NAMI-972

THE ELECTROENCEPHALOGRAM OF THE SQUIRREL MONKEY (*Saimiri sciureus*)

IN A VERY HIGH MAGNETIC FIELD

Dietrich E. Beischer and James C. Knepton, Jr.

JOINT REPORT

58729

04

GPO PRICE $
CFSTI PRICE(S) $
Hard copy (HC)
Microfiche (MF)

NAVAL AEROSPACE MEDICAL INSTITUTE

[NATI]ONAL AERONAUTICS AND SPACE ADMINISTRATION

June 1966

Distribution of this document is unlimited.

Distribution of this document is unlimited.

THE ELECTROENCEPHALOGRAM OF THE SQUIRREL MONKEY (*Saimiri sciureus*) IN A VERY HIGH MAGNETIC FIELD*

Dietrich E. Beischer and James C. Knepton, Jr.

Bureau of Medicine and Surgery
MR005.13-9010.1.10

NASA Order R-39

Approved by

Captain Ashton Graybiel, MC USN
Director of Research

Released by

Captain H. C. Hunley, MC USN
Commanding Officer

9 June 1966

*This research was conducted under the sponsorship of the Office of Biotechnology and Human Research, National Aeronautics and Space Administration.

NAVAL AEROSPACE MEDICAL INSTITUTE
NAVAL AVIATION MEDICAL CENTER
PENSACOLA, FLORIDA

SUMMARY PAGE

THE PROBLEM

Electromagnetic propulsion systems, shielding, and other onboard magnetic devices may expose astronauts for prolonged periods of time to strong magnetic fields. Experiments with sublimis primates are necessary in preparation for systematic investigation of possible effects of such fields on man. A study of the electrical activity of the cerebrum in a strong magnetic field is of special interest.

FINDINGS

In preparation for an appraisal of the possible effect of strong magnetic fields on cerebral functions electroencephalograms of squirrel monkeys subjected to strong homogeneous and gradient fields (up to 91,250 oersted) were measured. Higher than normal amplitudes and frequencies were found in the recordings from exposed animals. The unusual EEG records are discussed and an attempt is made to explain the observation. The study is part of a plan to investigate interaction of magnetic fields with the nervous system in general.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the staffs of the Cryogenics Branch, Solid State Division, U. S. Naval Research Laboratory, Washington, D. C., and the National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts. In particular, the assistance and cooperation of Mr. J. Reid Clement, NRL, and Mr. Lawrence Rubin, NML, have contributed to the success of these experiments.

Experiments reported herein were conducted according to the principles enunciated in "Guide for Laboratory Animal Facilities and Care" prepared by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences-National Research Council.

INTRODUCTION

The application of high magnetic fields is being considered for future space travel in a number of respects (1). Since astronauts may become exposed to such fields for prolonged periods of time, studies of the effects on nonhuman primates seem essential. A study of the influence of magnetic fields on electrical phenomena in living organisms promised to be particularly rewarding after significant changes of the electrocardiogram were observed in strong magnetic fields (2). This report demonstrates that the electroencephalogram (EEG) of squirrel monkeys is also subject to changes by high magnetic fields: Higher than normal frequences and amplitudes were observed in the EEG of animals exposed to strong fields, as high as 91,250 oersted.

PROCEDURE

Two types of magnets built according to the Bitter principle were used, one located at the U. S. Naval Research Laboratory (NRL), Washington, D. C., and the other at the National Magnet Laboratory (NML), Massachusetts Institute of Technology, Cambridge, Massachusetts (Figure 1). Both magnets with vertical cores four inches in diameter can be operated for prolonged periods of time at high field strengths.

A total of nine squirrel monkeys (Saimiri sciureus), 4 females and 5 males (316 to 560 grams), were used in three separate series of experiments. The animals had been kept in the colony at Pensacola for some time prior to the experiments under the supervision of a veterinarian. The monkeys were prepared to tolerate restraint by systematically increased periods of immobilization applied for several weeks before the exposure to magnetic fields. During the experiment an animal was placed with its back on a fitted, half-cylindrical couch and restrained by Velcro (American Velcro, Inc.) fasteners (Figure 2). The couch with the animal was inserted into a nonmagnetic cylinder which fitted into the core of the magnet.

For measurement of the electroencephalogram during the last two series of the experiments five silver needle electrodes were inserted just through the scalp on the left side in the frontal (F), parietal (P), temporal (T), occipital (O), and median (ground) cranial regions. Six channels (F-P, P-O, F-T, O-T, P-T, F-O) of bipolar EEG recordings were registered. The first series of experiments was conducted with only the P, O, and ground leads. Various amplifier and recording systems were utilized: in the first set of experiments a Taber Instrument Corporation Model 228 amplifier and a Sanborn Model 51 recorder; in the second series of experiments, Sanborn 350-2700 amplifiers, a Sanborn 350 paper recorder, and a Sanborn 2000 tape recorder; and in the third series, an Offner Electronics Incorporated Type T electroencephalograph. The amplifiers were connected by shielded, nonmagnetic wires to the electrodes, and tracings were obtained several weeks and immediately before, as well as during and after the exposure to magnetic fields. All amplifier inputs are of the differential kind.

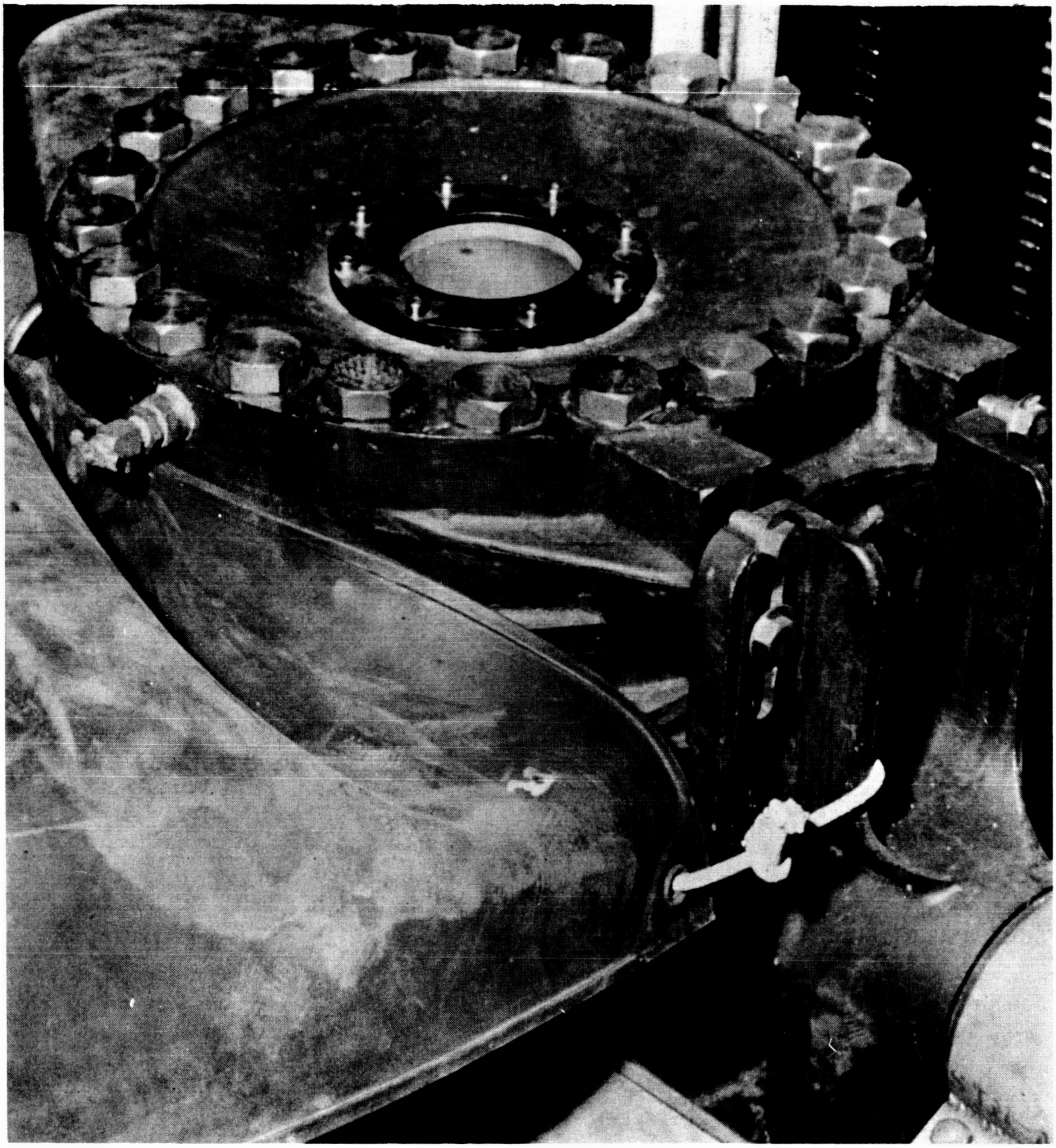

Figure 1

Top view of a Bitter magnet with 4-inch core at the National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts

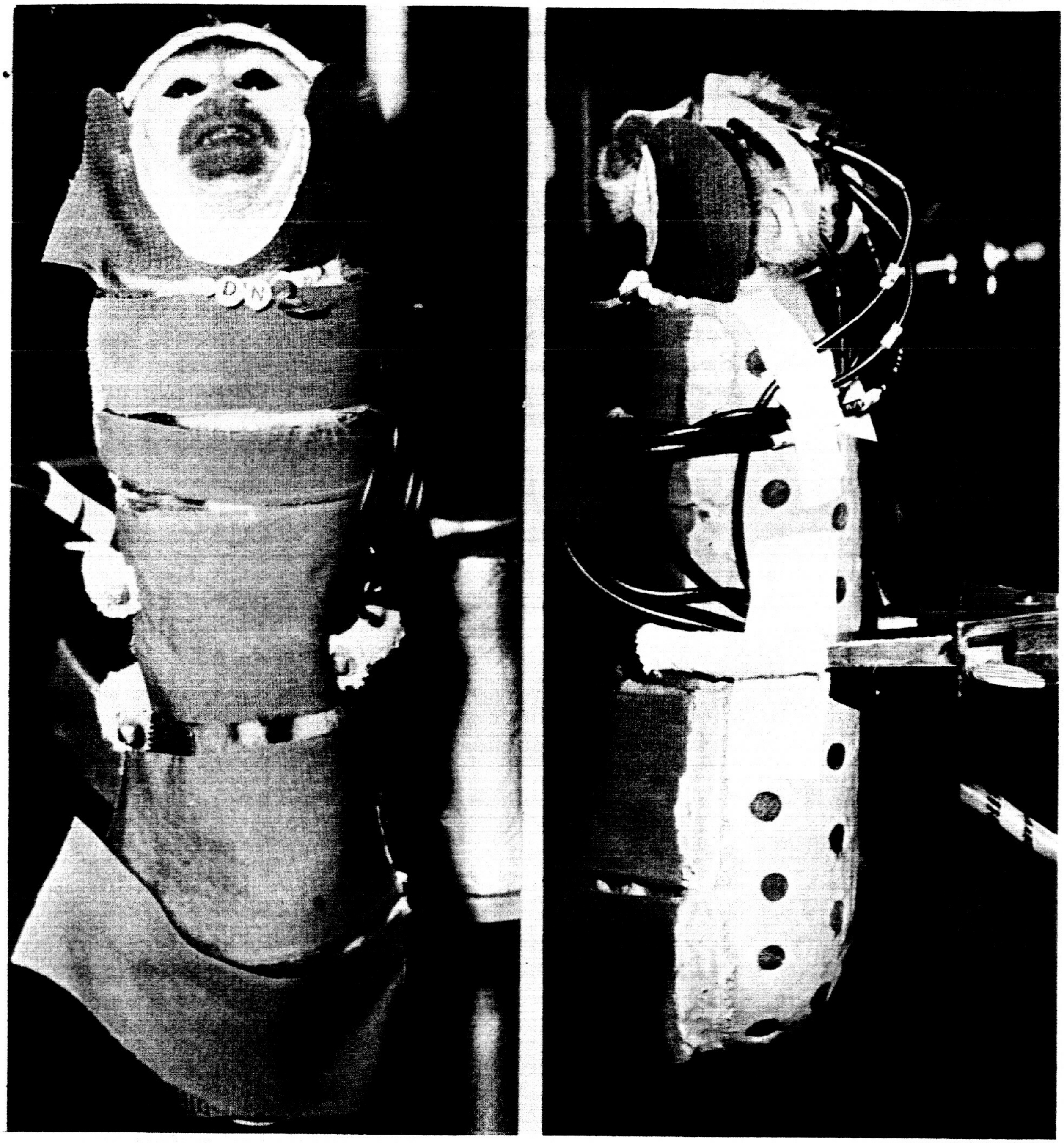

Figure 2

Front and side view of a restrained squirrel monkey (<u>Saimiri</u> <u>sciureus</u>) with inserted scalp electrodes

For insertion into the magnet the cylinder containing the animal was lowered into the core to a preselected position which either placed its head in the center of the magnet with the strongest homogeneous field or at various distances above or below the center in a gradient field of lesser intensity. Figure 3 illustrates the relationship of the animal's position and field strength during the second series of experiments at the Naval Research Laboratory. In the first series at NRL the maximal field strength was 72,450 oersted. The last series of experiments conducted at NML used fields as high as 91,250 oersted. The field of the NRL magnet was increased and decreased at a rate of 500 - 1,000 oersted per second, and the NML magnet's rate was approximately 6,000 oersted per second. Both magnets provided automatically regulated constant fields.

Regulation of the environmental temperature for the animal in the magnet presented some problems. The temperature in the core changed with the load and varied along the length of the core, with the highest temperature at the ends where the current is conducted to the magnet. At NRL during the first experiments a plastic cylinder with abundant air flow created suitable ambient conditions for the monkeys, as indicated by normal rectal temperature readings. For the second series at NRL a copper-metal water-jacket maintained the ambient air around the animal at $26^\circ \pm 1^\circ$ C. Rectal temperature measurements of these animals were also normal during the entire experiments. At NML a plastic water-jacket kept the ambient air at $24.8^\circ \pm 0.2^\circ$ C.

The following schedules of exposure of monkeys to very high magnetic fields were chosen:

SERIES I (NRL) (2 animals)

1. 30-minute baseline (magnet not activated).

2. Homogeneous field, normal polarity (north pole at bottom of magnet, south pole at top), in stepwise fashion from 0 to 40,000 oersted, to 72,450 oersted, remaining at each step for 45 minutes during which time EEG recordings were taken.

3. Corresponding stepwise decrease to magnet power cut-off.

4. Baseline.

SERIES II (NRL) (5 animals)

1. 15-minute baseline (magnet not activated).

2. Homogeneous field, normal polarity (north pole at bottom of magnet, south pole at top), in stepwise fashion from 0 to 20,000 oersted, to 40,000 oersted, and to 60,000 oersted, remaining at each step for 3 minutes with EEG recordings.

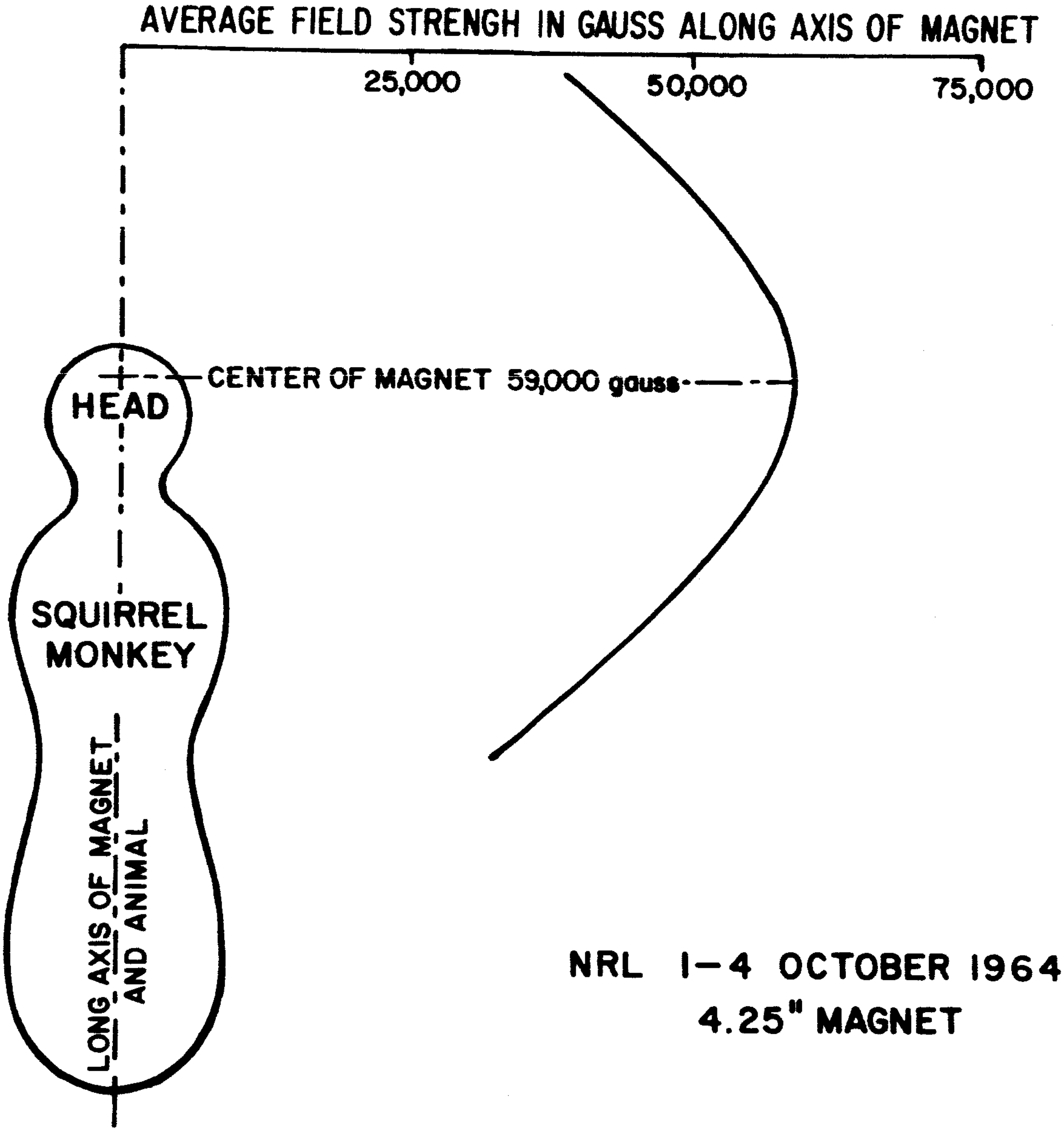

Figure 3

Relationship of a squirrel monkey's brain position to the field distribution of the 4-inch magnet at the U. S. Naval Research Laboratory, Washington, D. C.

3. Corresponding stepwise decrease to magnet power cut-off.

4. Reverse polarity of magnet and repeat 2 and 3.

5. Gradient field, normal polarity and repeat 2 and 3.

6. Gradient field, reverse polarity to 44,000 oersted and decrease to power cut-off, recording EEG continuously.

7. Baseline.

SERIES III (NML) (2 animals)

1. 10-minute baseline (magnet not activated).

2. Gradient field, normal polarity, in stepwise fashion from 0 to 22,540 oersted, to 45,472 oersted, to 68,414 oersted, to 91,258 oersted, remaining at each step for 1 minute with EEG recordings.

3. Corresponding stepwise decrease to magnet power cut-off.

4. Baseline.

EEG EVALUATION AND RESULTS

Visual examination of the single-channel electroencephalograms taken during the Series I experiments suggested a possible influence of the magnetic field. Subsequent Series II experiments were conducted using the same magnet, but deriving 6 bipolar channels of EEG recordings from five left-side electrodes. This set of experiments was analyzed by measuring each cycle within varying lengths of the continuous spontaneous EEG at different stages of the experimental protocol. Also, continuous three-minute spontaneous recordings were computer-analyzed (Mnemotron CAT Model 400B) for presence of repetitive signals of the EEG at different field strengths. Typical findings using these analytical methods are given for two different animals in Figures 4 and 5. The EEG's of three of the second series monkeys recorded during power-off and power-on conditions of the magnet are illustrated in Figures 6 and 7. It was observed that the prevailing frequencies of the squirrel monkey in the power-off phase were from 8 to 12 cps, with a peak-to-peak amplitude of 25 to 50 microvolts. During the power-on phase the majority of the frequencies were higher than 12 cps, usually between 14 and 50 cps, and with an amplitude of 50-400 microvolts. No differences in the EEG's were recorded while the monkeys were exposed to homogeneous and to gradient fields nor could any influences of polarity changes be found.

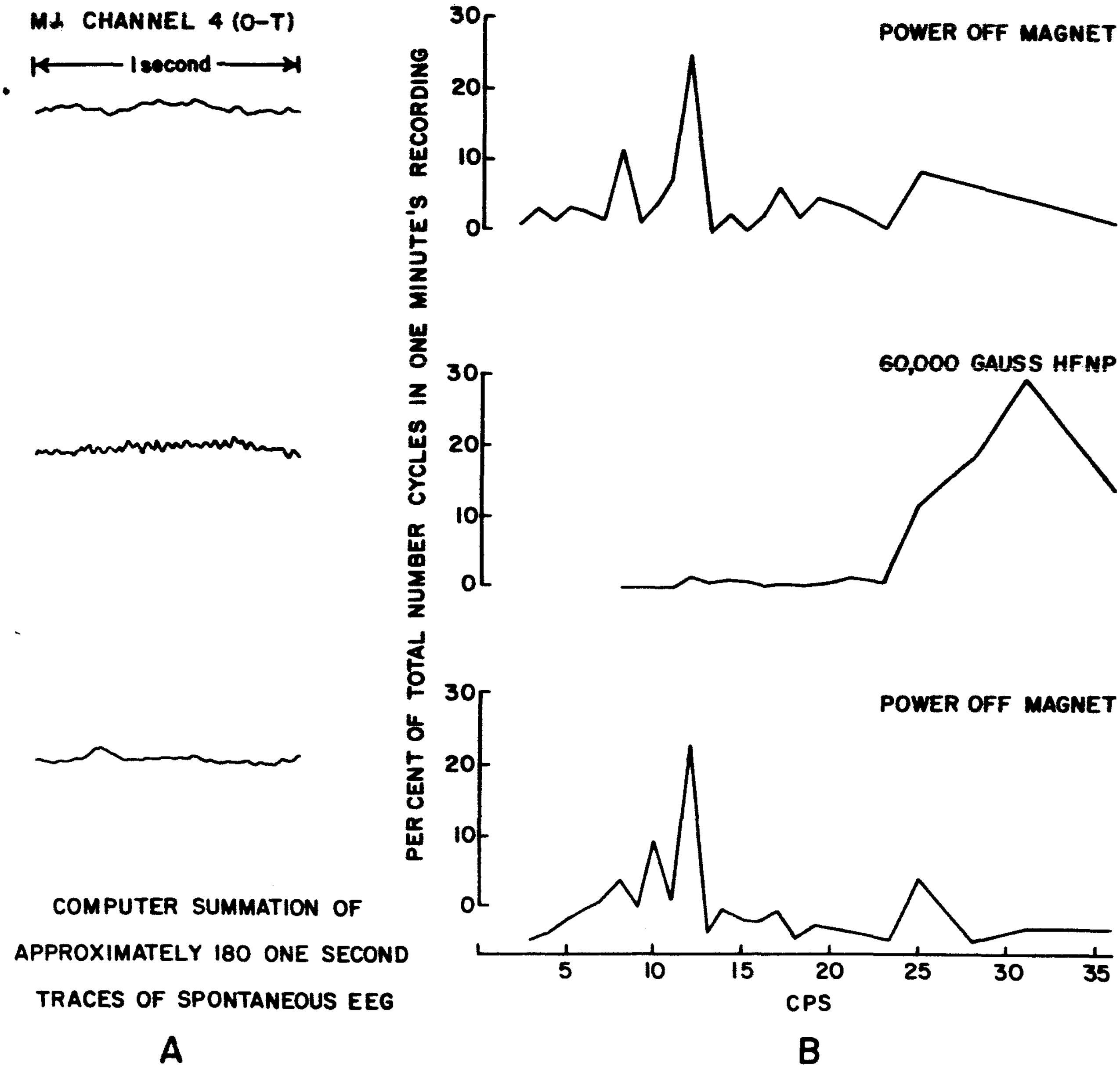

Figure 4

Typical results from two analytical methods utilized for evaluation of the spontaneous electroencephalograms of squirrel monkey "MJ": (A) CAT computer summation of about 180 serial one-second EEG records before, during, and after magnetic field exposures; (B) Graphs derived from measurement of each successive cycle in one-minute EEG's before, during, and after magnetic field exposures.

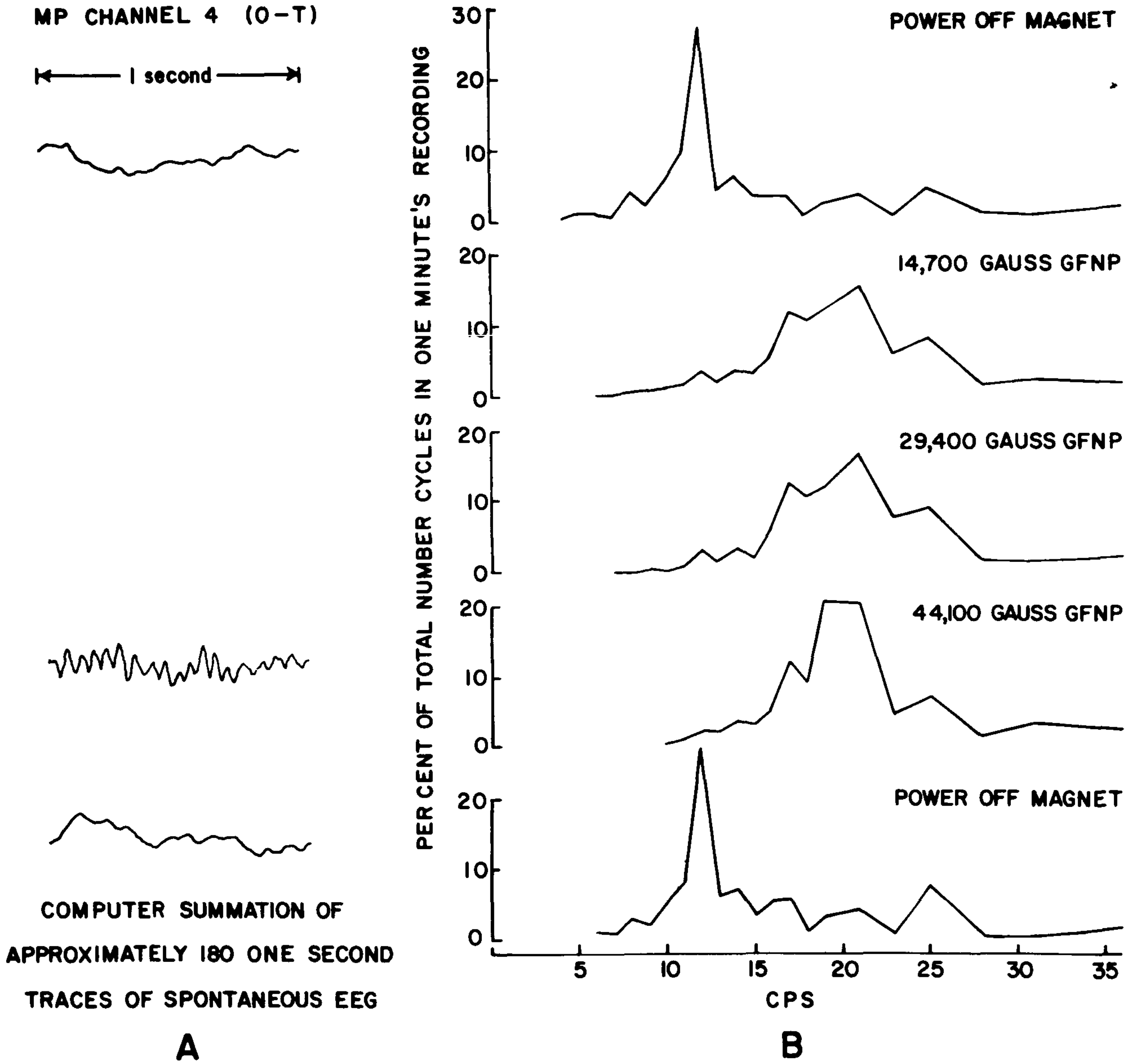

Figure 5

Typical results from two analytical methods utilized for evaluation of the spontaneous electroencephalograms of squirrel monkey "MP": (A) CAT computer summation of about 180 serial one-second EEG records before, during, and after magnetic field exposures; (B) Graphs derived from measurement of each successive cycle in one-minute EEG's before, during, and after magnetic field exposures.

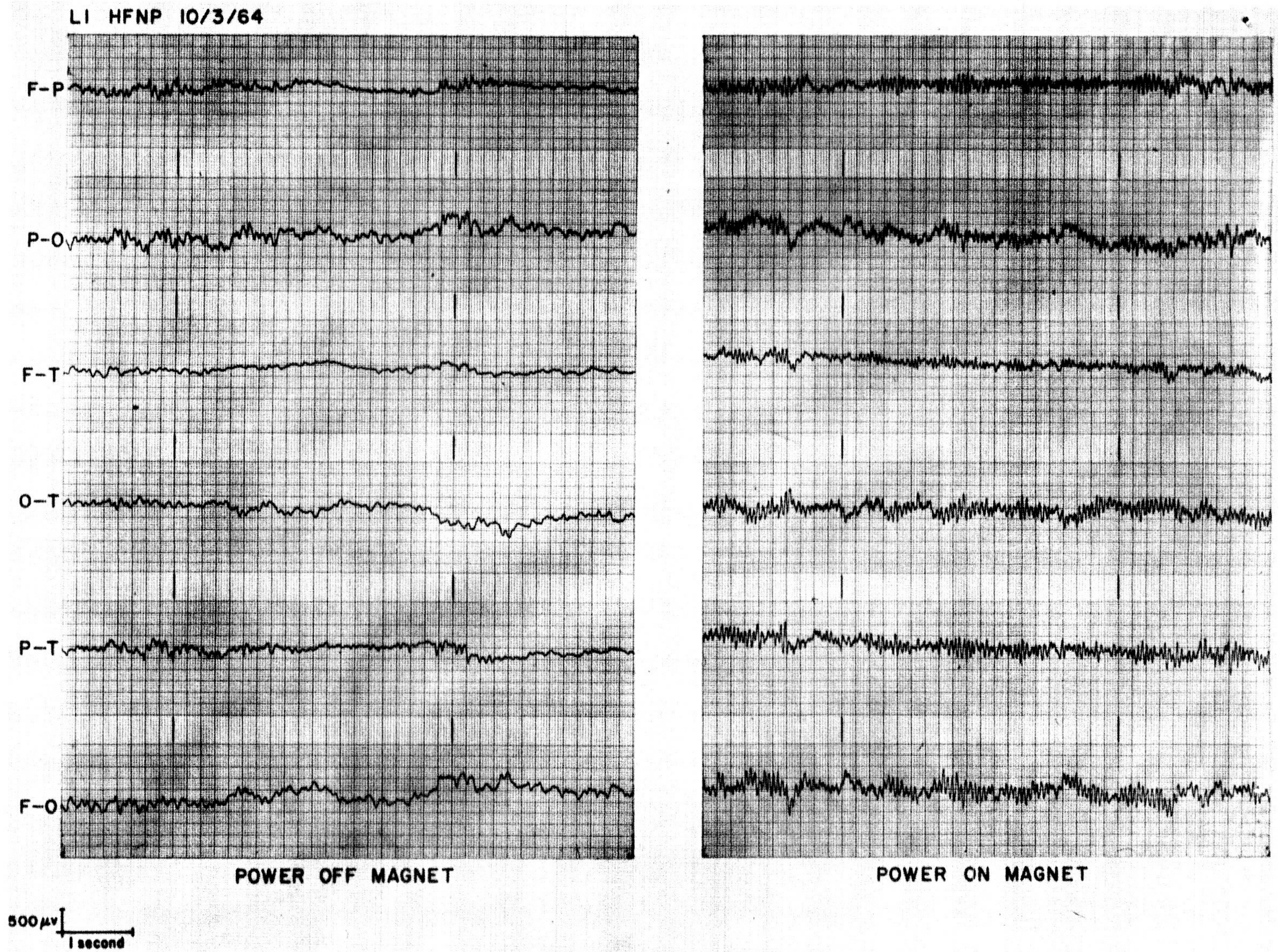

Figure 6

Representative traces of electroencephalograms derived from left scalp electrodes (F, frontal; P, parietal; O, occipital; T, temporal) of squirrel monkey "LI." Field conditions of NRL magnet at head of animal: Homogeneous field 60,000 oersted, normal polarity (NP = south pole at top of magnet).

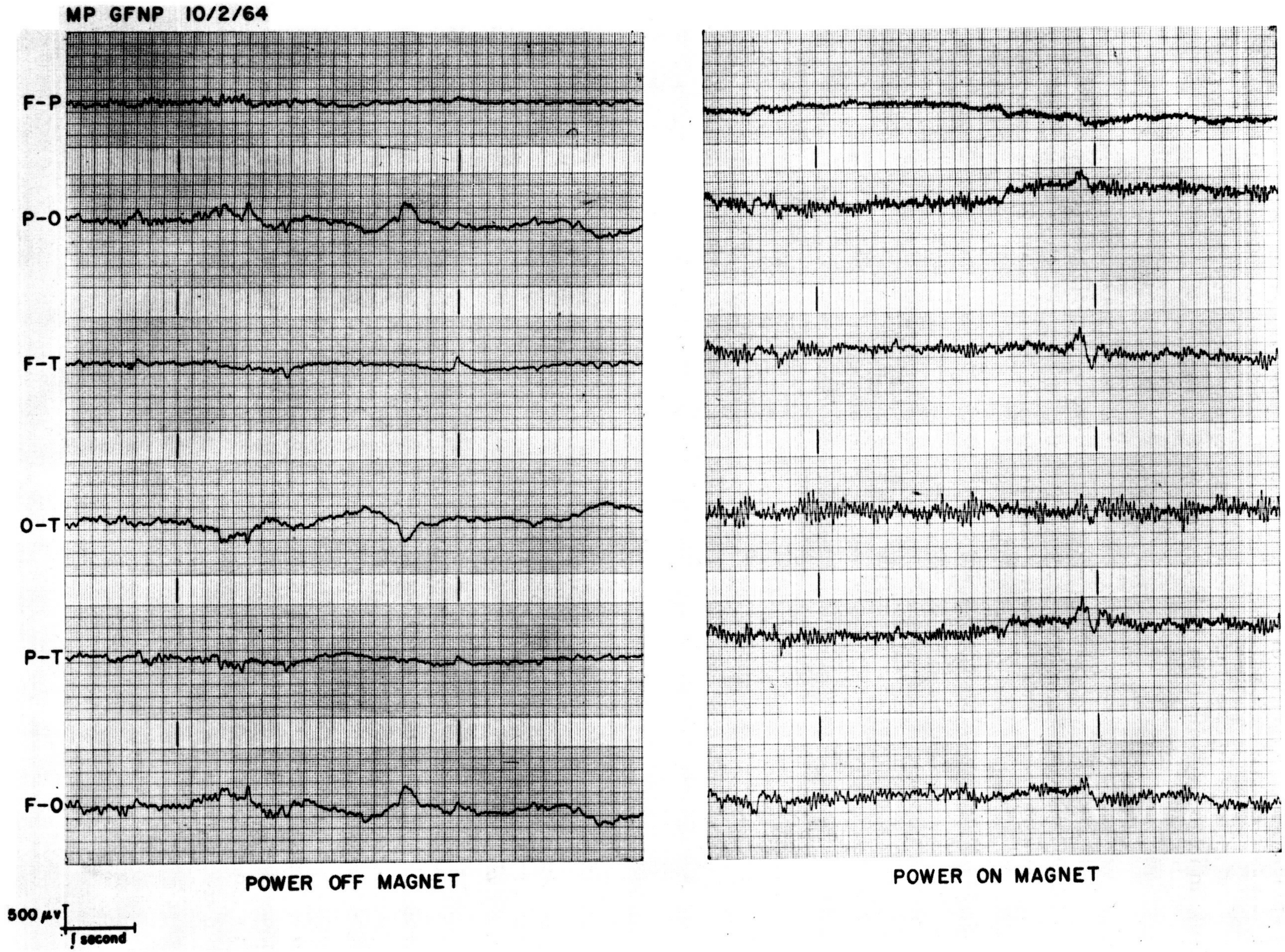

Figure 7

Representative traces of electroencephalograms derived from left scalp electrodes of squirrel monkey "MP." Field conditions of NRL magnet at head of animal: Gradient field with 2,500 oersted gradient at 44,100 oersted, normal polarity.

Figure 8 is representative of the EEG's obtained from the two monkeys exposed at NML and demonstrates the characteristic features found in high magnetic field recordings: 1) an increase in amplitude following the increase in field strength, and 2) an increase in frequency with little field dependence.

DISCUSSION

Artifacts in the EEG measurement may be produced by the induction of a signal in the EEG loop by several nonrelated sources. Potential origins of such an artifact are: 1) the ripple component of the generator used to energize the magnet, 2) involuntary movements of the animal connected with heart rate and breathing, 3) mechanical vibration of the magnet caused by cooling water, 4) 50-cycle interference, and 5) skeletal muscle tonicity and tremor. The first four sources of artifact may be reasonably excluded because their characteristic frequencies are outside the spectrum of predominant frequencies of the measured tracings. The ripple frequency of the NML magnet of 6, 12, and 85 cps was well below and above the predominant electroencephalographic frequency of the animal in the magnetic field. Respiratory rate (1 cps), heart rate (3-5 cps), and mechanical vibration (4 cps) were lower than the 14-50 cps EEG range, and the 60 cps line frequency was higher. This leaves muscle tremor as a possible source of artifact. The recordings in Figure 8 show a tracing which is similar to the EMG of skeletal muscle with abnormal tonus. The possibility of this artifact cannot be excluded before subcranially implanted electrodes have replaced scalp electrodes and results have been evaluated.

The EEG registered in the magnetic field did not reveal any signals constant in frequency and amplitude as might be expected from some of the above sources of artifact but did show current oscillations which changed randomly in amplitude and frequency, the characteristic waxing and waning of an EEG. Furthermore, differences of signal strengths and frequencies in the leads were observed, indicating absence of extrinsic induction which would influence all leads to a similar extent.

If artifacts can be considered eliminated, it may be inferred that strong magnetic fields exert a significant synchronizing effect on brain waves as demonstrated by the high amplitude of the waves. The high predominant frequency of the EEG of squirrel monkeys in strong magnetic fields would normally be associated with activation and tension of the animal. However, preliminary results of behavioral studies of squirrel monkeys in strong magnetic fields, which will be reported later, demonstrated decreasing performance in a visual discrimination task. At a field strength of 90,000 oersted the animals ceased to perform their task.

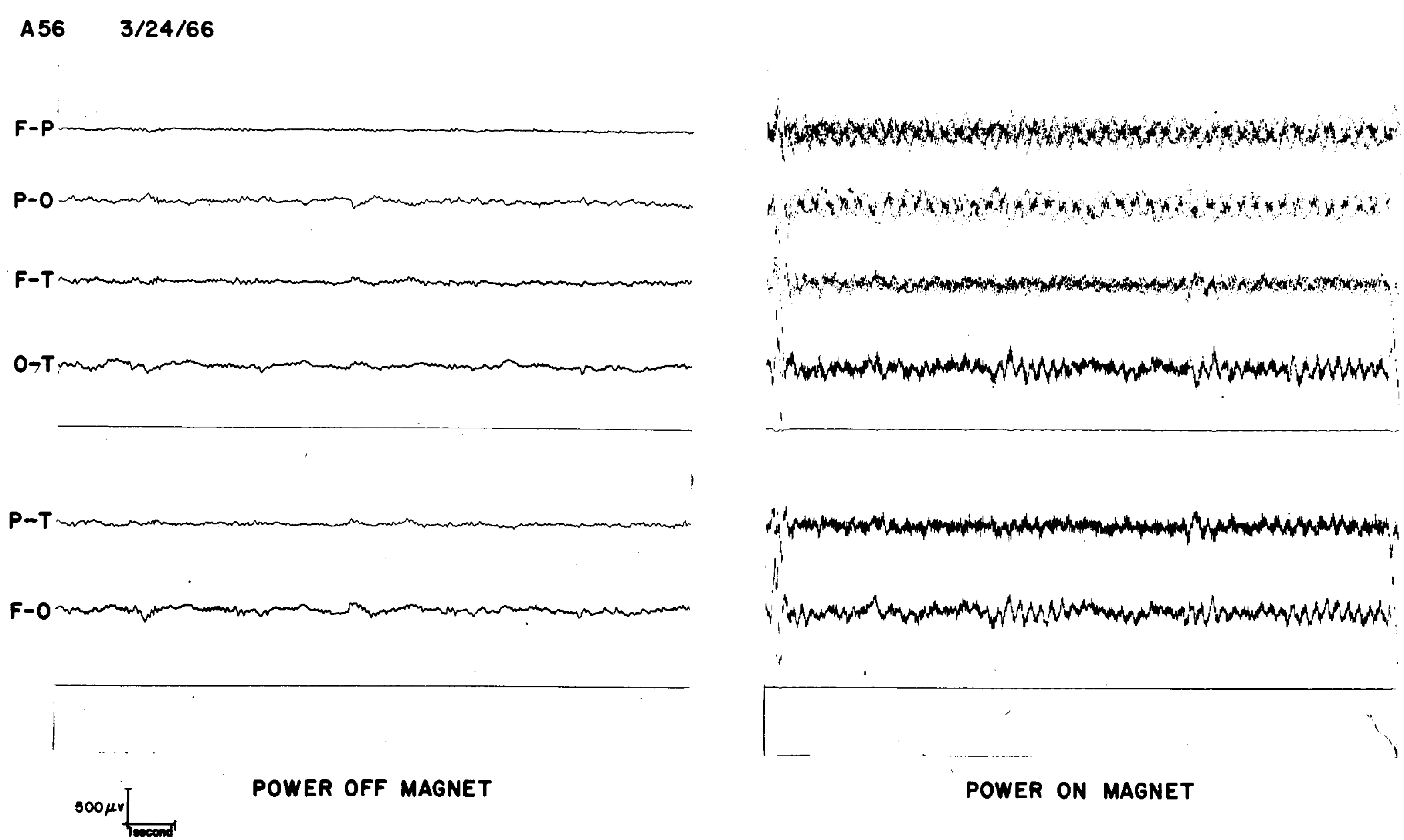

Figure 8

Characteristic traces of electroencephalograms derived from left scalp electrodes of squirrel monkey "A56." Field conditions of NML magnet at head of animal: Gradient field with 3,260 oersted gradient at 91,250 oersted.

Kholodov (3,4) has found that the character of the reaction to a magnetic field depended on the initial functional state of the central nervous system. In his experiments using encephale isole of rabbits in a static magnetic field of about 800 oersted the EEG showed a highly significant increase in the number of spindles in the frontal region of the cerebral cortex, as well as an increase in the number of slow high-amplitude oscillations in the occipital region. Under the action of the magnetic field the EEG of rabbits (it is assumed intact animals were used) exhibited acute (beta) waves which reflected a process of excitation. He further states that although a magnetic field produced an inhibitory state, it may also provoke excitation in the central nervous system. Observations of Becker (5) on a tranquilized amphibian in a magnetic field of 3,400 oersted showed diminution of alpha waves and the appearance of delta waves in the EEG. The waveform in the magnetic field is characterized by Becker as typical for moderate to deep surgical anesthesia of the animal.

Judging from all these observations it appears that strong magnetic fields have a significant effect on the central nervous system and that this effect is predominantly manifested as deactivation. However, the high frequencies in the EEG of squirrel monkeys in strong fields do not fit into this general picture and are either due to an artifact or represent a sequence of rapid discharges which disrupt the coordinated functioning of the central nervous system.

REFERENCES

1. Beischer, D. E., Biomagnetics. In: Civilian and Military Uses of Aerospace. Ann. N. Y. Acad. Sci., 134:454-458, 1965.

2. Beischer, D. E., and Knepton, J. C., Jr., Influence of strong magnetic fields on the electrocardiogram of squirrel monkeys (Saimiri sciureus). Aerospace Med., 35:939-944, 1964.

3. Kholodov, Yu. A. Effects on the central nervous system. In: Barnothy, M. F. (Ed.), Biological Effects of Magnetic Fields. New York: Plenum Press, 1964. Pp 196-200.

4. Kholodov, Yu. A., A magnetic field as a stimulus. In: Gaaze-Rapoport, M. G., and Yakobi, V. E. (Eds.), Bionics. Moscow: Nauka Publishing House, 1965. JPRS Translation. Washington, D. C.: U. S. Department of Commerce.

5. Becker, R. O., Relationship of geomagnetic environment to human biology. N. Y. St. J. Med., 63:2215-2219, 1963.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Aerospace Medical Institute Pensacola, Florida	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

THE ELECTROENCEPHALOGRAM OF THE SQUIRREL MONKEY (SAIMIRI SCIUREUS) IN A VERY HIGH MAGNETIC FIELD

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

N/A

5. AUTHOR(S) (Last name, first name, initial)

Beischer, Dietrich E., and Knepton, James C., Jr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
9 June 1966	14	5

8a. CONTRACT OR GRANT NO. NASA Order R-39 b. PROJECT NO. MR005.13-9010.1 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NAMI-972 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) 10

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

In preparation for an appraisal of the possible effect of strong magnetic field on cerebral function electroencephalograms of squirrel monkeys subjected to strong homogeneous and gradient fields (up to 91,250 oersted) were measured. Higher than normal amplitudes and frequencies were found in the recordings from exposed animals. The unusual EEG records are discussed and an attempt is made to explain the observation. The study is part of a plan to investigate interaction of magnetic fields with the nervous system in general.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electroencephalogram (EEG)						
Oersted						
Squirrel monkey						
Very high magnetic fields						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, *or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

Unclassified
Security Classification