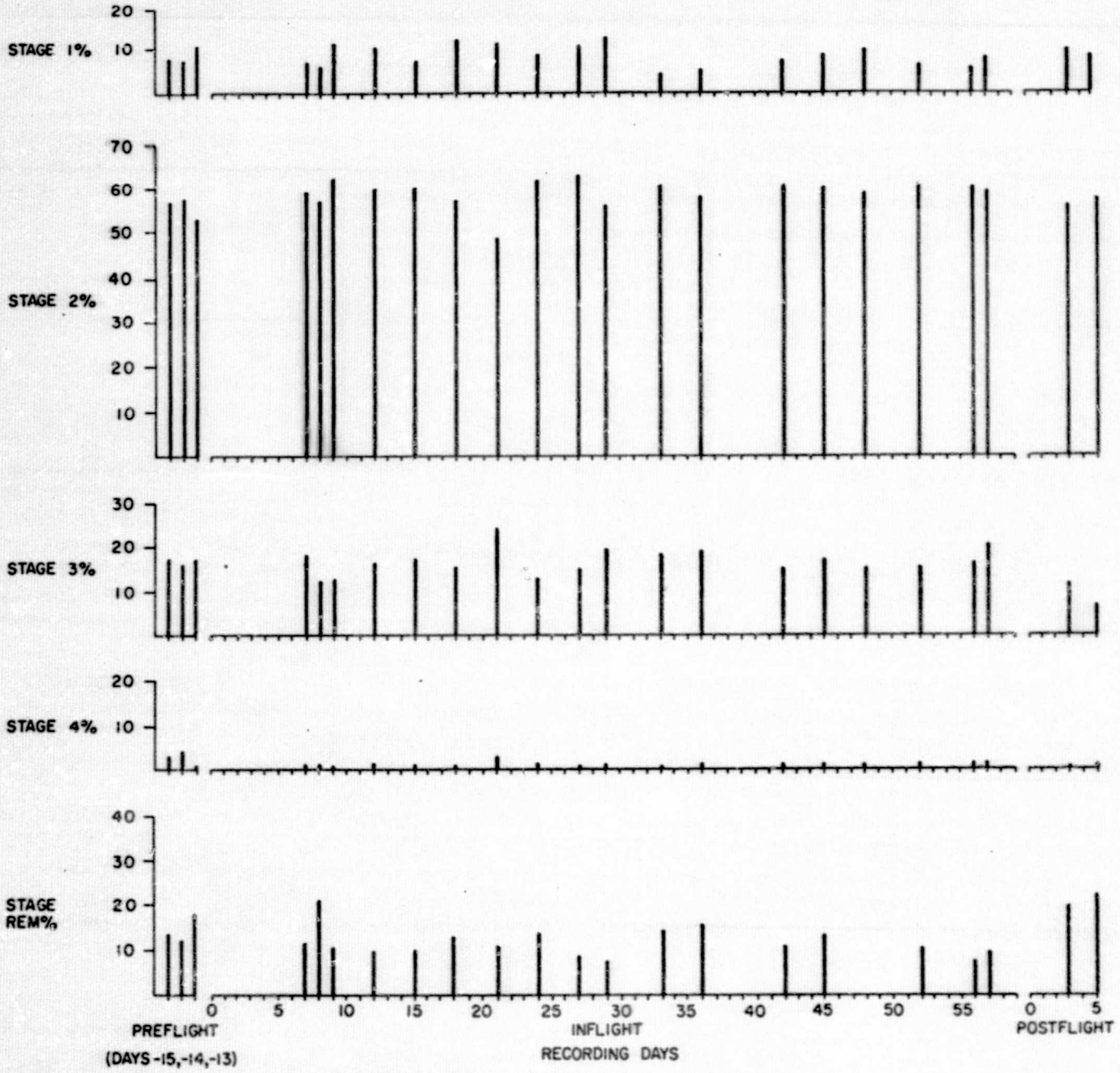

STAGE 1%
20
10
STAGE 2%
70
60
50
40
30
20
10
STAGE 3%
30
20
10
STAGE 4%
20
10
STAGE REM%
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
55
0
5
PREFLIGHT
(DAYS -15,-14,-13)
INFLIGHT
RECORDING DAYS
POSTFLIGHT

FIG. 46

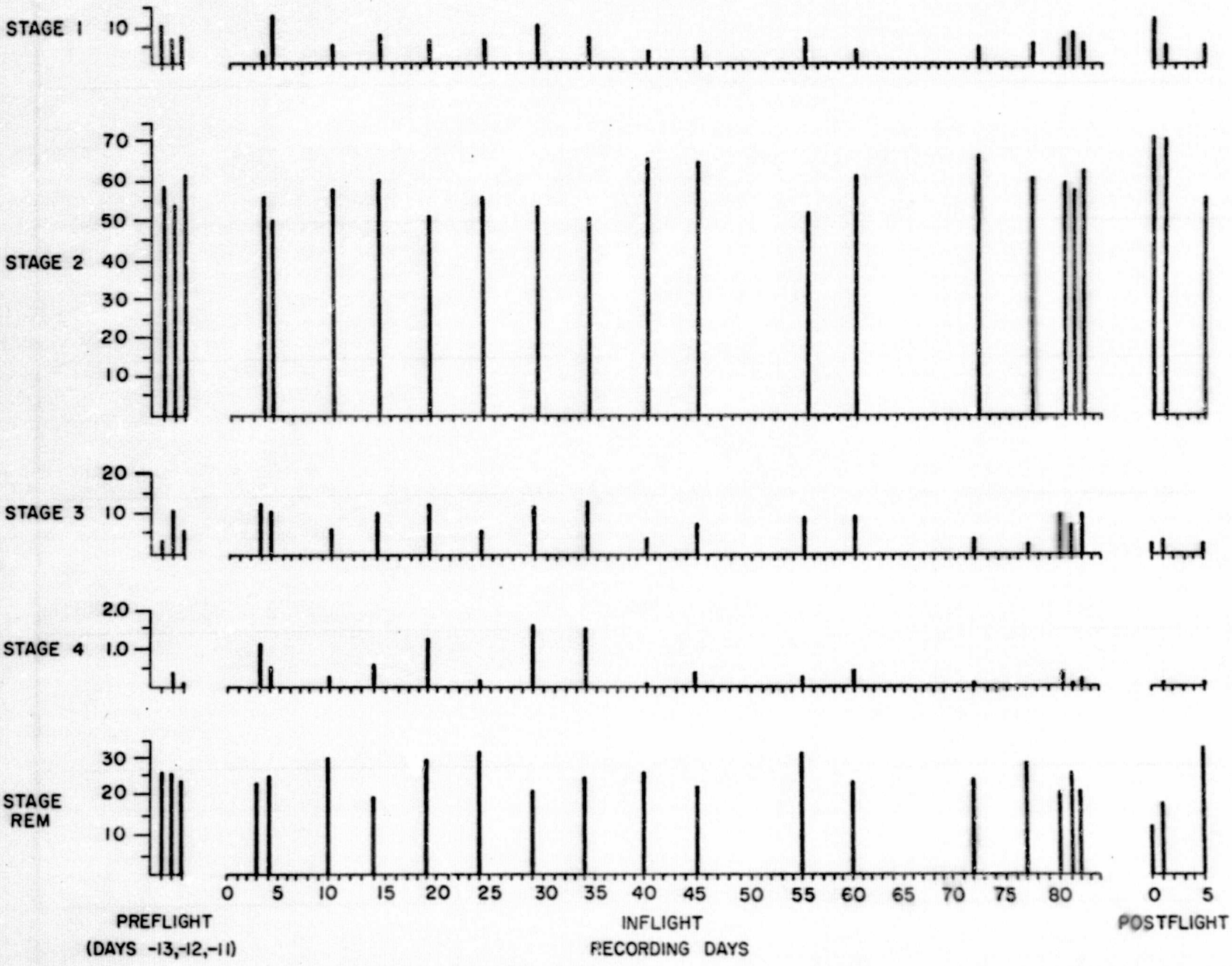

STAGE 1
10
STAGE 2
70
60
50
40
30
20
10
STAGE 3
20
10
STAGE 4
2.0
1.0
STAGE REM
30
20
10
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
0 5
PREFLIGHT
(DAYS -13,-12,-11)
INFLIGHT
RECORDING DAYS
POSTFLIGHT

FIG. 47

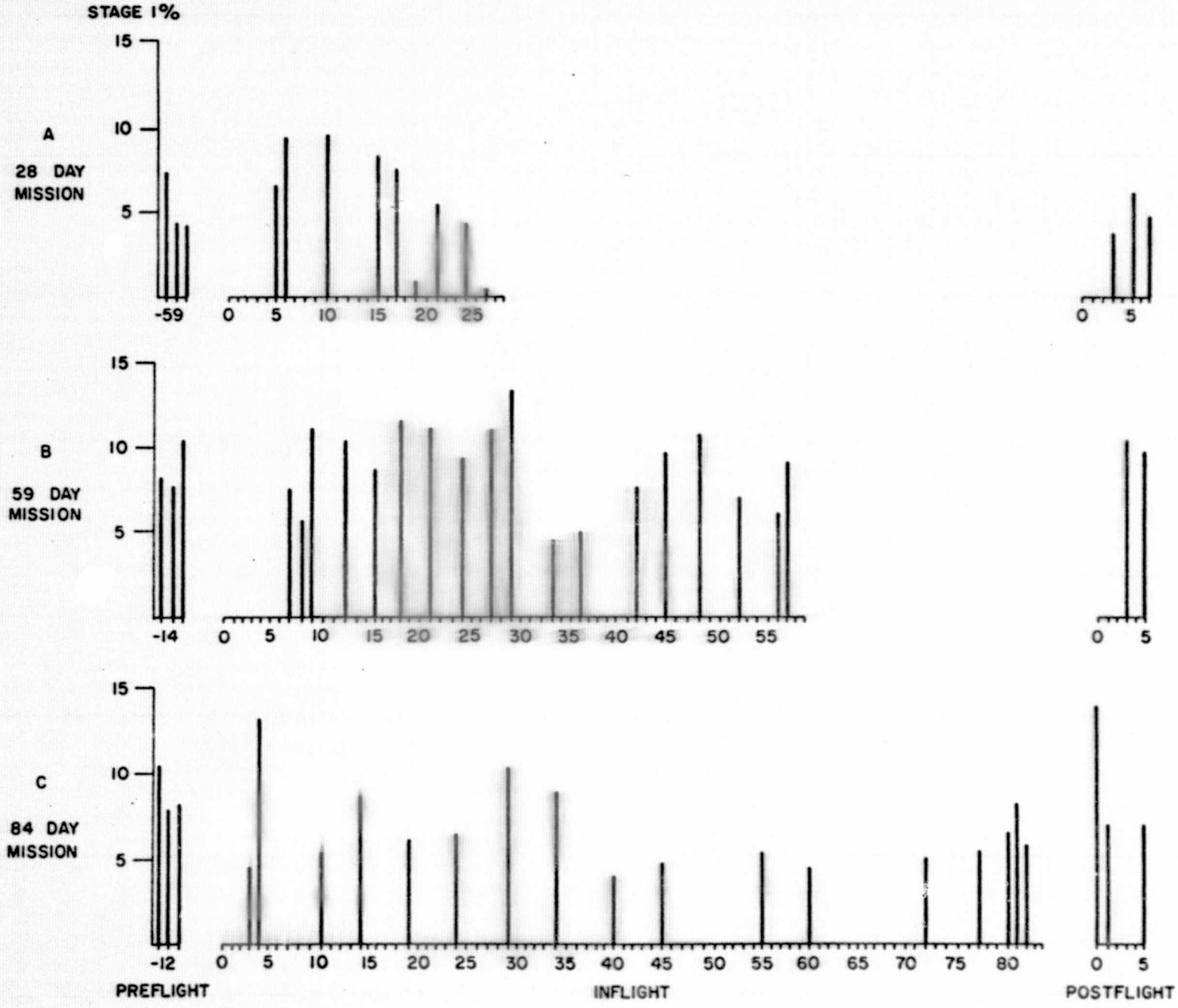

STAGE 1%
A
28 DAY
MISSION
B
59 DAY
MISSION
C
84 DAY
MISSION
15
10
5
-59
-14
-12
0 5 10 15 20 25
0 5 10 15 20 25 30 35 40 45 50 55
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
0 5
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 48

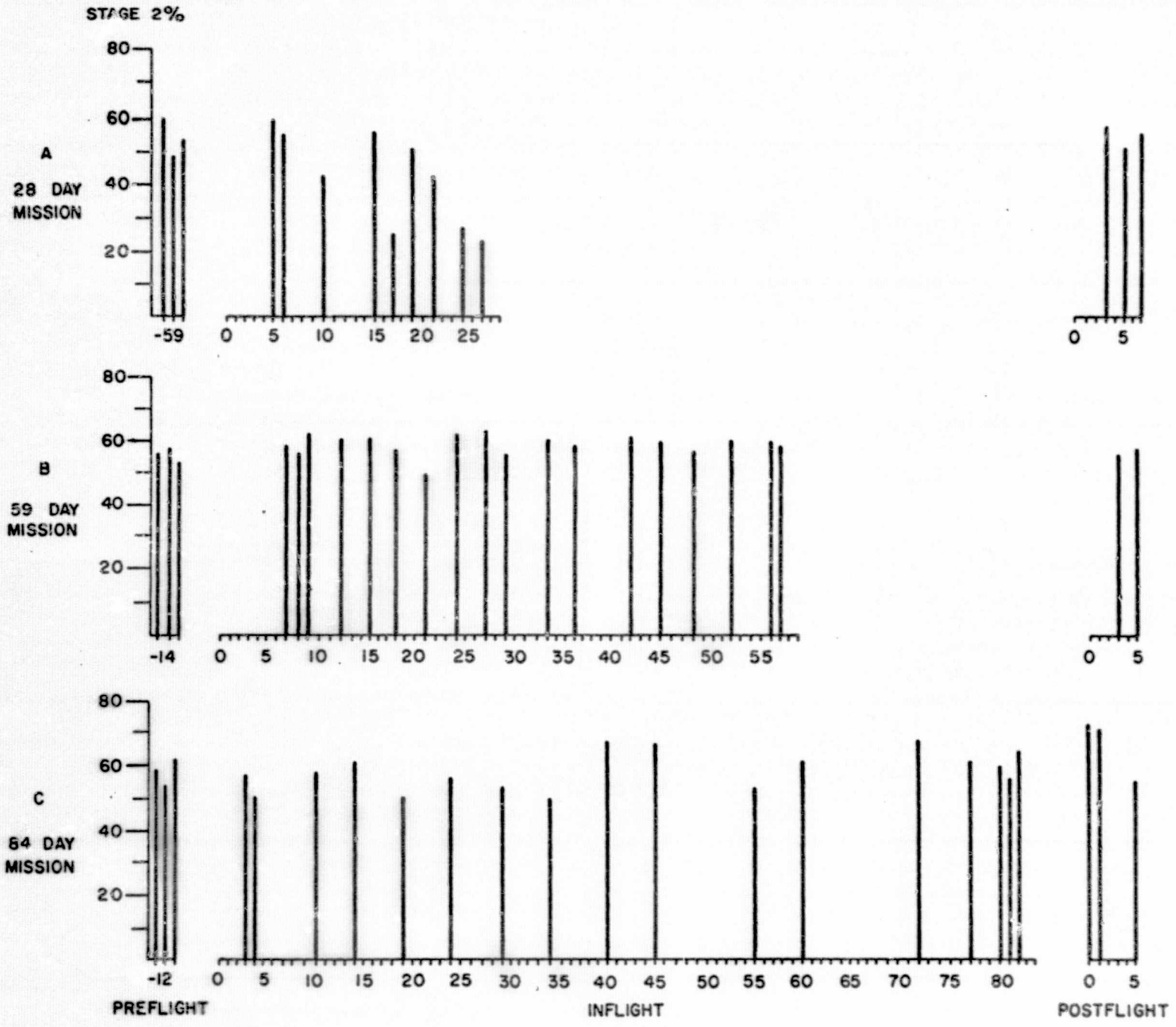

STAGE 2%
A
28 DAY
MISSION
B
59 DAY
MISSION
C
64 DAY
MISSION
80
60
40
20
-59
-14
-12
0 5 10 15 20 25
0 5 10 15 20 25 30 35 40 45 50 55
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
0 5
0 5
0 5
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 49

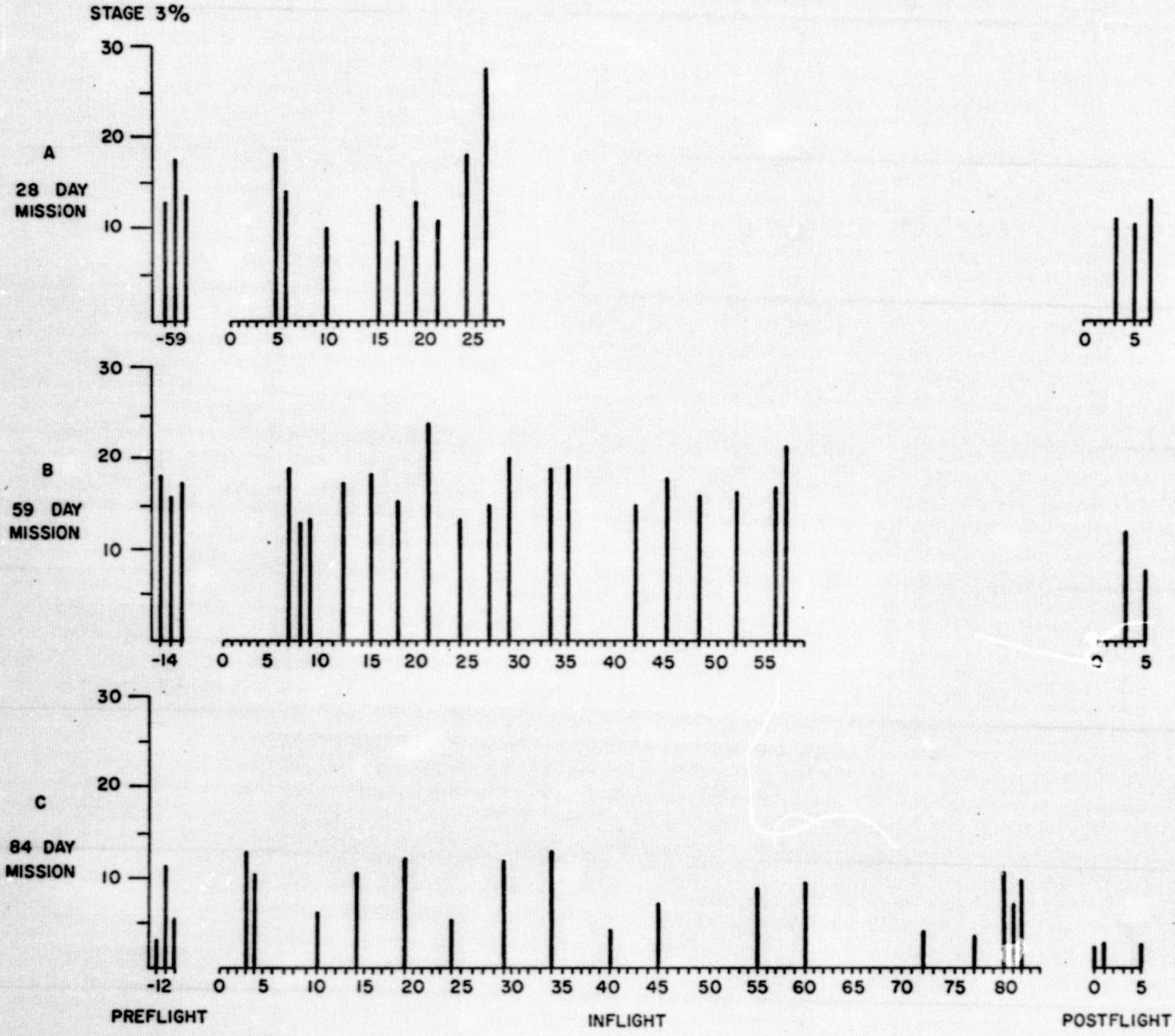

STAGE 3%
A
28 DAY
MISSION
B
59 DAY
MISSION
C
84 DAY
MISSION
30
20
10
-59
-14
-12
0 5 10 15 20 25
0 5 10 15 20 25 30 35 40 45 50 55
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
0 5
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 50

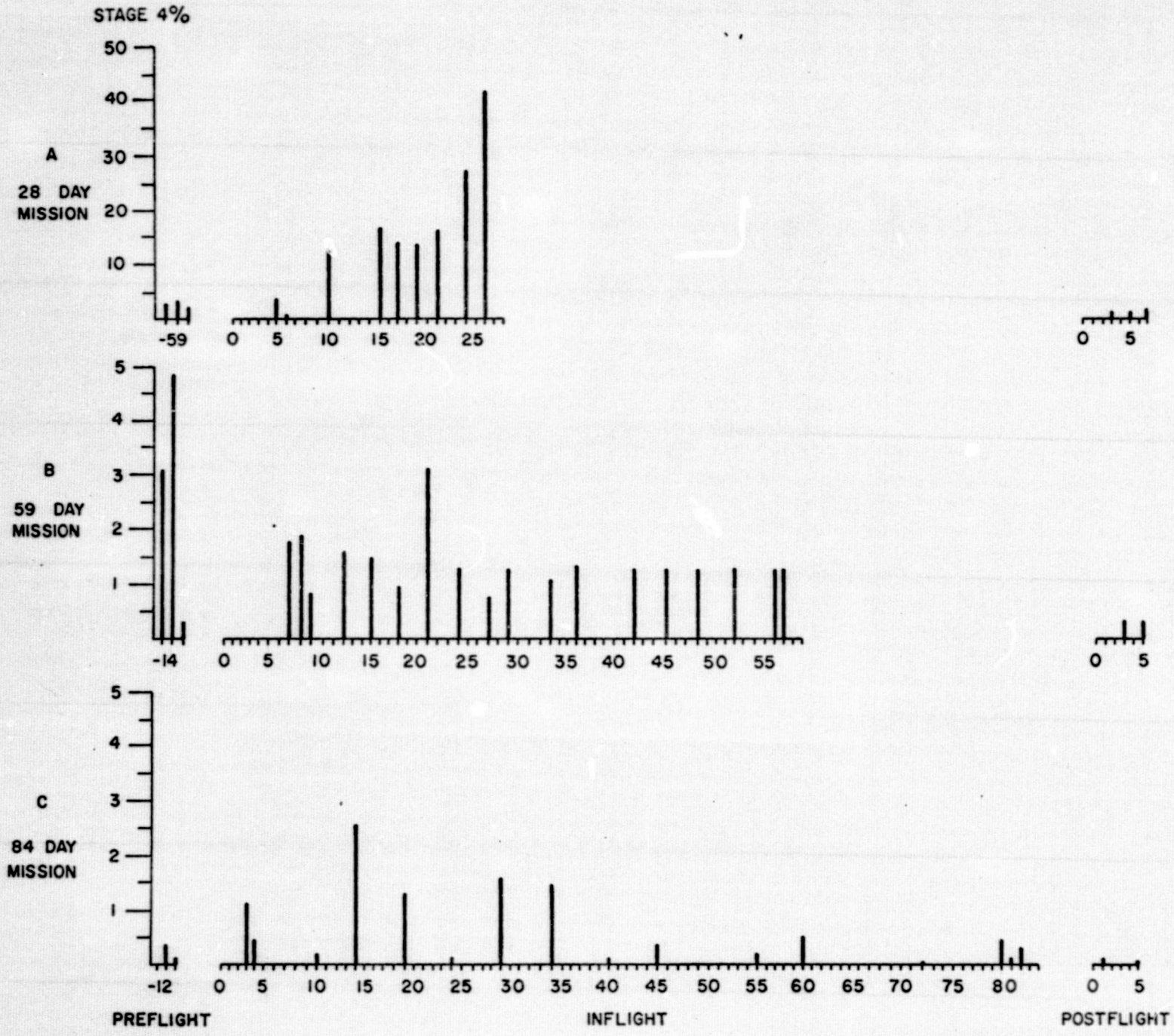

STAGE 4%
A
28 DAY
MISSION
50
40
30
20
10
-59
0 5 10 15 20 25
0 5
B
59 DAY
MISSION
5
4
3
2
1
-14
0 5 10 15 20 25 30 35 40 45 50 55
0 5
C
84 DAY
MISSION
5
4
3
2
1
-12
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
0 5
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 51

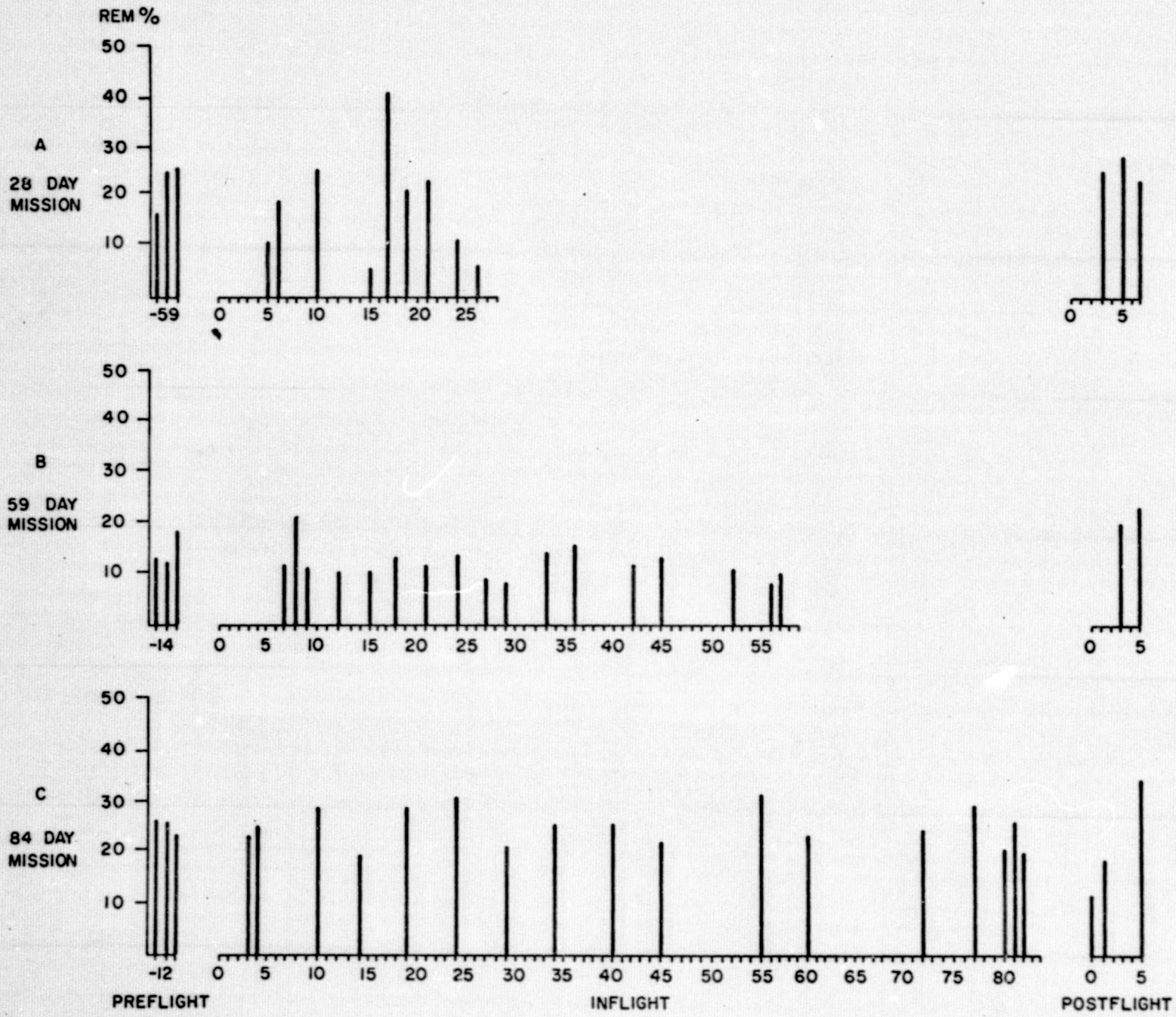

REM %
A
28 DAY
MISSION
B
59 DAY
MISSION
C
84 DAY
MISSION
50
40
30
20
10
-59
-14
-12
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 52

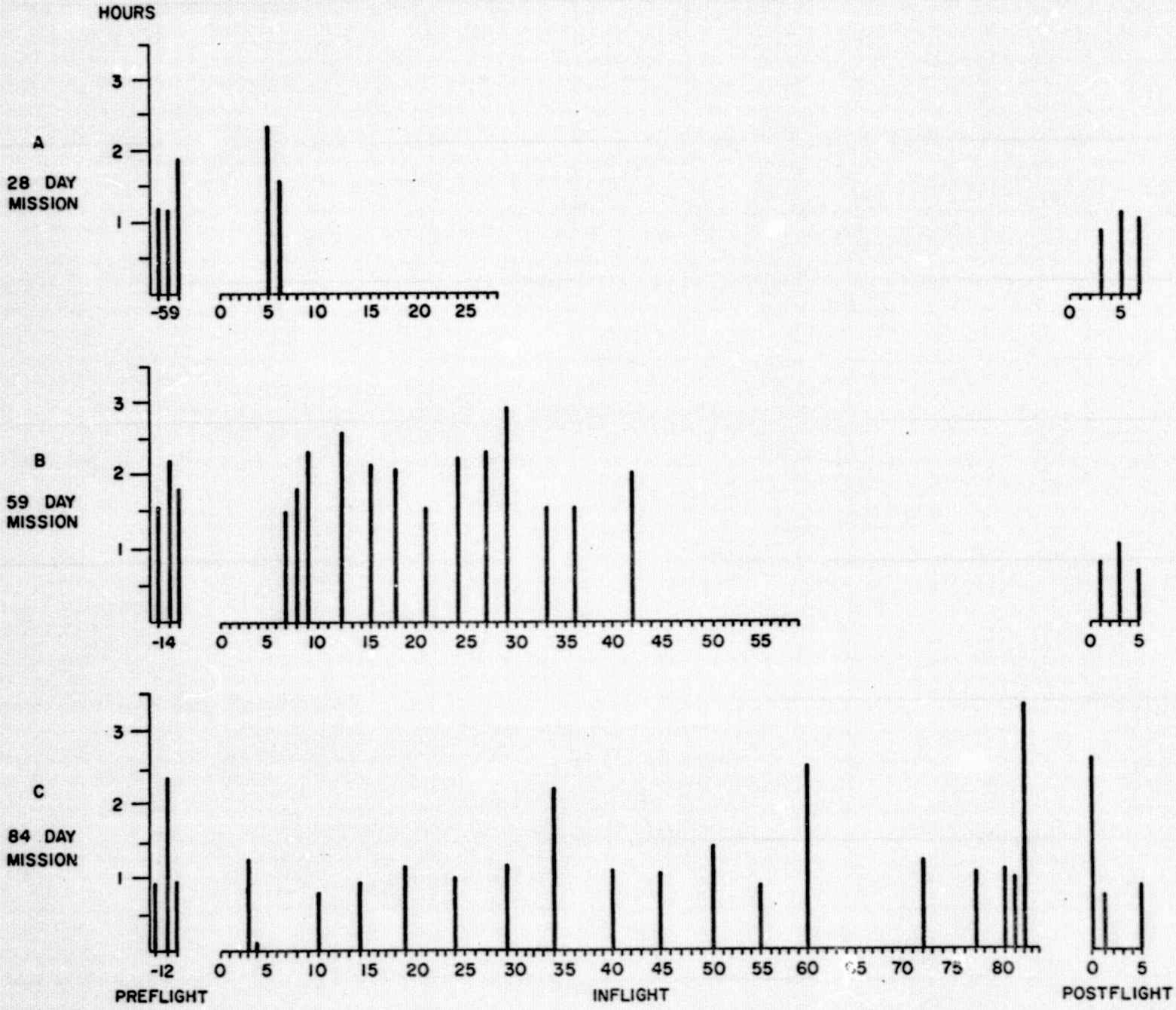

HOURS
A
28 DAY MISSION
B
59 DAY MISSION
C
84 DAY MISSION
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 53

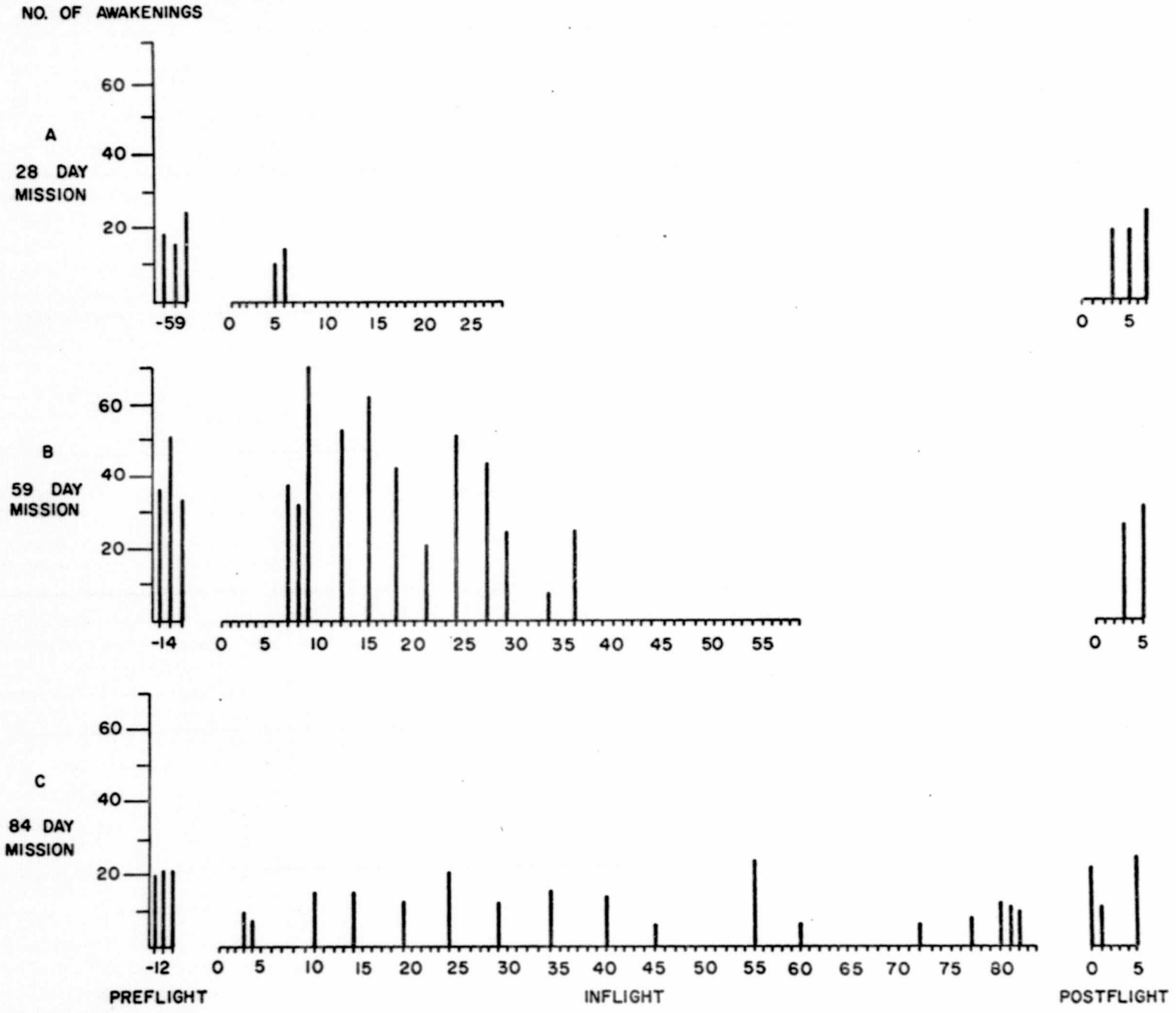
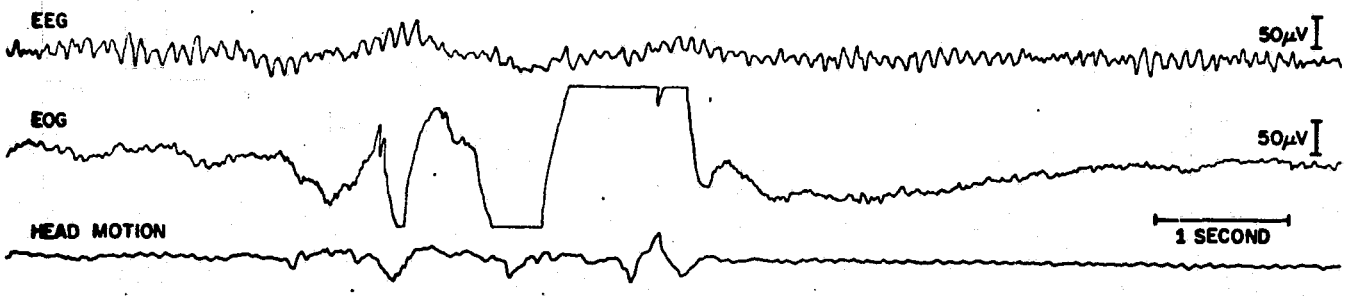
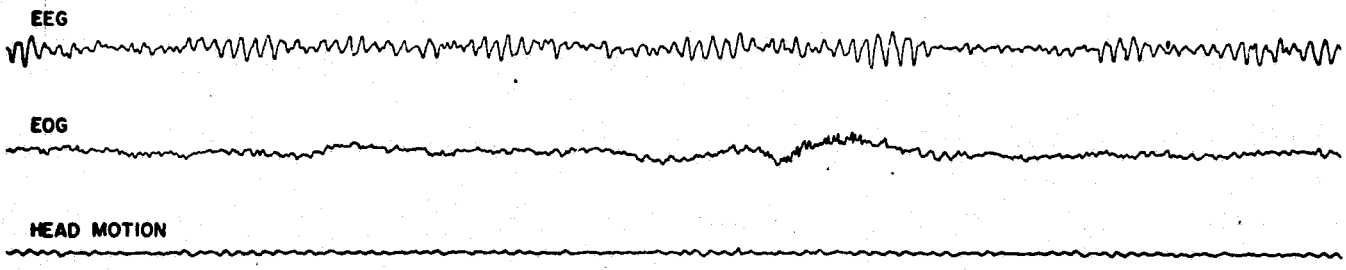

NO. OF AWAKENINGS
A
28 DAY
MISSION
60
40
20
-59
0 5 10 15 20 25
0 5
B
59 DAY
MISSION
60
40
20
-14
0 5 10 15 20 25 30 35 40 45 50 55
0 5
C
84 DAY
MISSION
60
40
20
-12
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
0 5
PREFLIGHT
INFLIGHT
POSTFLIGHT

FIG. 54

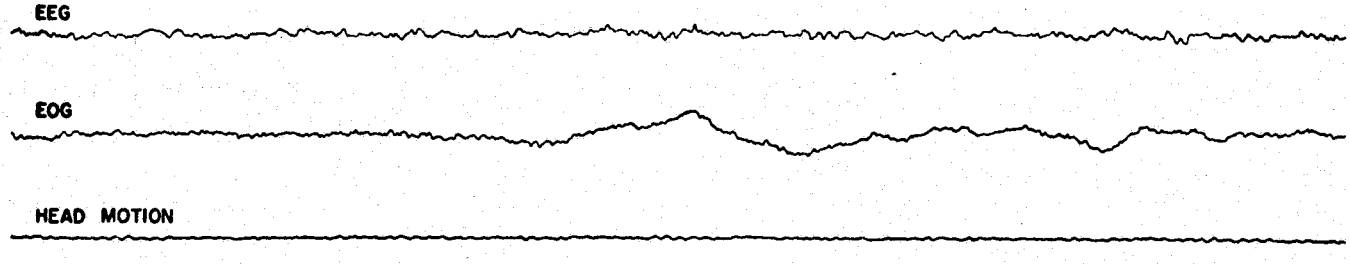
J.K. SL/2 M.D. 6



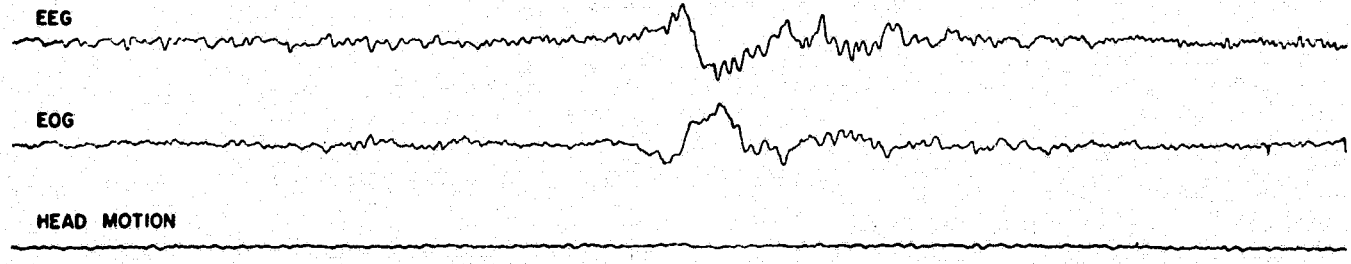
A. AWAKE, MOVING



B. AWAKE, RELAXED



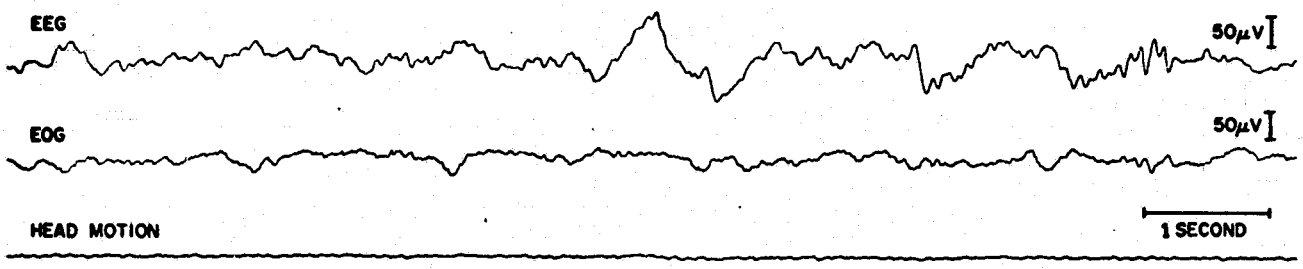
C. STAGE 1



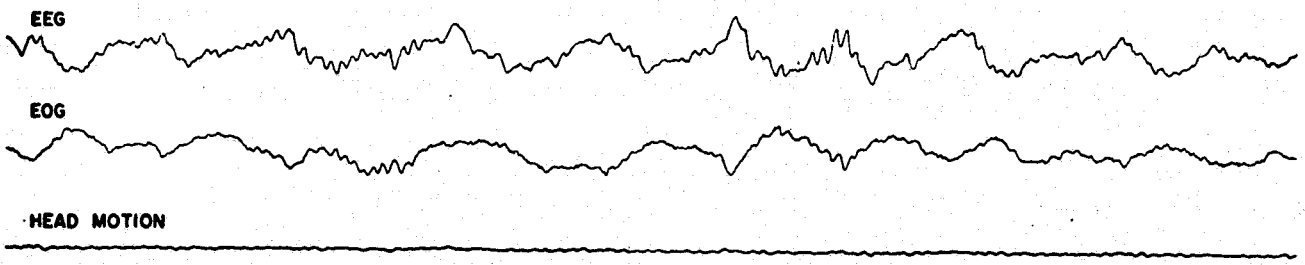
D. STAGE 2

FIG.55

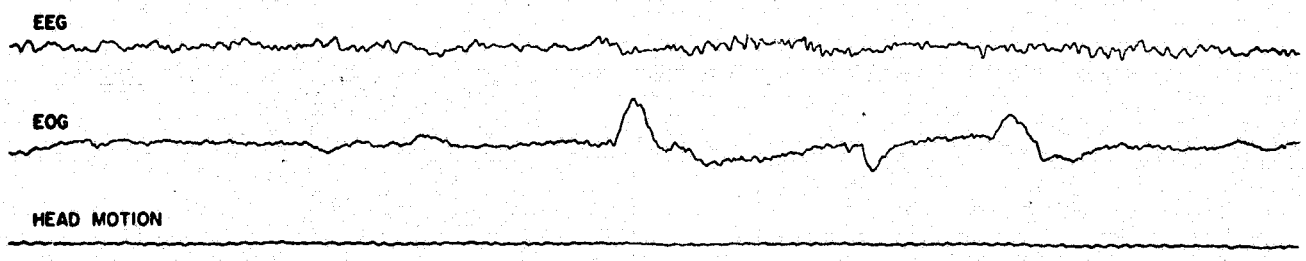
J.K. SL/2 M.D. 6



A. STAGE 3



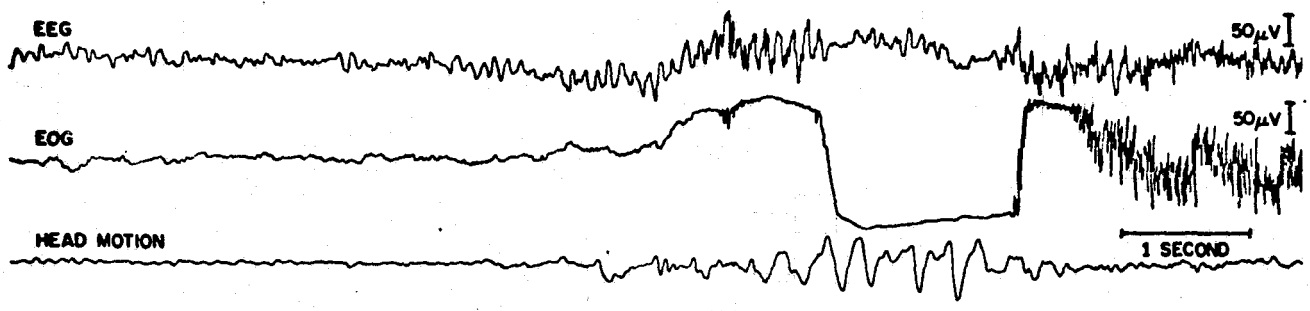
B. STAGE 4



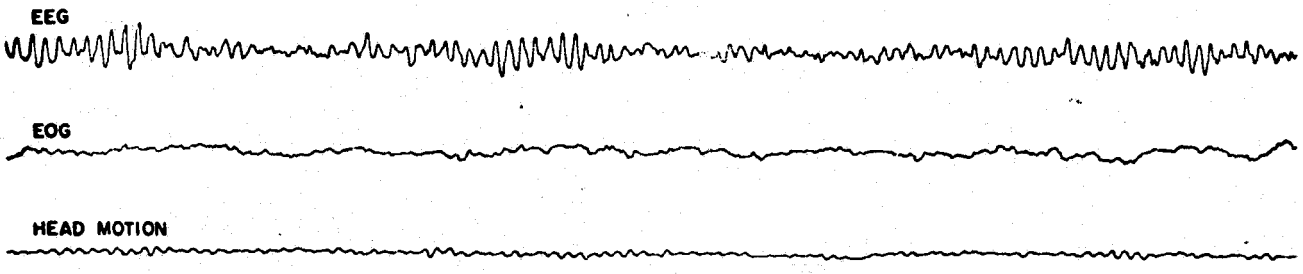
C. STAGE REM

FIG. 56

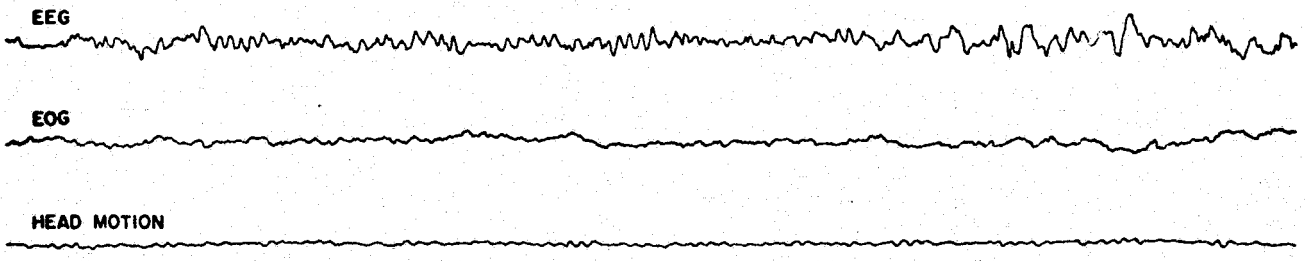
O.G. SL/3 M.D. 29



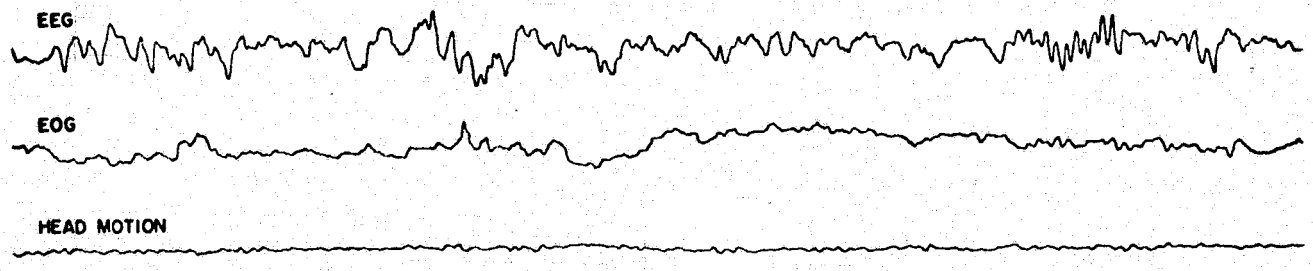
A. AWAKE, MOVING



B. AWAKE, RELAXED



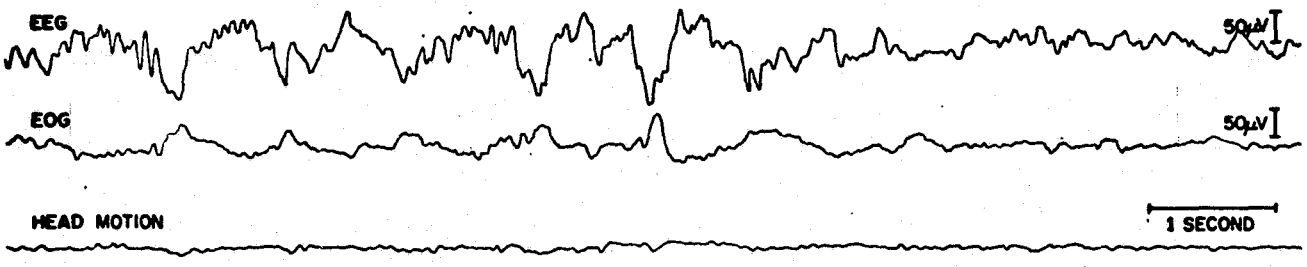
C. STAGE 1



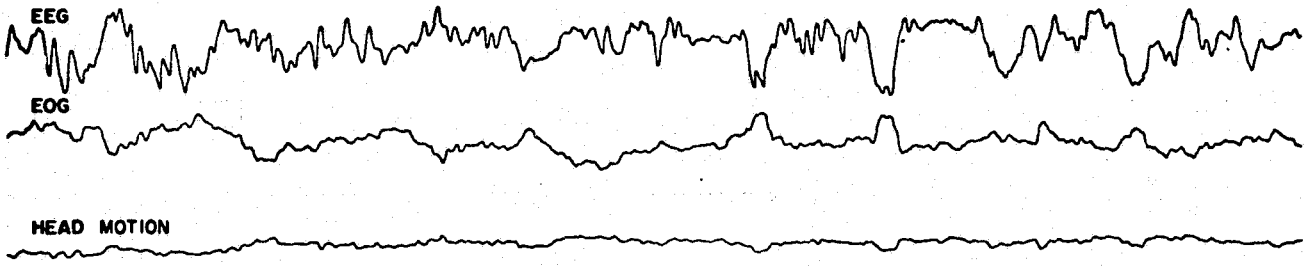
D. STAGE 2

FIG. 57

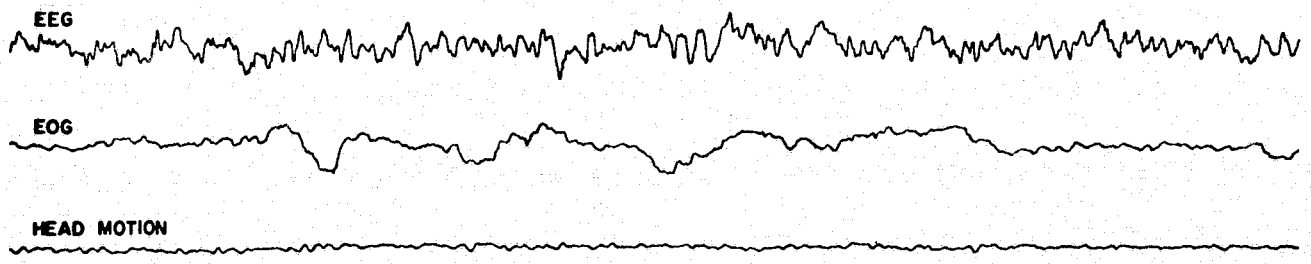
O.G. SL/3 M.D. 29



A. STAGE 3

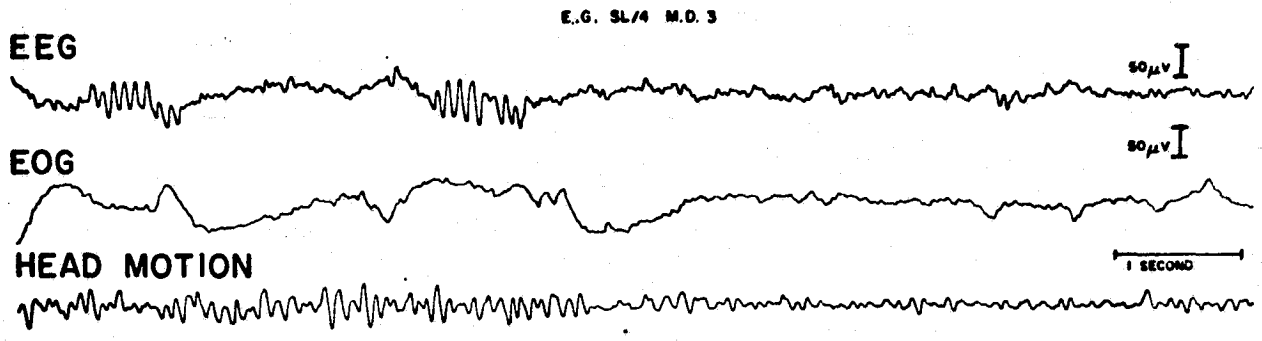


B. STAGE 4

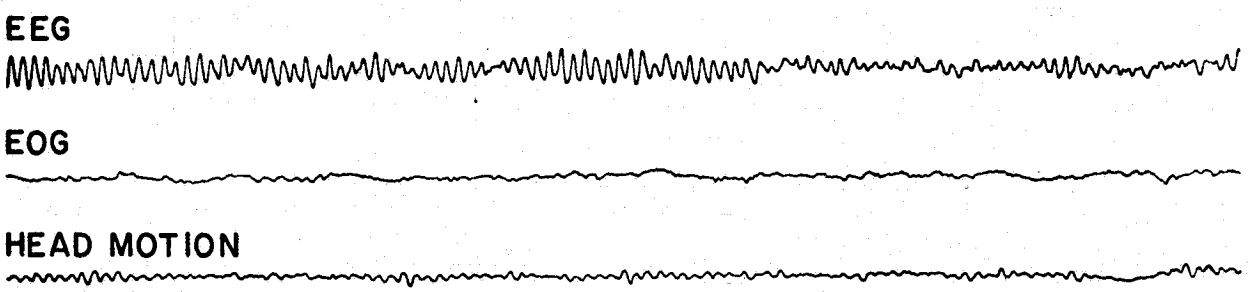


C. STAGE REM

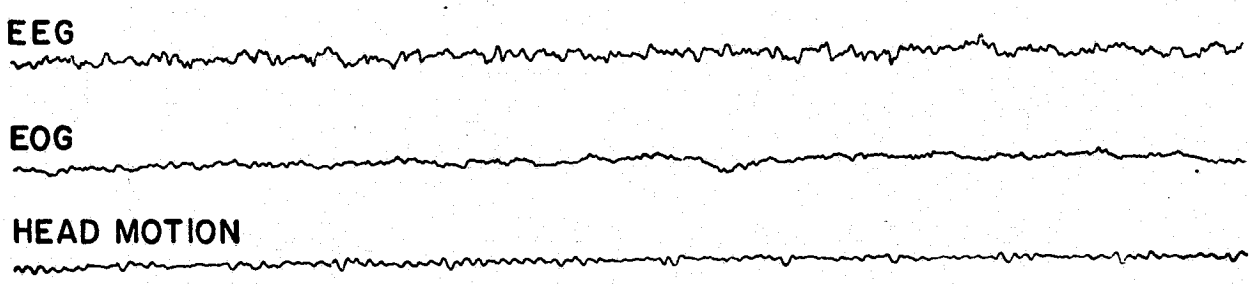
FIG. 58



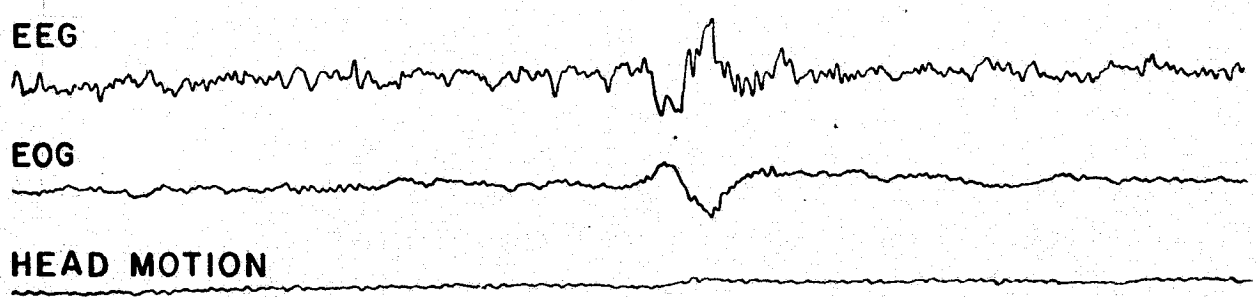
A. AWAKE, MOVING



B. AWAKE, RELAXED

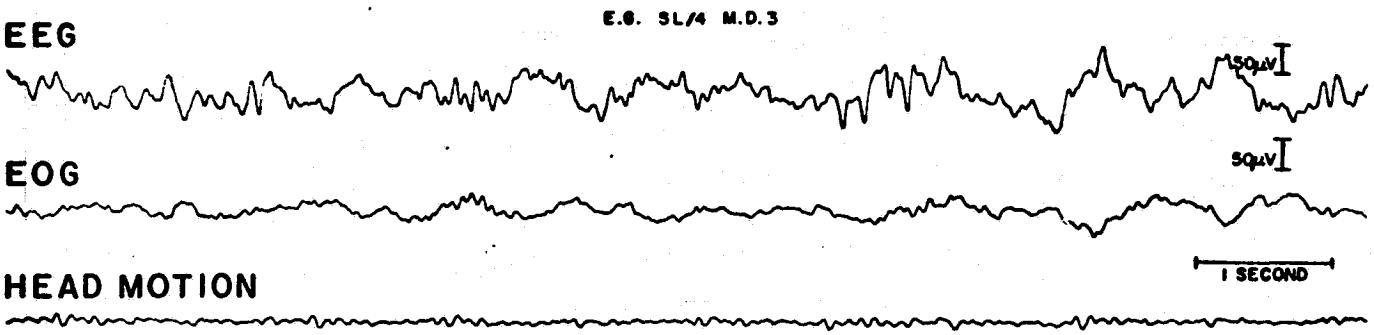


C. STAGE 1

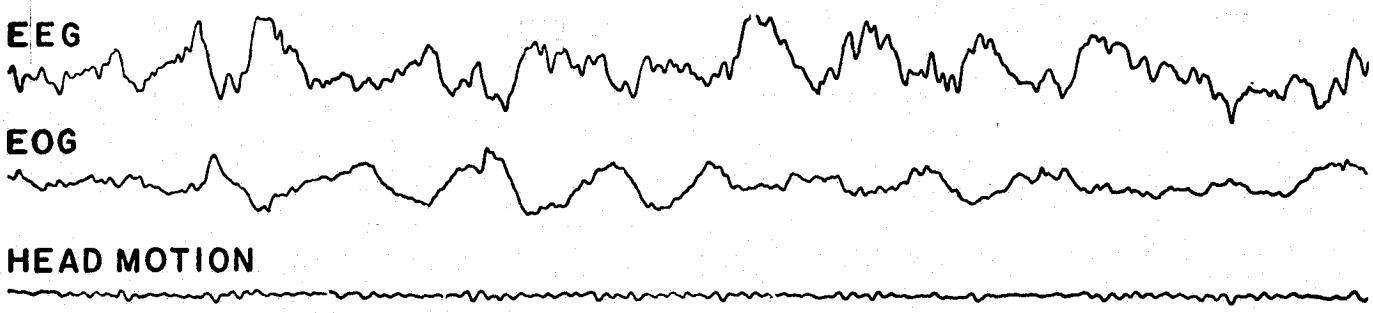


D. STAGE 2

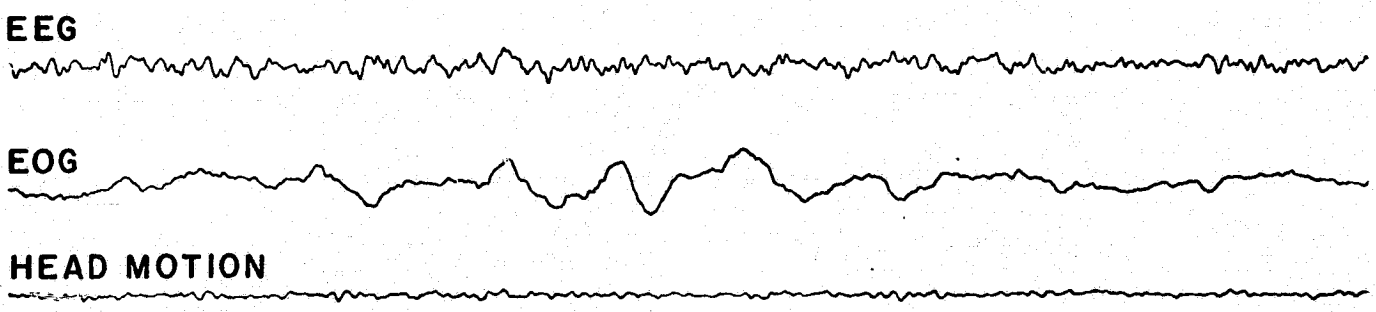
FIG. 59



A. STAGE 3



B. STAGE 4



C. STAGE REM

FIG. 60

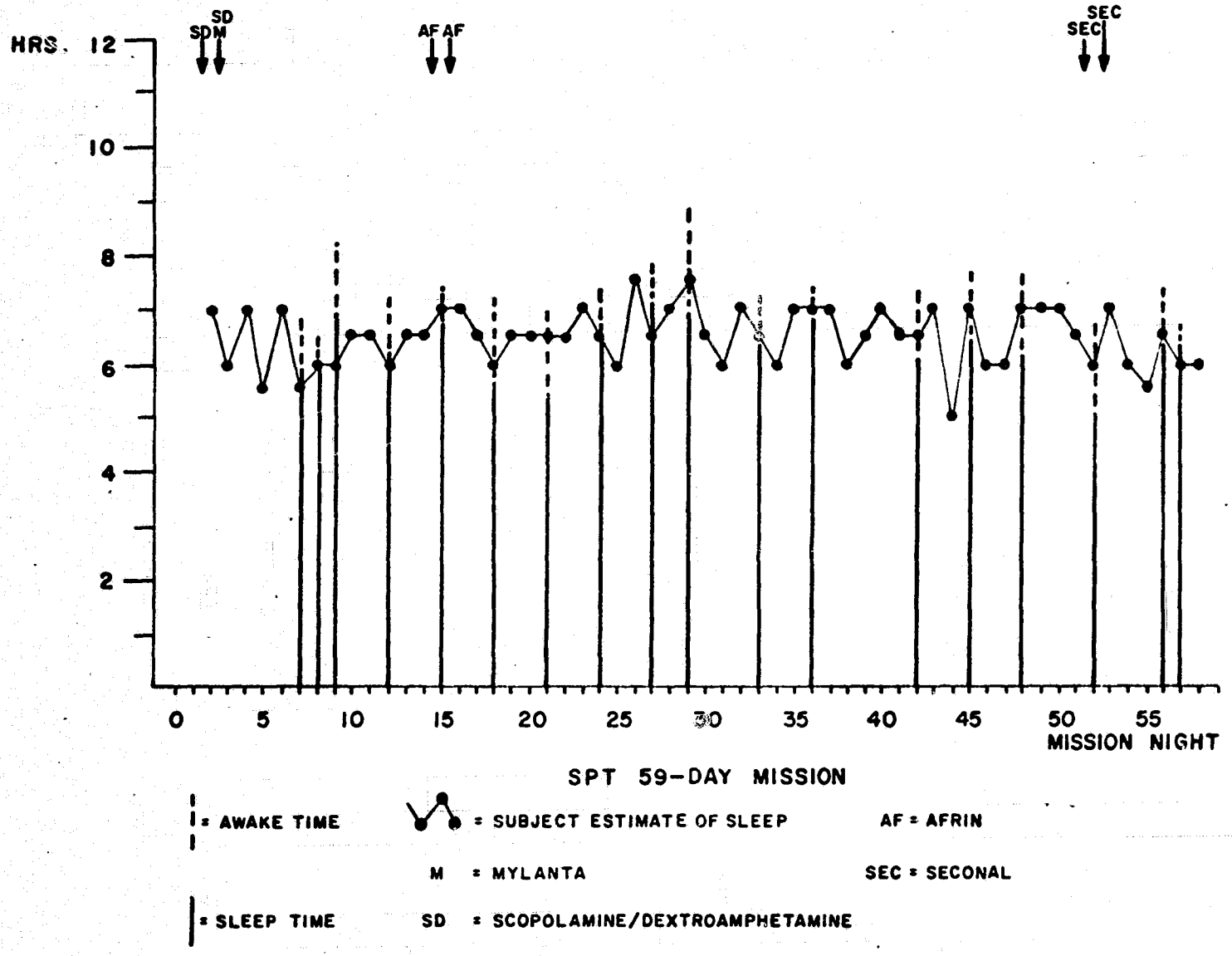

HRS. 12
10
8
6
4
2
SD
SDM
AF AF
SEC
SEC
0
5
10
15
20
25
30
35
40
45
50
55
MISSION NIGHT
SPT 59-DAY MISSION
= AWAKE TIME
= SUBJECT ESTIMATE OF SLEEP
AF = AFRIN
M = MYLANTA
SEC = SECONAL
= SLEEP TIME
SD = SCOPOLAMINE/DEXTROAMPHETAMINE

FIG. 61

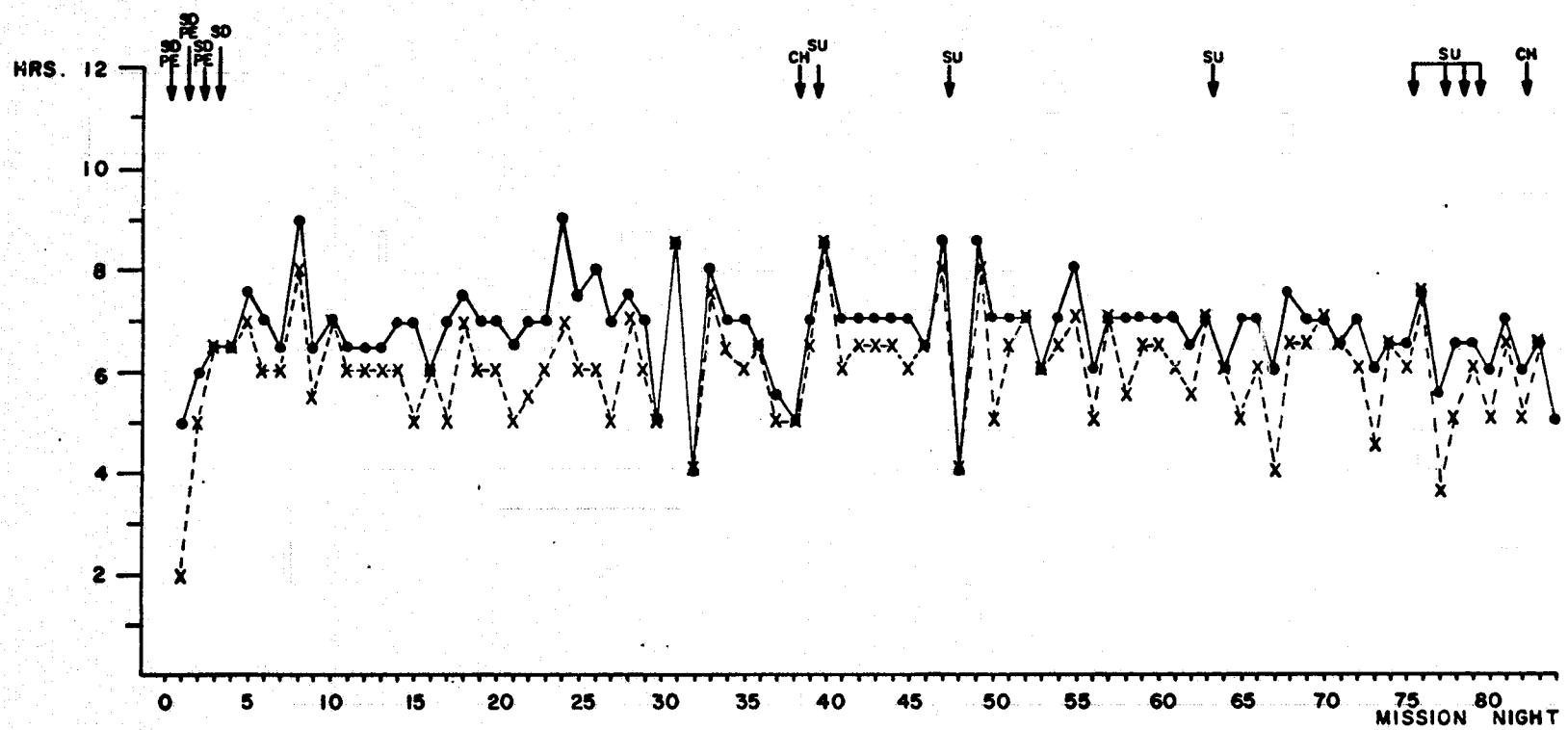

HRS.
12
10
8
6
4
2
SD
PE
SD
PE
SD
PE
SD
CH
SU
SU
SU
SU
CH
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
MISSION NIGHT
CDR 84 - DAY MISSION
= ESTIMATE OF TOTAL SLEEP TIME
= ESTIMATE OF HEAVY SLEEP
CH = CHLORAL HYDRATE
PE = PROMETHAZINE/EPHEDRINE
SD = SCOPOLAMINE/DEXTROAMPHETAMINE
SU = SUDAFED

FIG. 62

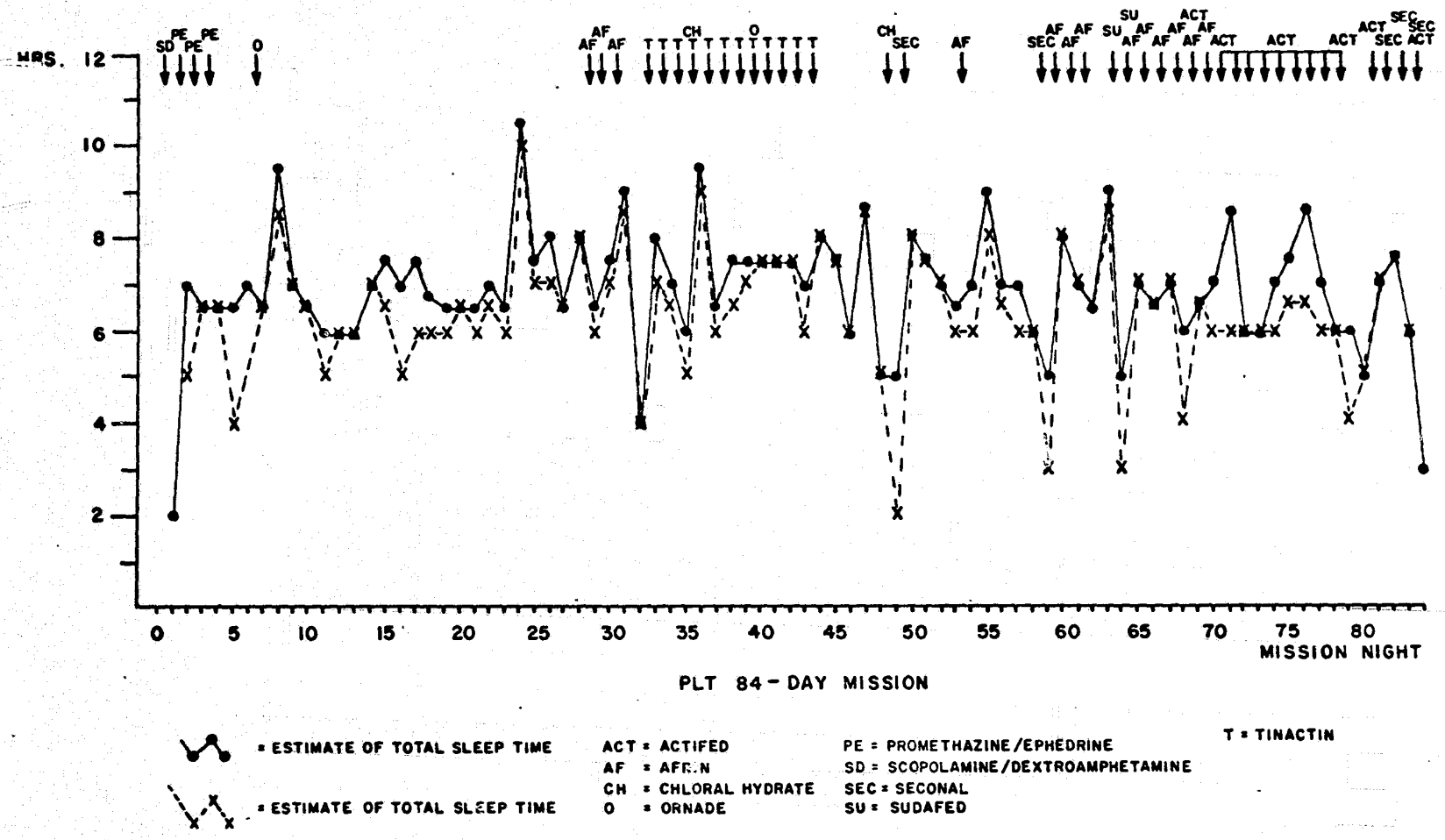
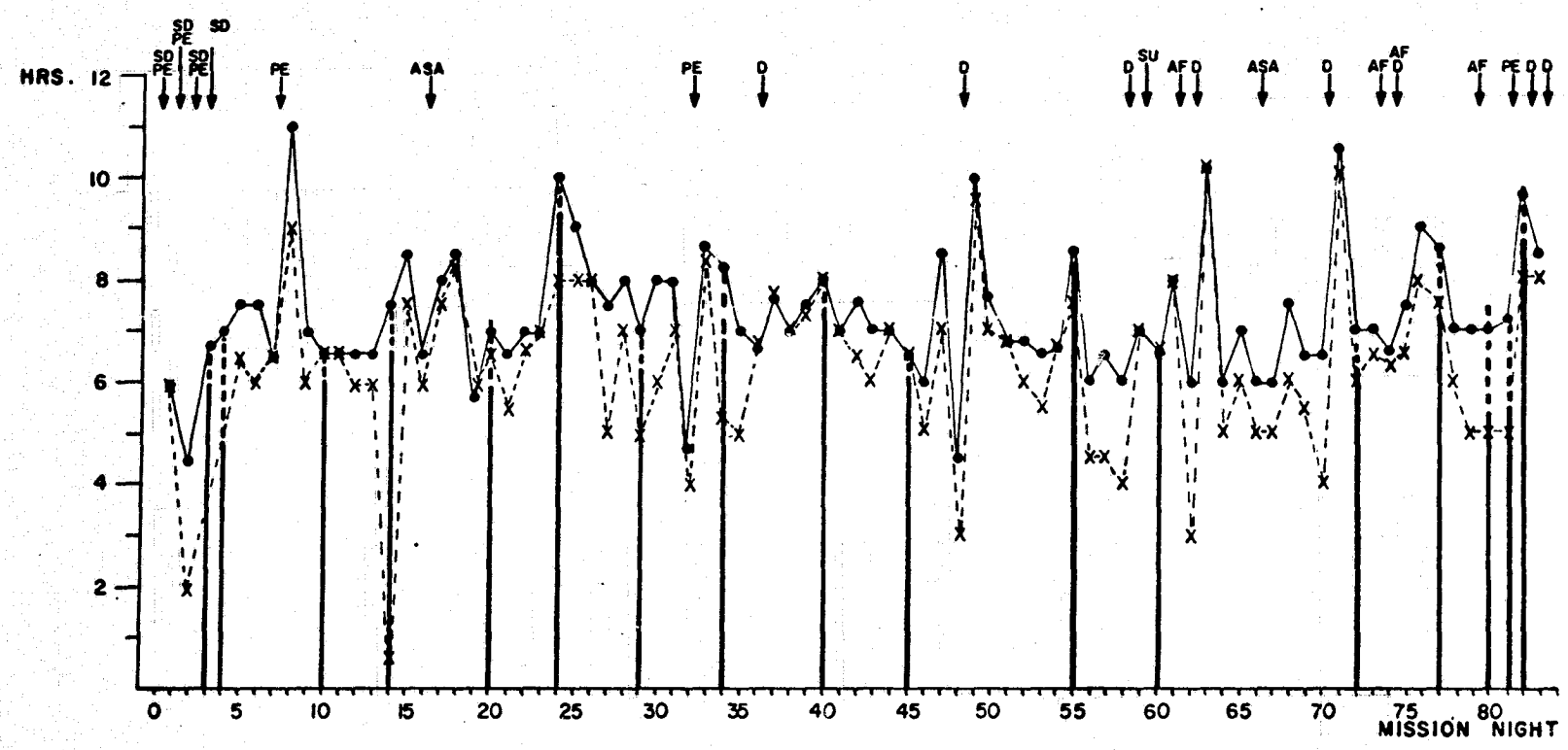

HRS.
12
10
8
6
4
2
SD PE PE PE
O
AF AF AF
T T T T CH T T T T T O T T T T T
CH SEC
AF
SEC AF AF
SU SU AF AF
ACT AF AF AF
ACT
ACT
ACT
ACT SEC SEC
SEC ACT
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
MISSION NIGHT
PLT 84 - DAY MISSION
= ESTIMATE OF TOTAL SLEEP TIME
= ESTIMATE OF TOTAL SLEEP TIME
ACT = ACTIFED
AF = AFRIN
CH = CHLORAL HYDRATE
O = ORNADE
PE = PROMETHAZINE/EPHEDRINE
SD = SCOPOLAMINE/DEXTROAMPHETAMINE
SEC = SECONAL
SU = SUDAFED
T = TINACTIN

FIG. 63



SPT 84 - DAY MISSION

= SUBJECTIVE ESTIMATE OF SLEEP

= AWAKE TIME

= SLEEP TIME

AF = AFRIN
ASA = ASPRIN
D = DALMANE
PE = PROMETHAZINE/EPHEDRINE
SD = SCOPOLAMINE/DEXTROAMPHETAMINE
SU = SUDAFED

FIG. 64

TABLES

TABLE I
DATA FROM ALL-NIGHT SLEEP PROFILES
28 DAY MISSION

	PREFLIGHT			AV.		INFLIGHT									AV.		POSTFLIGHT			AV.
MISSION DAY	-60	-59	-58			5	6	10	15	17	19	21	24	26			+3	+5	+7	
ANALYSIS TYPE	V	V	V			V	V	MA	MA	MA	MA	MA	MA	MA			V	V	V	
TOTAL REST TIME	7.3	7.3	8.7	7.8		6.6	6.3	7.7	7.4	5.6	7.7	6.5	8.0	6.0	6.86		9.3	9.0	8.5	8.9
TOTAL SLEEP TIME	6.5	6.5	7.7	6.9		6.1	5.4	5.3	7.0	5.2	6.6	6.2	7.2	5.4	6.04		9.0	8.5	8.0	8.5
TOTAL AWAKE TIME	0.74	0.81	0.96	0.84		0.31	0.85	2.43	0.45	0.47	0.81	0.25	0.67	0.26	0.72		0.26	0.45	0.44	0.38
SLEEP LATENCY	0.46	0.70	0.73	0.63		0.35	0.33	0.28	0.35	0.18	0.76	0.06	0.10	0.30	0.30		0.17	0.24	0.16	0.19
STAGE 1%	7.4	4.3	4.2	5.3		6.8	9.5	9.8	8.3	7.7	1.1	5.4	4.4	0.6	5.95		4.0	6.5	4.8	5.1
STAGE 2%	60.3	49.6	54.5	54.8		60.2	56.4	43.4	56.4	26.7	50.9	43.8	28.9	24.0	43.4		58.5	53.8	57.4	56.6
STAGE 3%	12.8	17.9	13.8	14.8		18.3	14.6	10.0	12.6	8.8	13.1	11.2	28.0	27.8	16.0		11.8	11.1	13.7	12.2
STAGE 4%	2.9	3.4	2.4	2.9		4.6	0.8	12.6	17.1	14.9	14.5	16.5	27.7	41.6	16.7		1.0	1.0	1.3	1.1
STAGE REM%	16.6	24.8	25.1	22.2		10.1	18.6	24.1	5.5	41.9	20.4	23.2	11.0	5.9	17.9		24.7	27.5	22.8	25.0
REM LATENCY	1.24	1.24	1.91	1.46		2.31	1.66								1.98		0.93	1.18	1.11	1.07
NO. OF AWAKENINGS	19	16	24	19.7		10	14								12		20	20	26	22

TABLE II
DATA FROM ALL-NIGHT SLEEP PROFILES
59 DAY MISSION

	PREFLIGHT			AV.		INFLIGHT																			AV.		POSTFLIGHT			AV.
MISSION DAY	-15	-14	-13			7	8	9	12	15	18	21	24	27	29	33	36	39	42	45	48	52	55	56	57			+1	+3	+5	
ANALYSIS TYPE	V	V	V	V		V	V	V	V	V	V	V	V	V	V	V	V	M_{CA}	M_{CA}	M_{CA}	M_{CA}	M_{CA}	M_{CA}	M_{CA}	M_{CA}			V	V	V	
TOTAL REST TIME	7.7	8.4	6.5	7.5		6.90	6.59	8.23	7.14	7.32	7.05	6.95	7.27	7.87	8.90	7.19	7.38	7.21	7.23	7.55	7.68	6.82	6.78	7.32	6.61	7.32			7.09	8.44	7.77
TOTAL SLEEP TIME	6.4	7.6	5.2	6.4		5.95	6.08	6.94	6.24	6.86	5.75	5.47	6.50	7.03	6.96	6.46	6.99		6.16	6.47	6.14	5.04		6.48	6.44	6.3			5.77	7.38	6.58
TOTAL AWAKE TIME	1.3	0.8	1.3	1.1		0.95	0.51	1.28	0.90	0.46	1.30	1.49	0.77	0.87	1.94	0.73	0.38		1.07	1.08	1.54	1.78		0.84	0.17	1.00			1.32	1.06	1.19
SLEEP LATENCY	0.3	0.09	0.2	0.2		0.21	0.24	0.32	0.32	0.13	0.15	0.06	0.15	0.26	0.36	0.19	0.12		0.14	0.37	0.12	0.36	0.10	0.16	0.17	0.2		0.08	0.15	0.24	0.16
STAGE 1%	8.3	7.6	10.6	8.8		7.5	5.9	11.2	10.6	8.7	11.9	11.6	9.5	11.3	13.5	4.3	5.0		7.5	9.4	10.5	7.3		6.4	8.8	8.9			10.4	9.9	10.2
STAGE 2%	57.3	58.3	53.3	56.3		59.5	57.4	63.2	60.4	60.7	57.8	49.2	62.4	63.6	56.6	60.8	59.1		61.0	60.5	59.6	60.9		61.0	60.1	59.7			57.1	58.4	57.8
STAGE 3%	18.0	16.4	17.7	17.4		19.1	13.5	13.8	17.2	18.6	15.8	24.6	13.9	15.1	20.0	19.1	19.4		15.4	17.9	16.2	16.6		17.4	21.1	17.5			12.0	8.2	10.1
STAGE 4%	3.1	4.9	0.3	2.8		1.8	1.9	0.8	1.6	1.5	1.0	3.1	1.3	0.8	1.3	1.1	1.4		1.3	1.3	1.3	1.3		1.3	1.3	1.4			0.4	0.4	0.4
STAGE REM%	13.2	12.7	18.2	14.7		12.1	21.3	11.0	10.2	10.7	13.4	11.5	13.0	9.2	8.6	14.7	15.1		11.8	13.2		10.8		8.5	10.1	12.1			20.1	23.0	21.6
REM LATENCY	1.6	2.2	1.8	1.87		1.5	1.8	2.3	2.6	2.2	2.1	1.6	2.2	2.3	2.9	1.6	1.6		2.0							2.05		0.8	1.1	0.7	0.87
NO. OF AWAKENINGS	37	51	34	40.7		39	32	70	52	62	43	21	51	44	25	8	25									39.3			26	31	28.5

TABLE III
DATA FROM ALL-NIGHT SLEEP PROFILES
84 DAY MISSION

	PREFLIGHT			AV.	INFLIGHT																	AV.	POSTFLIGHT			AV.
MISSION DAY	-13	-12	-11		3	4	10	14	19	24	29	34	40	45	50	55	60	72	77	80	81	82		+0	+1	+5	
ANALYSIS TYPE	V	V	V		V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V		V	V	V	
TOTAL REST TIME	7.43	8.11	8.64	8.06	6.51	6.82	6.40	7.30	7.28	9.78	6.92	8.33	7.67	6.49		8.65	6.73	6.69	8.60	7.32	7.21	9.82	7.56	8.67	6.25	8.09	7.67
TOTAL SLEEP TIME	6.59	7.43	7.85	7.29	5.90	4.88	6.00	6.65	5.93	9.37	6.26	6.83	7.49	6.16		8.39	6.43	6.29	7.38	5.43	5.58	8.80	6.69	7.69	4.50	7.40	6.53
TOTAL AWAKE TIME	0.84	0.68	0.78	0.77	0.61	1.94	0.39	0.65	1.35	0.40	0.66	1.50	0.18	0.33		0.26	0.31	0.39	1.22	1.90	1.64	1.01	0.87	0.98	0.78	0.69	0.82
SLEEP LATENCY	0.16	0.55	0.10	0.27	0.26	0.82	0.33	0.53	0.26	0.18	0.59	0.20	0.04	0.24	0.08	0.14	0.19	0.09	0.27	0.11	0.22	0.12	0.26	0.04	0.13	0.23	0.13
STAGE 1%	10.6	7.8	8.2	8.9	4.9	13.3	5.7	8.6	6.4	6.8	10.4	8.8	4.0	4.9		5.3	4.6	5.0	5.4	6.9	7.8	6.2	6.76	14.2	7.0	7.0	9.4
STAGE 2%	59.5	54.1	62.0	58.5	57.3	50.2	58.4	61.4	50.8	56.1	54.3	50.9	65.5	65.0		53.8	61.6	66.8	61.8	60.7	58.0	62.5	58.5	71.5	71.1	55.8	66.1
STAGE 3%	3.7	11.7	5.9	7.1	13.0	10.6	6.4	10.3	12.2	5.4	12.2	13.5	4.6	7.6		9.2	9.5	3.6	3.3	11.0	7.3	10.0	8.8	2.2	3.3	2.5	2.7
STAGE 4%	0.0	0.4	0.1	0.2	1.2	0.5	0.2	0.6	1.3	0.1	1.6	1.5	0.1	0.4		0.2	0.5	0.04	0.0	0.5	0.1	0.3	0.5	0.0	0.1	0.04	0.05
STAGE REM%	26.2	26.0	23.8	25.3	23.6	25.4	29.3	19.2	29.4	31.6	21.4	25.2	25.7	22.1		31.6	23.8	24.5	29.5	20.9	26.8	20.9	25.3	12.1	18.6	34.6	21.8
REM LATENCY	0.96	2.45	1.01	1.47	1.24	0.12	0.79	0.95	1.15	1.03	1.19	2.22	1.11	1.08	1.49	0.84	2.55	1.23	1.13	1.17	1.01	3.34	1.31	2.68	0.79	0.90	1.46
NO. OF AWAKENINGS	20	21	21	20.7	10	8	15	15	13	20	12	16	14	6		22	6	6	8	12	11	10	12	21	11	24	18.7

TABLE IV

REM-Period Characteristics: 28-Day Mission

Day	Average REM-Period Length (min)	Average REM-Cycle Length (min)
-60	17.6	92.0
-59	21.0	75.1
-58	31.5	111.0
Preflight Average	23.4	92.7
5	22.3	134.2
6	15.4	70.7
Inflight Average	18.8	102.5
R+3	21.5	73.7
R+5	24.0	79.3
R+7	20.3	75.3
Postflight Average	21.9	76.1

TABLE V

REM-Period Characteristics: 59-Day Mission

Day	Average REM-Period Length (min)	Average REM-Cycle Length (min)
-15	25.6	158.3
-14	15.8	115.1
-13	20.6	111.4
Preflight Average	20.7	128.3
7	10.9	89.8
8	20.3	87.4
9	12.1	106.8
12	11.2	115.7
15	22.3	85.9
18	16.3	102.2
21	10.2	69.3
24	12.8	95.2
27	21.3	185.3
29	23.8	126.4
33	14.3	79.7
36	16.6	86.2
Inflight Average	16.0	102.5
R+1	10.0	44.3
R+3	18.0	98.0
R+5	20.7	77.0
Postflight Average	16.2	73.1

TABLE VI

REM-Period Characteristics: 84-Day Mission

Day	Average REM-Period Length (min)	Average REM-Cycle Length (min)
-13	22.0	79.1
-12	41.0	121.9
-11	29.0	123.0
Preflight Average	31.0	108.0
3	14.8	61.0
4	12.2	58.6
10	22.7	79.3
14	13.8	64.4
19	25.4	95.5
24	26.2	79.7
29	13.9	62.7
34	19.7	72.3
40	24.3	72.0
45	28.8	97.5
55	35.0	93.8
60	32.2	118.5
72	25.8	88.4
77	33.0	106.6
80	13.8	61.1
81	22.8	85.0
82	19.2	94.0
Inflight Average	22.6	81.8
R+0	15.3	124.7
R+1	12.6	64.9
R+5	33.9	80.4
Postflight Average	20.6	90.0

TABLE VII

Subjective Sleep Estimates by All Three Crewmen: 59-Day Mission

Mission Day	Sleep (in hours) SPT	CDR	PLT	Medications SPT	CDR	PLT
1					2 aspirin 1 seconal	1 scop/dex 1 seconal
2	7 good/fair	5 fair	7 fair	2 scop/dex	2 scop/dex	2 scop/dex
3	6 good	5 good 2 fair	7 good	1 mylanta 2 scop/dex		3 scop/dex
4	7 very good	7 good	7 good		1 seconal	
5	5.5 good	6 good	6 good			
6	7 good	7 good	7 good			
7	5.5 fair	6 fair	6 good			
8	6 good	6 good	6 good			
9	6 fair to good	6.5 good	7 good			
10	6.5 good	4.5 good to fair	6 good			
11	6.5 good	6 good	6 good (?)			
12	6 fair	7 good	6.5 good			
13	6.5 good	6.5 good	6.5 good (?)			
14	6.5 good	7 good	6.5 good			
15	7 good	7 good	7 good	afrin		
16	7 good	6 good	6 good	afrin		
17	6.5 good	7 good	7 good			
18	6 fair	6.5 good	6.5 good			
19	6.5 good	6.5 good	6.5 good			

TABLE VII (continued)

Subjective Sleep Estimates by All Three Crewmen: 59-Day Mission

Mission Day	Sleep (in hours) SPT	CDR	PLT	Medications SPT	CDR	PLT
20	6.5 good	6.5 good	6.5 good			
21	6.5 good	7 good $\frac{1}{2}$ fair	7 good			
22	6.5 good	6 good	6 good			
23	7 good	7 good	6.5 good			
24	6.5 fair	6.5 good	6.5 good			
25	6 good	6 good	6 good	no medication report given		
26	7.5 good	6.5 good	6.5 good			
27	6.5 fair	6.5 good	6.5 good	no medication report given		
28	7 good	6.5 good	6.5 good			neosporin for sty in eye
29	7.5 fair	9 good	6.5 good			
30	6.5 good	6.5 good	6.5 good			neosporin
31	6 good	7 good	6.5 good			
32	7 good	6 good	6.5 good			
33	6.5 good	6.5 good	6.5 good			
34	6 good	7 good	6 good			
35	7 good	7 good	6.5 good	no medication report given		
36	7 good	8 good	7 good	no medication report given		
37	7 good	7 good	6.5 good			
38	6 good	7 good	6.5 good			

TABLE VII (continued)

Subjective Sleep Estimates by All Three Crewmen: 59-Day Mission

Mission Day	Sleep (in hours) SPT	CDR	PLT	Medications SPT	CDR	PLT
39	6.5 good	7 good	6.5 good			
40	7 good	7 good	6.5 good			
41	6.5 good	7 good	6.5 good			
42	6.5 good	7 good	6.5 good			
43	7 good	6.5 good	6.5 good			
44	5 good	6 good	6 good			
45	7 good	7 good	6.5 good			
46	6 good	6.5 good	6 good			
47	6 fair	6 fair	6 good			
48	7 good	7 good	6.5 good			
49	7 good	8 good	6.5 good			
50	7 good	8 good	6.5 good	no medication report given		
51	6.5 good	6.5 good	6 good			
52	6 fair	6 good	5.5 good		1 seconal	
53	7 good	7 good	7 good	1 seconal		
54	6 fair	5 good	6.5 good	1 seconal	1 seconal	1 chloral hydrate
55	5.5 fair	6 good	6 good	1 seconal	1 seconal	1 chloral hydrate
56	6.5 good	6 good	6 good	1 seconal	1 seconal	1 chloral hydrate
57	6 good	5.5 fair	5-5.5 good			

TABLE VII (continued)

Subjective Sleep Estimates by All Three Crewmen: 59-Day Mission

Mission Day	Sleep (in hours) SPT	CDR	PLT	Medications SPT	CDR	PLT
58	6 good	6 good	6 good			
59					1 seconal	
60				1 scop/dex	1 seconal 1 scop/dex	1 chloral hydrate 1 scop/dex

TABLE VIII

Subjective Sleep Estimates by CDR: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
1	3.0	2.0	5.0	1 scop/dex 1 pro/eph
2	1.0	5.0	6.0	1 scop/dex 1 pro/eph
3	0.0	6.5	6.5	2 scop/dex 1 pro/eph
4	0.0	6.5	6.5	1 scop/dex
5	0.5	7.0	7.5	
6	1.0	6.0	7.0	
7	0.5	6.0	6.5	
8	1.0	8.0	9.0	
9	1.0	5.5	6.5	
10	0.0	7.0	7.0	
11	0.5	6.0	6.5	
12	0.5	6.0	6.5	
13	0.5	6.0	6.5	
14	1.0	6.0	7.0	
15	2.0	5.0	7.0	
16	0.0	6.0	6.0	
17	2.0	5.0	7.0	
18	0.5	7.0	7.5	
19	1.0	6.0	7.0	

TABLE VIII (continued)

Subjective Sleep Estimates by CDR: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
20	1.0	6.0	7.0	
21	1.5	5.0	6.5	
22	1.5	5.5	7.0	
23	1.0	6.0	7.0	
24	2.0	7.0	9.0	
25	1.5	6.0	7.5	
26	2.0	6.0	8.0	
27	2.0	5.0	7.0	
28	0.5	7.0	7.5	
29	1.0	6.0	7.0	
30	0.0	5.0	5.0	
31	0.0	8.5	8.5	
32	0.0	4.0	4.0	
33	0.5	7.5	8.0	
34	0.5	6.5	7.0	
35	1.0	6.0	7.0	
36	0.0	6.5	6.5	
37	0.5	5.0	5.5	
38	0.0	5.0	5.0	

TABLE VIII (continued)

Subjective Sleep Estimates by CDR: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
39	0.5	6.5	7.0	1 chloral hydrate
40	0.0	8.5	8.5	1 sudafed
41	1.0	6.0	7.0	
42	0.5	6.5	7.0	
43	0.5	6.5	7.0	
44	0.5	6.5	7.0	
45	1.0	6.0	7.0	
46	0.0	6.5	6.5	
47	0.5	8.0	8.5	
48	0.0	4.0	4.0	1 sudafed
49	0.5	8.0	8.5	
50	2.0	5.0	7.0	
51	0.5	6.5	7.0	
52	0.0	7.0	7.0	
53	0.0	6.0	6.0	
54	0.5	6.5	7.0	1 sudafed
55	1.0	7.0	8.0	
56	1.0	5.0	6.0	
57	0.0	7.0	7.0	

TABLE VIII (continued)

Subjective Sleep Estimates by CDR: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
58	1.5	5.5	7.0	
59	0.5	6.5	7.0	
60	0.5	6.5	7.0	
61	1.0	6.0	7.0	
62	1.0	5.5	6.5	
63	0.0	7.0	7.0	
64	0.0	6.0	6.0	1 sudafed
65	2.0	5.0	7.0	
66	1.0	6.0	7.0	
67	2.0	4.0	6.0	
68	1.0	6.5	7.5	
69	0.5	6.5	7.0	
70	0.0	7.0	7.0	
71	0.0	6.5	6.5	
72	1.0	6.0	7.0	
73	1.5	4.5	6.0	
74	0.0	6.5	6.5	
75	0.5	6.0	6.5	
76	0.0	7.5	7.5	1 sudafed

TABLE VIII (continued)

Subjective Sleep Estimates by CDR: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown
77	2.0	3.5	5.5	
78	1.5	5.0	6.5	3 sudafed
79	0.5	6.0	6.5	2 sudafed
80	1.0	5.0	6.0	1 sudafed
81	0.5	6.5	7.0	
82	1.0	5.0	6.0	
83	0.0	6.5	6.5	1 chloral hydrate
84			5.0	

TABLE IX

Subjective Sleep Estimates by PLT: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
1	2.0	0.0	2.0	1 scop/dex
2	2.0	5.0	7.0	1 pro/eph
3	0.0	6.5	6.5	2 pro/eph
4	0.0	6.5	6.5	1 pro/eph
5	2.5	4.0	6.5	
6	7.0	0.0	7.0	
7	0.0	6.5	6.5	1 ornade
8	1.0	8.5	9.5	
9	0.0	7.0	7.0	
10	0.0	6.5	6.5	
11	1.0	5.0	6.0	
12	0.0	6.0	6.0	
13	0.0	6.0	6.0	
14	0.0	7.0	7.0	
15	1.0	6.5	7.5	
16	2.0	5.0	7.0	
17	1.5	6.0	7.5	
18	1.8	6.0	7.8	
19	0.5	6.0	6.5	

TABLE IX (continued)

Subjective Sleep Estimates by PLT: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
20	0.0	6.5	6.5	
21	0.5	6.0	6.5	
22	0.5	6.5	7.0	
23	0.5	6.0	6.5	
24	0.5	10.0	10.5	
25	0.5	7.0	7.5	
26	1.0	7.0	8.0	
27	0.0	6.5	6.5	
28	0.0	8.0	8.0	
29	0.5	6.0	6.5	afrin drops
30	0.5	7.0	7.5	afrin drops
31	0.5	8.5	9.0	afrin drops
32	0.0	4.0	4.0	
33	1.0	7.0	8.0	tinactin
34	0.5	6.5	7.0	tinactin
35	1.0	5.0	6.0	tinactin
36	0.5	9.0	9.5	1 chloral hydrate tinactin
37	0.5	6.0	6.5	tinactin
38	1.0	6.5	7.5	tinactin

TABLE IX (continued)

Subjective Sleep Estimates by PLT: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
39	0.5	7.0	7.5	tinactin
40	0.0	7.5	7.5	1 ornade tinactin
41	0.0	7.5	7.5	tinactin
42	0.0	7.5	7.5	tinactin
43	1.0	6.0	7.0	tinactin
44	0.0	8.0	8.0	tinactin
45	0.0	7.5	7.5	
46	0.0	6.0	6.0	
47	0.0	8.5	8.5	
48	0.0	5.0	5.0	
49	3.0	2.0	5.0	1 chloral hydrate
50	0.0	8.0	8.0	1 seconal
51	0.0	7.5	7.5	
52	0.0	7.0	7.0	
53	0.5	6.0	6.5	
54	1.0	6.0	7.0	1 afrin
55	1.0	8.0	9.0	
56	0.5	6.5	7.0	
57	1.0	6.0	7.0	

TABLE IX (continued)

Subjective Sleep Estimates by PLT: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
58	0.0	6.0	6.0	
59	2.0	3.0	5.0	1 seconal
60	0.0	8.0	8.0	2 afrin
61	0.0	7.0	7.0	afrin
62	0.0	6.5	6.5	afrin
63	0.5	8.5	9.0	
64	2.0	3.0	5.0	sudafed
65	0.0	7.0	7.0	sudafed 2 afrin
66	0.0	6.5	6.5	afrin
67	0.0	7.0	7.0	2 afrin
68	2.0	4.0	6.0	2 afrin
69	0.0	6.5	6.5	actifed afrin
70	1.0	6.0	7.0	
71	2.5	6.0	8.5	3 actifed
72	0.0	6.0	6.0	3 actifed
73	0.0	6.0	6.0	3 actifed
74	1.0	6.0	7.0	3 actifed
75	1.0	6.5	7.5	2 actifed
76	2.0	6.5	8.5	2 actifed

TABLE IX (continued)

Subjective Sleep Estimates by PLT: 84-Day Mission

Mission Day	Sleep Time (in hours) Light or Med. Sleep	Heavy Sleep	Total	Medications (taken day before sleep period shown)
77	1.0	6.0	7.0	actifed
78	0.0	6.0	6.0	actifed
79	2.0	4.0	6.0	actifed
80	0.0	5.5	5.5	
81	0.0	7.0	7.0	actifed
82	0.0	7.5	7.5	1 seconal
83	0.0	6.0	6.0	1 seconal
84			≈3.0	1 seconal actifed

TABLE X

Subjective Sleep Estimates by SPT: 84-Day Mission

Mission Day * = M133	Sleep Time (Hrs)			Remarks	Sleep Quality				Medications (taken day before sleep period shown)
	Light or Medium Sleep	Heavy Sleep	Total		Long time to fall asleep	Frequent awakening	Unscheduled awakening, could not return to sleep	Very sleepy after scheduled awakening	
1	0.0	6.0	6.0						1 scop/dex 1 pro/eph
2	2.5	2.0	4.5						2 scop/dex 1 pro/eph
* 3			6.7	good				X	2 scop/dex 1 pro/eph
* 4			7.0	fair			X	X	1 scop/dex
5	1.0	6.5	7.5						
6	1.5	6.0	7.5						
* 7	0.0	6.5	6.5						
8	2.0	9.0	11.0						1 pro/eph
9	1.0	6.0	7.0						
*10	0.0	6.5	6.5	good				X	
11	0.0	6.5	6.5						
12	0.5	6.0	6.5						
13	0.5	6.0	6.5						
*14	6.9	0.5	7.4	good				X	
15	1.0	7.5	8.5						
16	0.5	6.0	6.5						

TABLE X (continued)

Subjective Sleep Estimates by SPT: 84-Day Mission

Mission Day * = M133	Sleep Time (Hrs)			Remarks	Sleep Quality				Medications (taken day before sleep period shown)
	Light or Medium Sleep	Heavy Sleep	Total		Long time to fall asleep	Frequent awakening	Unscheduled awakening, could not return to sleep	Very sleepy after scheduled awakening	
17	0.5	7.5	8.0						2 aspirin
18	0.3	8.2	8.5						
*19	1.7	6.0	7.7	good			X	X	
20	0.5	6.5	7.0						
21	1.0	5.5	6.5						
22	0.3	6.7	7.0						
23	0.0	7.0	7.0						
*24	2.0	8.0	10.0	good					
25	1.0	8.0	9.0						
26	0.0	8.0	8.0						
27	2.5	5.0	7.5						
28	1.0	7.0	8.0						
*29	2.0	5.0	7.0	fair	X		X	X	
30	2.0	6.0	8.0						
31	1.0	7.0	8.0						
32	0.8	4.0	4.8						

TABLE X (continued)

Subjective Sleep Estimates by SPT: 84-Day Mission

Mission Day * = M133	Sleep Time (Hrs)			Remarks	Sleep Quality				Medications (taken day before sleep period shown)
	Light or Medium Sleep	Heavy Sleep	Total		Long time to fall asleep	Frequent awakening	Unscheduled awakening, could not return to sleep	Very sleepy after scheduled awakening	
33	0.4	8.3	8.7						1 pro/eph
*34	3.0	5.2	8.2	poor	X	X		X	
35	2.0	5.0	7.0						
36	0.0	6.8	6.8						
37	0.0	7.8	7.8						1 dalmane
38	0.0	7.0	7.0						
39	0.2	7.3	7.5						
*40	0.0	8.0	8.0	good				X	
41	0.0	7.0	7.0						
42	1.0	6.5	7.5						
43	1.0	6.0	7.0						
44	0.0	7.0	7.0						
*45	0.0	6.5	6.5	good				X	
46	1.0	5.0	6.0						
47	1.5	7.0	8.5						
48	1.5	3.0	4.5						

TABLE X (continued)

Subjective Sleep Estimates by SPT: 84-Day Mission

Mission Day * = M133	Sleep Time (Hrs)			Remarks	Sleep Quality				Medications (taken day before sleep period shown)
	Light or Medium Sleep	Heavy Sleep	Total		Long time to fall asleep	Frequent awakening	Unscheduled awakening, could not return to sleep	Very sleepy after scheduled awakening	
49	0.5	9.5	10.0						1 dalmane
*50	0.7	7.0	7.7	good				X	
51	0.0	6.8	6.8						
52	0.8	6.0	6.8						
53	1.0	5.5	6.5						
54	0.0	6.7	6.7						
*55	1.0	7.5	8.5	good				X	
56	1.5	4.5	6.0						
57	2.0	4.5	6.5						
58	2.0	4.0	6.0						
59	0.0	7.0	7.0						1 dalmane
*60	0.0	6.7	6.7	good				X	1 sudafed
61	0.0	8.0	8.0						
62	3.0	3.0	6.0						1 afrin
63	0.0	10.3	10.3						1 dalmane
64	1.0	5.0	6.0						

TABLE X (continued)

Subjective Sleep Estimates by SPT: 84-Day Mission

Mission Day * = M133	Sleep Time (Hrs)			Remarks	Sleep Quality				Medications (taken day before sleep period shown)
	Light or Medium Sleep	Heavy Sleep	Total		Long time to fall asleep	Frequent awakening	Unscheduled awakening, could not return to sleep	Very sleepy after scheduled awakening	
65	1.0	6.0	7.0						
66	1.0	5.0	6.0						
67	1.0	5.0	6.0						2 aspirin
68	1.5	6.0	7.5						
69	1.0	5.5	6.5						
70	2.5	4.0	6.5						
71	0.5	10.0	10.5						1 dalmane
*72	1.0	6.0	7.0	good				X	
73	0.5	6.5	7.0						
74	0.4	6.3	6.7						1 afrin
75	1.0	6.5	7.5						1 afrin 1 dalmane
76	1.0	8.0	9.0						
*77	1.2	7.5	8.7	good			X		
78	1.0	6.0	7.0						
79	2.0	5.0	7.0						
*80	2.0	5.0	7.0	fair			X		1 afrin

TABLE X (continued)

Subjective Sleep Estimates by SPT: 84-Day Mission

Mission Day * = M133	Sleep Time (Hrs)			Remarks	Sleep Quality				Medications (taken day before sleep period shown)
	Light or Medium Sleep	Heavy Sleep	Total		Long time to fall asleep	Frequent awakening	Unscheduled awakening, could not return to sleep	Very sleepy after scheduled awakening	
*81	2.2	5.0	7.2						
*82	1.7	8.0	9.7						1 pro/eph
83	0.5	8.0	8.5						1 dalmane
84	?	?	?						1 dalmane

APPENDIX

Characteristics of the Alpha Rhythm during Prolonged Orbital Spaceflight — Preliminary Observations

INTRODUCTION

Crewmen of the three Skylab flights experienced, to various degrees, a complex of symptoms (a syndrome) associated primarily with the first few days spent in weightlessness; to a lesser extent it persisted in some degree throughout the missions. Originally tagged "motion sickness" by medical observers, it became apparent that this designation neither adequately nor completely described the phenomenon.

The most basic symptom experienced by all Skylab astronauts was the subjective sensation of head "fullness," beginning shortly after orbital insertion and persisting throughout the mission. In some cases, this was accompanied by headache of varying intensity during the first few days in orbit. The head and nasal passages seemed congested, venous distention was noted in the head and neck, and a general puffiness of the face was noted. Some crewmen experienced more severe symptoms, ranging from stomach awareness through nausea to vomiting, again confined primarily to the initial days of the flight. Medication, including mixtures of scopolamine and dextroamphetamine and a mixture of promethazine and ephedrine, was utilized to counteract these latter symptoms. Other symptoms and signs noted by more than one astronaut include paresthesias in the arms and feet, decreased muscle tone, increased tendon reflexes, and light-flash phenomena.

The postflight period was marked by an increase of symptomatology, with vertigo or dizziness commonly precipitated by motion or standing. Nausea sometimes was experienced, and vomiting occurred in at least one subject.

Two major etiological factors have been considered thus far: (1) altered input to the vestibular system, and (2) fluid shifts among the various body compartments.

There is no doubt that changes did occur in the vestibular system, as revealed by the results of the M131 Experiment. Similarly, fluid shifts definitely did occur, as indicated by the findings of the MO92 Series. Unresolved is whether or not these findings relate causally to the major symptoms and, if so, the precise mechanism involved.

Because of the nature of a number of the symptoms (e.g., headache, nausea, paresthesias) and observations (e.g., vomiting, altered tendon reflexes), a neurological basis for this syndrome, or portions of it, should be seriously considered. In particular, in view of the fluid-shift evidence, alterations of intracranial pressure, changes in cerebral hemodynamics, and metabolic factors influencing brain physiology deserve investigation.

Although the medical experiments performed during Skylab did not include the capability for comprehensively evaluating neurological functions, the electroencephalogram (EEG) was recorded periodically throughout the flights in the performance of the M133 Sleep Monitoring Experiment. Even though the data acquisition and analysis scheme developed for sleep monitoring was not designed to provide EEG signals in the proper configuration for clinical diagnosis, it seemed worthwhile to re-evaluate the M133 data in the hope that it might at least provide some additional clues or perhaps suggest future paths of investigation. Consequently, a preliminary review of the Skylab 2, 3, and 4 M133 data was carried out as a pilot study, and the results thus far are outlined below.

METHODS

Clinical electroencephalography is based upon interpretation of the graphically displayed electrical signals obtained from electrodes affixed to the scalp in precisely defined locations. Generally, a minimum of 12 recording electrodes arranged in an eight-channel montage are utilized for diagnostic purposes. Although EEG signals are known to occupy the frequency range from dc to several hundred Hz (cycles per second), clinically significant activity is currently confined to the approximate 0.5- to 40-Hz range. Activity is conventionally separated into four bands: delta activity, 0.5-3 Hz; theta activity, 3-7 Hz; alpha activity, 8-14 Hz; and beta activity, 14-40 Hz. In a normal individual, specific patterns consisting of mixtures of these frequency ranges are recorded from the various locations on the scalp. Interpretation of an electroencephalogram consists of evaluating and quantifying the background activity and recognizing certain sporadic or intermittent wave forms. Frequency and amplitude patterns vary with age, level of consciousness, and pathological conditions, and specific wave forms are associated with some neurological conditions.

The M133 data, while ideally suited for reliable and long-term determination of sleep status, was not adequate for a comprehensive clinical analysis: the single channel of EEG activity was derived from four electrodes (two placed centrally and paired, and two placed occipitally and paired). In addition to the limited spatial coverage of the head, the paired-electrode configuration prevented the detection of amplitude and frequency asymmetries between cerebral hemispheres.

The M133 protocol, designed to study the subject's sleep pattern, left the state of consciousness and degree of alertness uncontrolled. Thus, in the presleep period when the clinical observations were attempted, the subject might be moving, blinking his eyes, reading, relaxing, or drowsing. These factors also degraded the quality of the clinical interpretation. In addition, in some instances sleep onset occurred so rapidly after institution of the M133

Experiment that adequate waking samples were not available for evaluation.

Because of the above severe limitations, it was decided to confine the initial analysis to one specific aspect — the frequency characteristics of the alpha rhythm. The alpha rhythm is the most characteristic feature of the waking electroencephalogram in the typical individual and tends to be stable over time with respect to frequency. In addition, it is maximally expressed in the occipital area and consequently is recorded well by the single M133 channel.

The alpha rhythm ranges from 8 to 12 Hz in normal adults and achieves a maximal peak-to-peak amplitude of approximately 150 μV. Amplitude tends to wax and wane over time in the typical individual and under steady-state conditions. This activity is usually best seen when the subject is relaxed with eyes closed, and it typically is suppressed by eye-opening or by mental activity with eyes closed.

In a given normal individual, the alpha frequency usually does not change more than ± 0.5 Hz from one observation to the next, even over long periods. Various pathological conditions may disrupt the rhythm, and many drugs given in toxic doses are known to lower its frequency.

Measurements of alpha frequency were made on each of the M133 recording nights, as well as on the pre- and postflight baseline nights and on the data obtained during the preflight laboratory baseline examination. Frequency (expressed in Hz) was determined by manually counting the number of waves occurring over a period of time (typically ranging from 1 to 10 seconds) and dividing the total by the observation time. All measurements were made in the presleep period immediately after the subject activated the M133 hardware and before signs of drowsiness or sleep occurred. Several samples (typically eight) were measured in each presleep period, and the individual results were averaged to produce a single estimate of alpha frequency for that day; the variation among the individual samples constituted the range of that single estimate. In addition, all values were when necessary corrected for the M133 tape-recorder speed variation by utilizing the 10-Hz timing signal recorded on an auxiliary channel of the system.

Although a study of the alpha-amplitude characteristics would also have been worthwhile, the amplitude stability of the M133 recording system was not considered to be sufficiently reliable over the course of the missions to warrent a quantitative study.

RESULTS

The scientist pilot (SPT) of the 84-day Skylab flight showed a clear-cut and persistent elevation of his alpha frequency during the inflight and early postflight portions of the mission as compared to his preflight studies (Fig. A1). The overall average of the four preflight studies was 9.6 Hz, with a range of 9.1 to 9.8 for the individual daily averages. Inflight, the overall average rose to 10.4 Hz, with a range of 9.7 to 10.9 Hz. The postflight period was marked by a decline toward baseline from 10.3 Hz on day R+0 to 9.7 Hz on day R+5. Only the single value for inflight day 10 (9.7 Hz) fell within the range of averages seen preflight. When considering the range of individual samples making up each daily average (Fig. A2), the inflight period was still clearly marked by values well outside the maximal preflight range. In fact, no inflight individual sample fell as low as the average for preflight day -11.

The effect showed two peaks, one in the initial period of the flight and another near the midportion, although this aspect was difficult to evaluate due to the occasionally long sample intervals. The alteration of alpha frequency was evident visually when comparing samples of the recorded record obtained from the last session preflight (Fig. A3, day -11) and the first inflight recording (Fig. A4, mission day 3). Although maximal peak-to-peak amplitudes appeared comparable in these two tracings, the alpha activity occurred more continuously in the inflight case.

The data obtained from the SPT of the 59-day mission, while not as clear-cut, did show several similarities to the 84-day mission. As illustrated graphically in Fig. A5, most inflight daily averages for the alpha frequency were above the overall preflight average of 9.3 Hz, and the overall inflight average of 9.5 Hz was itself elevated. Postflight, as in the case of the 84-day mission, the early results were elevated, while the final value attained the preflight range. Since recording was not initiated until mission day 7, an early peak such as that noted in the 84-day flight may have been missed.

The range of individual sample values comprising the daily averages is illustrated in Fig. A6, and again, though not as marked as in the 84-day mission, the inflight values were often considerably above the maximal value noted in the preflight period.

The 28-day-mission results (Fig. A7) are of limited value, since only two inflight recording samples were obtained. These values (average, 10.2 Hz) were both above the preflight average of 9.9 Hz, but as indicated in Fig. A8, they were within the range of individual values seen preflight. This flight also differed from the other two with respect to the postflight findings. All three measurements, obtained on days R+3, R+5, and R+7, and averaging 9.5 Hz, were below the preflight value of 9.9 Hz.

DISCUSSION

In all three Skylab missions, there was at least a tendency toward an increased alpha frequency during the inflight portion as compared to preflight studies. In two of the three flights, the early postflight period likewise was characterized by a period of increased alpha frequency, with a return toward baseline seen by day R+5.

The alpha rhythm, recorded from the posterior scalp areas in normal adults, is believed to arise as a result of synaptically induced electrical activity in the neurons of the occipital portion of the cerebral cortex. Its hypothesized role in the cerebral integration and processing of visually obtained information is borne out by its anatomical location in the occipital region and its reactivity to various visual inputs (e.g., suppression by eye-opening and by visual imagery). Maintenance of the frequency stability of the rhythm is thought to be dependent upon an interplay between the cortical neurons originating the electrical activity and more-deeply lying neurons within the thalamic-projection nuclei that seem to pace the cortical cells. Within the thalamic nuclei, relatively random input from more-peripheral neurons is transmitted to the cortex in rhythmical bursts gated by an interplay of excitatory and inhibitory groups of interneurons. Ultimately, then, the frequency of the rhythm is dependent upon biochemical or metabolic factors at the level of the excitatory and inhibitory synaptic junctions within the thalamic neuronal network.

As noted above, the alpha rhythm is usually quite stable over time, and variations of more than ± 0.5 Hz are unusual. Most pathological conditions either lower the frequency or leave it unchanged. Thus, for example, certain drugs (e.g., Dilantin) in low doses have little influence upon the alpha rhythm; however, with increasing or toxic doses, the alpha rhythm may slow in frequency by as much as 1-2 Hz.

Conditions causing an absolute increase in the alpha frequency are quite rare. It has been reported, for example, as a manifestation of nitrogen narcosis (euphoria, impairment of mental processes, motor incoordination) in divers exposed to elevated pressures of inspired air (Roger et al., 1954, 1955; Cabarrou, 1966). In these studies, it was demonstrated that the partial pressure of nitrogen was the critical element, and elevation of the oxygen partial pressure independently did not produce the phenomenon.

Transient increases of alpha frequency have been reported to occur in association with various alterations of mental state. Becker-Carus (1971) reported an augmentation in alpha frequency while subjects performed tasks of relative difficulty, whereas Martinson (1939) had earlier reported similar observations during mental work, both easy and difficult. Other investigators (Knott, 1938; Travis and Egan, 1938; Hadley, 1940, 1941) found comparable frequency shifts during various other mental tasks as compared to the relaxed

or resting state. Kamiya (1969) has reported that biofeedback techniques may be successfully utilized to produce changes in alpha frequency.

While the possible role of such mental or psychological factors in the Skylab situation is difficult to assess due to the uncontrolled nature of the recording sessions, it is unlikely that these influences could produce the sustained and persistent alterations seen in the 84-day-mission results.

The Skylab findings must consequently be viewed conservatively. In the absence of the demonstration of other pathological alterations, the presence of an increased alpha frequency inflight and early postflight is a nonspecific finding. The lack of adequate controls over the experimental situation, the limited scalp coverage available in this experiment, and the limited sample lengths available also argue against premature conclusions concerning the influence of the weightless environment upon neurological function.

On the other hand, despite the numerous experimental deficiencies resulting from our attempt to extract certain types of data from sources not originally designed for that purpose, it does appear necessary to tentatively conclude that some change in brain physiology did occur concomitantly with the alpha alterations. The conclusion that brain physiology was influenced inflight in turn appears to argue for a more thorough investigation of factors (e.g., fluid shifts) that might conceivably elicit such alterations. Thus, the results of this preliminary investigation of the EEG characteristics during Skylab appear to add some evidence in favor of the hypothesis that some of the symptoms seen during the prolonged exposure to the weightless environment of orbital spaceflight may be of neurological origin.

Future experiments utilizing EEG could be designed to further elaborate this problem. An adequate montage, computer quantification of the entire EEG spectrum, and careful clinical evaluation of properly recorded preflight, inflight, and postflight data should provide conclusive evidence for or against this hypothesis.

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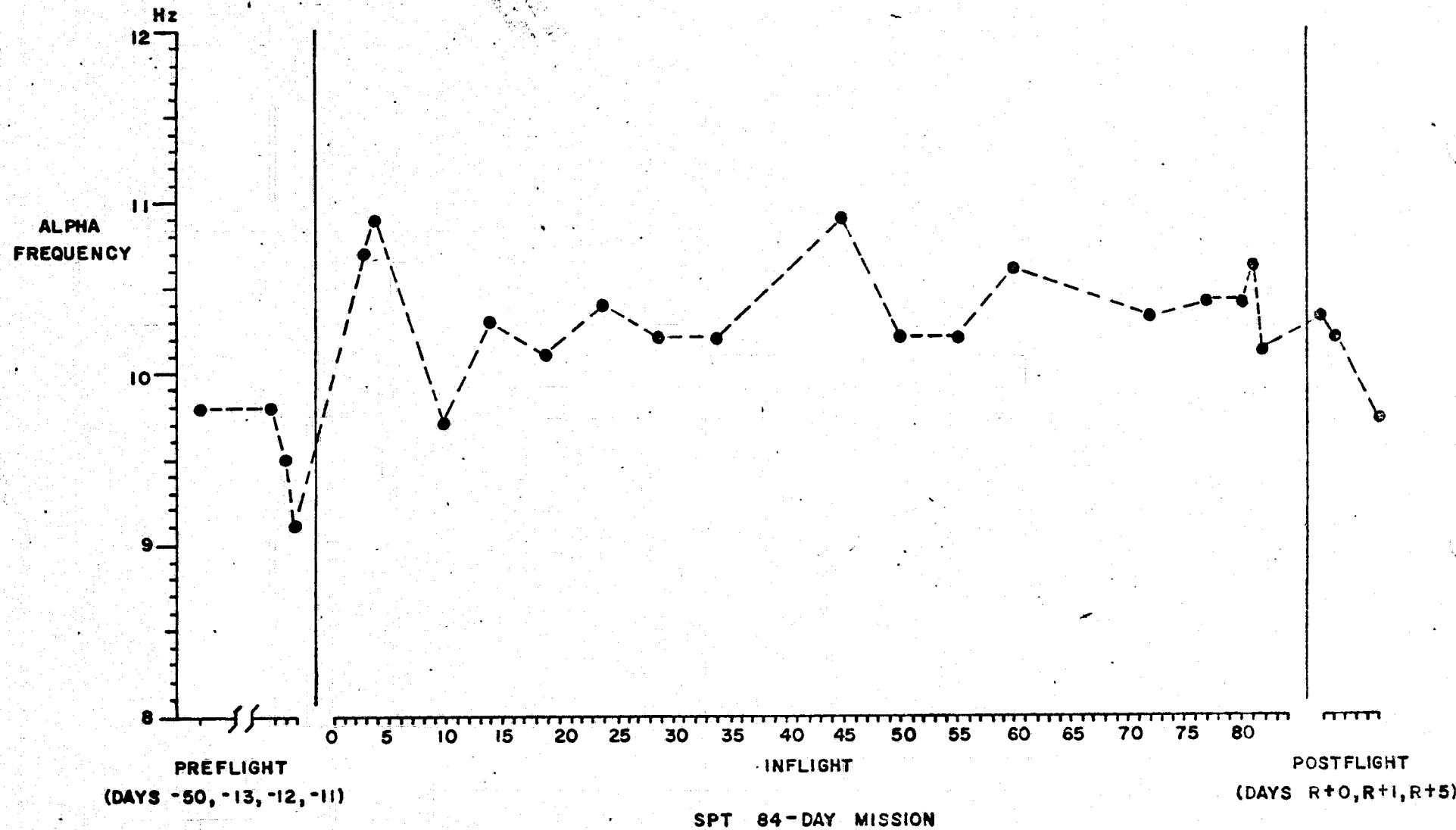


SPT 84-DAY MISSION

FIG. A1

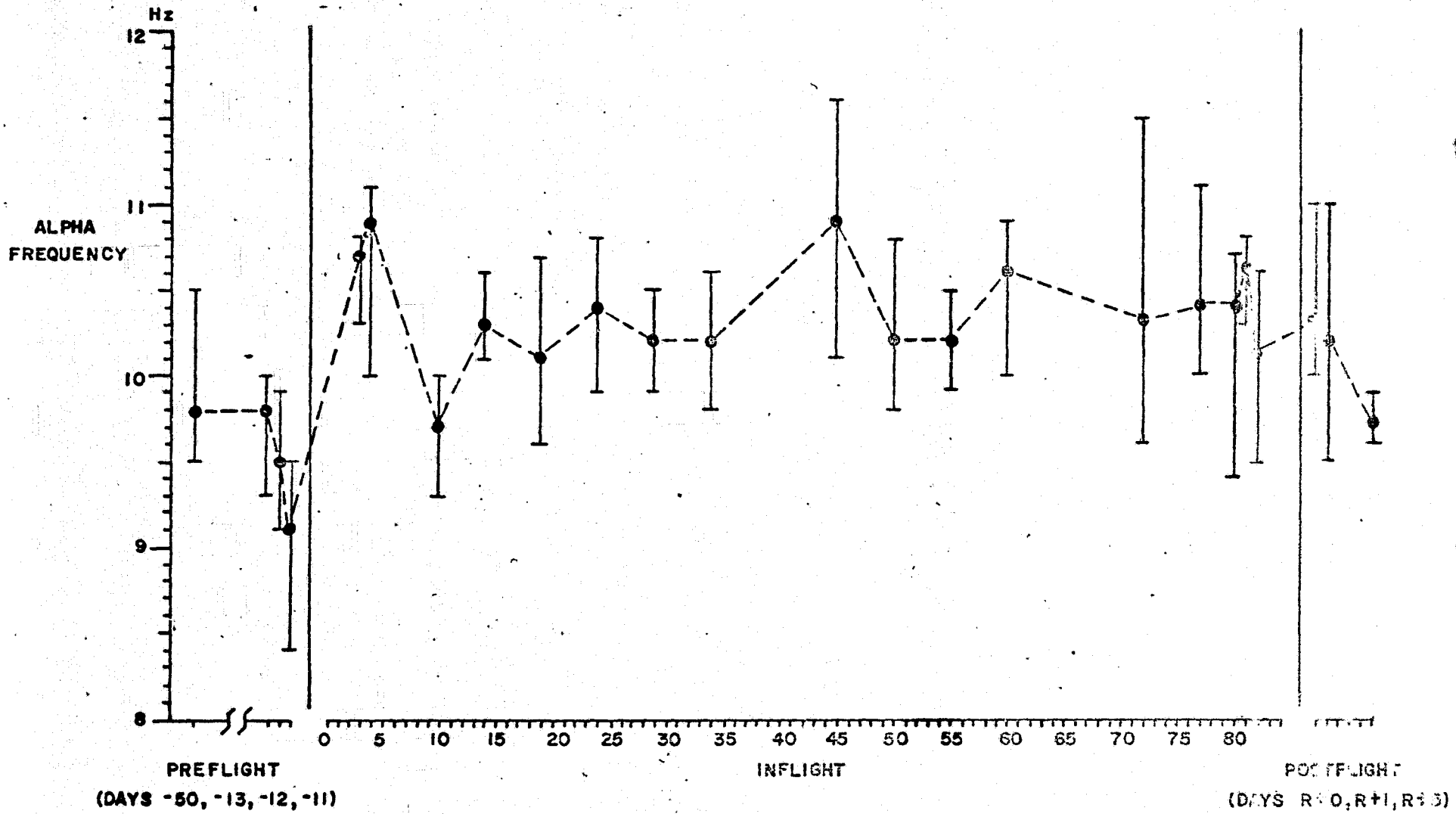
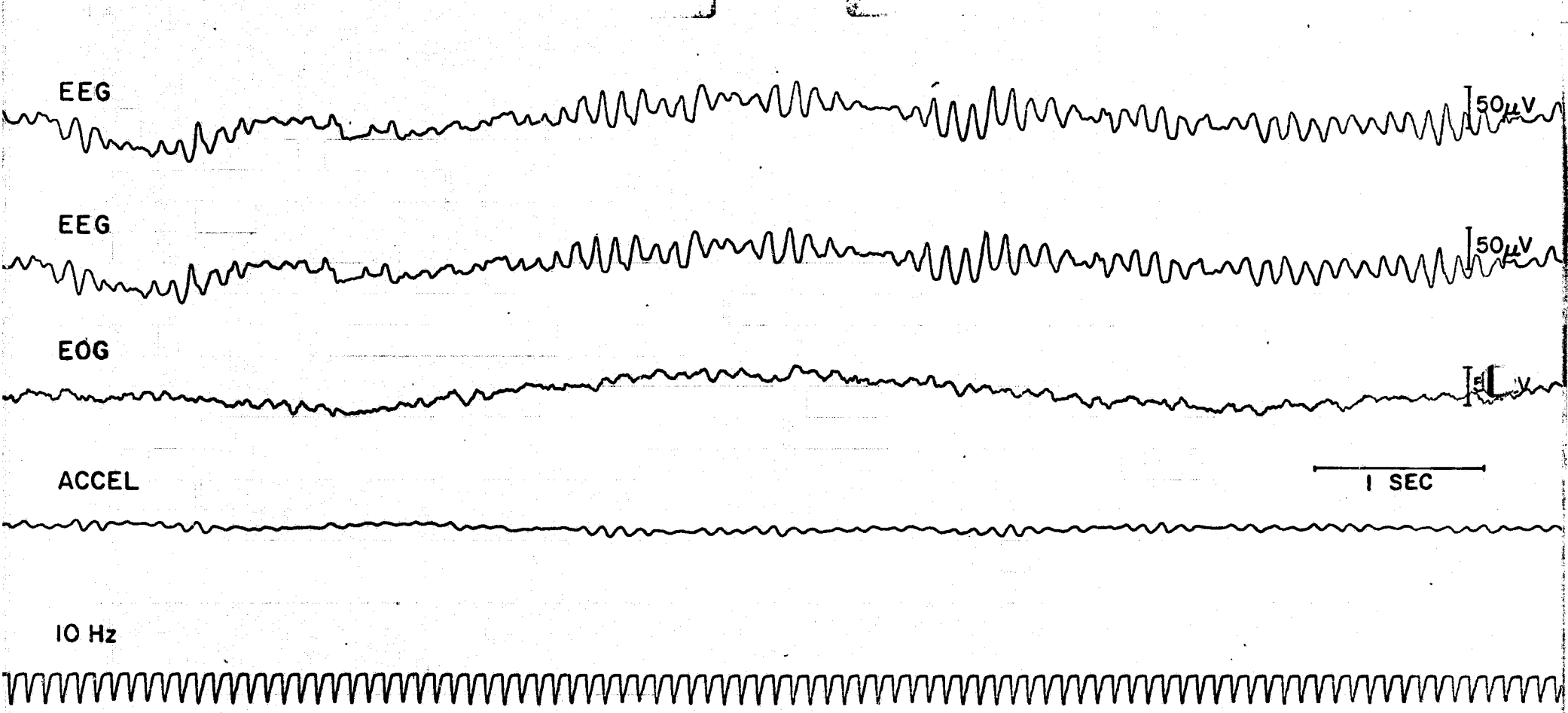
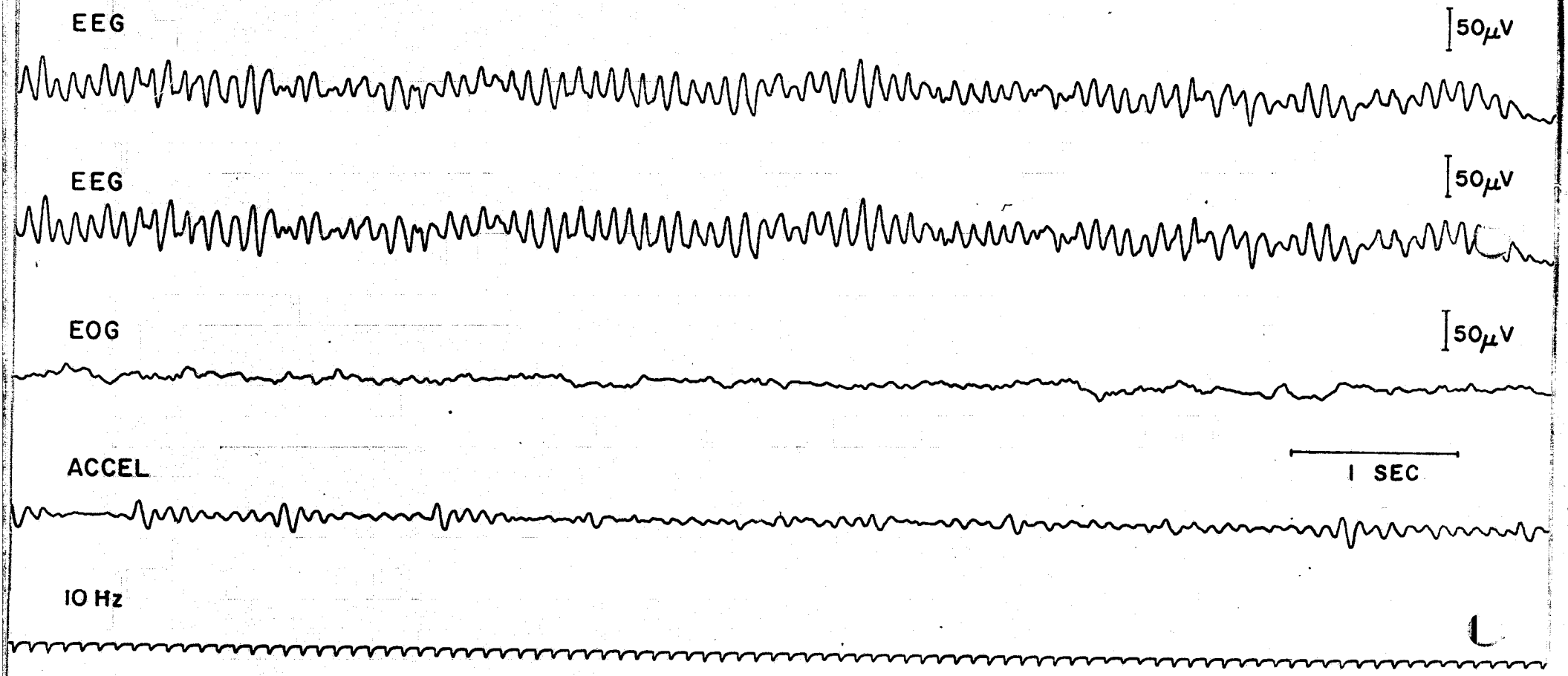

Hz
12
11
10
9
8
ALPHA
FREQUENCY
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
PREFLIGHT
(DAYS -50, -13, -12, -11)
INFLIGHT
POSTFLIGHT
(DAYS R+0, R+1, R+3)
SPT 84-DAY MISSION

FIG. A2



SL/4 SPT PREFLIGHT DAY - 11 (PRESLEEP) FIG. A3



SL/4 SPT MD 3 (PRESLEEP) FIG. A4

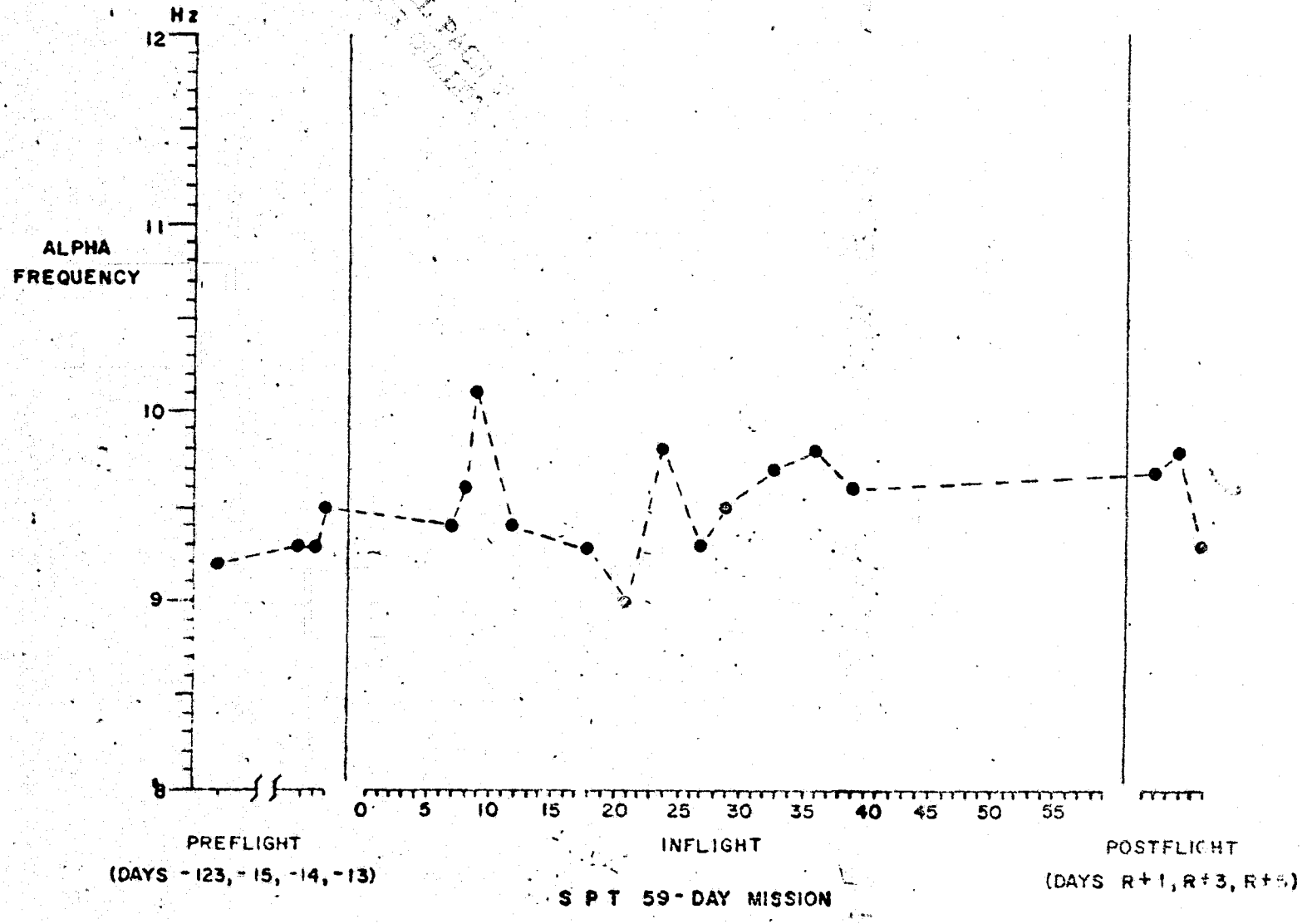

Hz
12
11
10
9
8
ALPHA
FREQUENCY
0
5
10
15
20
25
30
35
40
45
50
55
PREFLIGHT
(DAYS -123, -15, -14, -13)
INFLIGHT
POSTFLIGHT
(DAYS R+1, R+3, R+5)
S P T 59-DAY MISSION

FIG. A5

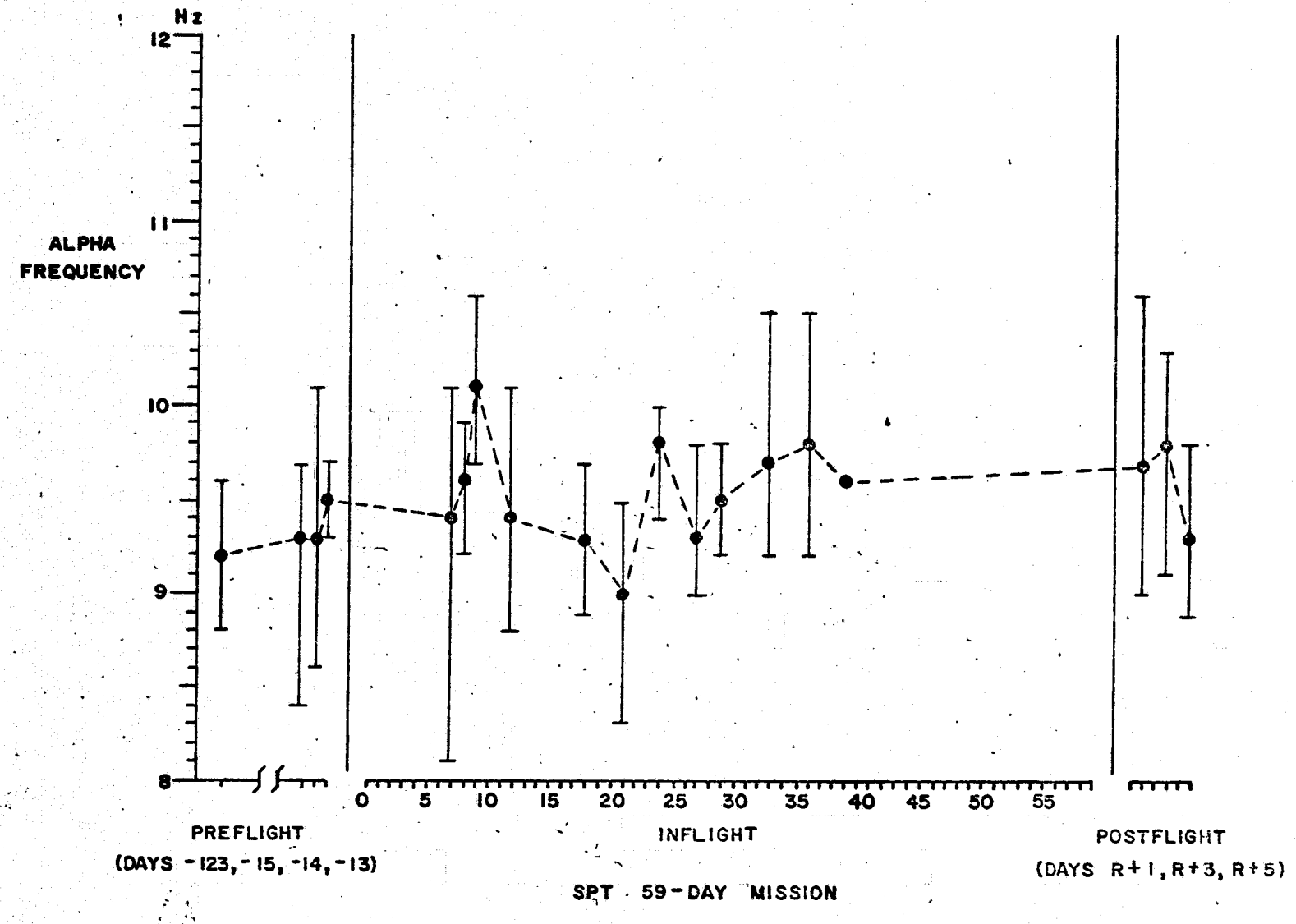

Hz
12
11
10
9
8
ALPHA
FREQUENCY
0
5
10
15
20
25
30
35
40
45
50
55
PREFLIGHT
(DAYS -123, -15, -14, -13)
INFLIGHT
POSTFLIGHT
(DAYS R+1, R+3, R+5)
SPT - 59-DAY MISSION

FIG. A6

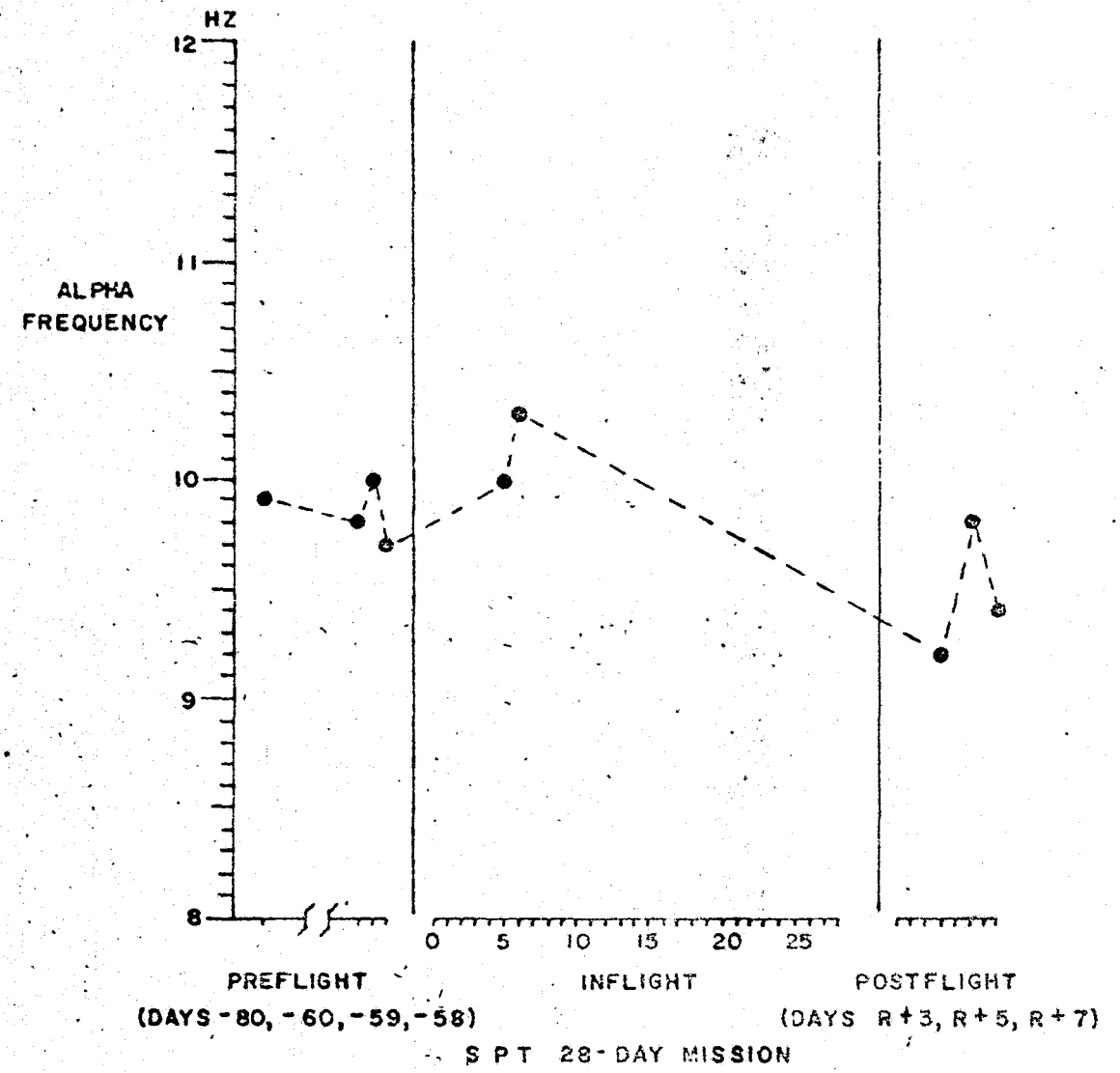
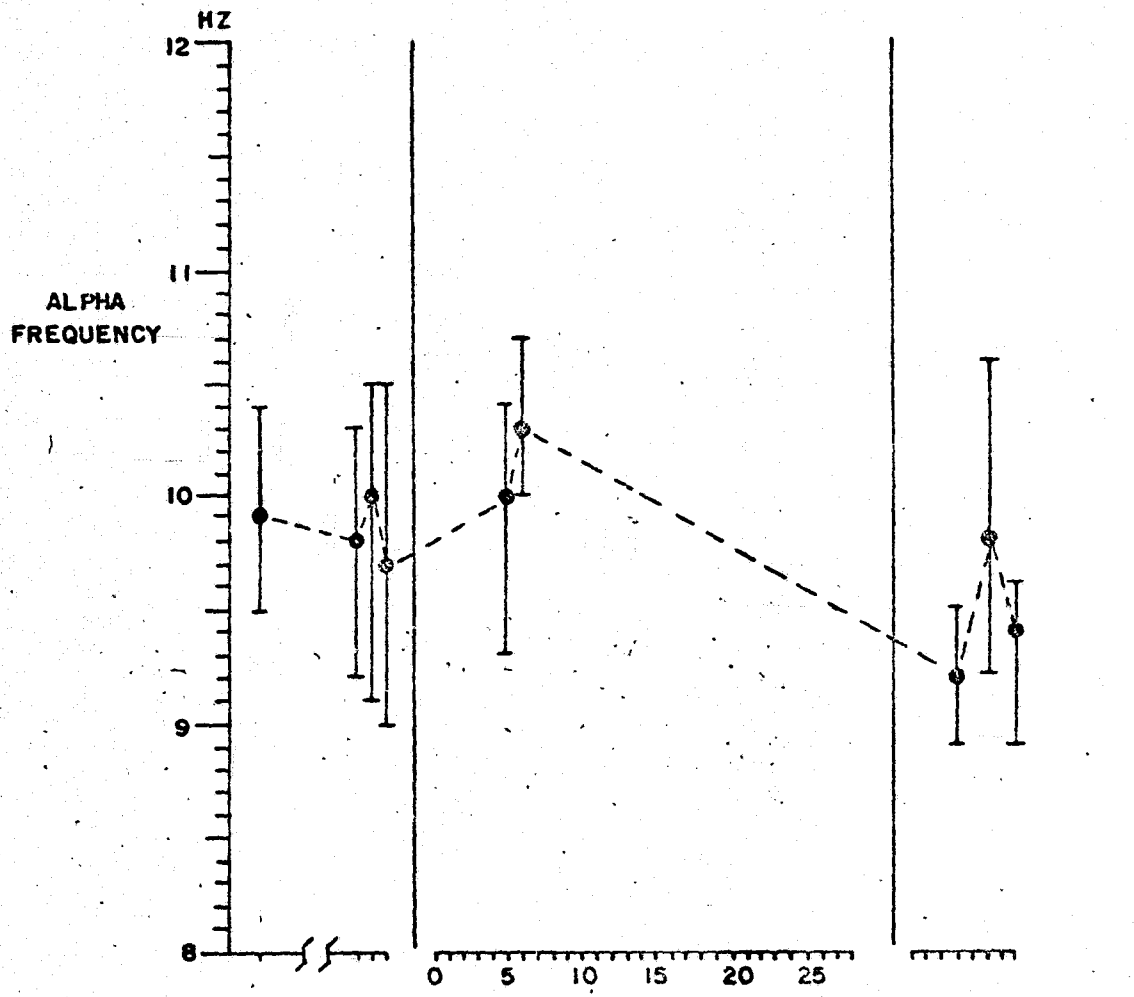

HZ
12
11
10
9
8
ALPHA
FREQUENCY
0
5
10
15
20
25
PREFLIGHT
(DAYS -80, -60, -59, -58)
INFLIGHT
POSTFLIGHT
(DAYS R+3, R+5, R+7)
S P T 28-DAY MISSION

FIG. A7



SPT 28-DAY MISSION

FIG. A8