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EXPOSURE OF SQUIRREL MONKEYS FOR LONG PERIODS TO  
EXTREMELY LOW-FREQUENCY MAGNETIC FIELDS: CENTRAL-  
NERVOUS-SYSTEM EFFECTS AS MEASURED BY REACTION TIME

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13. ABSTRACT <p>The U.S. Navy is currently interested in the physiological effects of electromagnetic radiation. This interest covers a broad range of the spectrum, including the extremely low-frequency (ELF) region used in power generation and distribution systems. Operation and maintenance personnel on these systems are often exposed to significant ELF fields for short periods. The present experiment was designed to detect cumulative central-nervous-system effects resulting from exposure to ELF magnetic fields.</p> <p>Three squirrel monkeys were exposed continuously for 42 days to a 10-gauss magnetic field at 45 Hz. Reaction-time measurements were taken daily for 23 days prior to exposure, during the exposure period, and for 9 days after exposure. No significant changes in these measurements were observed between control sessions and exposure or postexposure sessions. Two other indices of performance, reinforcement ratio and efficiency ratio, were also unchanged. These results indicate that if a psychophysiological significant effect exists, it is probably quite subtle and will therefore require a broad range of very sensitive experiments to evaluate properly the long-term effects of the ELF environment.</p>			

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## SUMMARY PAGE

### THE PROBLEM

The U.S. Navy is currently interested in the physiological effects of nonionizing electromagnetic radiation. This interest covers a broad range of the spectrum, including the extremely low-frequency (ELF) region used in power generation and distribution systems. Operation and maintenance personnel on these systems are often exposed to ELF fields of substantial intensity for short periods. Medical evaluation of such workers has not revealed deleterious effects. Psychophysiological studies have indicated that neuromuscular reaction time may be affected by ELF fields. The present experiment was designed to detect any cumulative central-nervous-system effects that might result from exposure to ELF magnetic fields for extended periods of time.

### FINDINGS

Three squirrel monkeys were exposed continuously for 42 days to a 10-gauss magnetic field at 45 Hz. Reaction-time measurements were taken daily for 23 days prior to exposure, during the exposure period, and for 9 days after exposure. No significant changes in these measurements were observed between control sessions and exposure or post exposure sessions. Two other indices of performance, reinforcement ratio and efficiency ratio, were also unchanged. These results indicate that if a psychophysiological significant effect exists, it is probably quite subtle and will therefore require a broad range of very sensitive experiments to evaluate properly the long-term effects of the ELF environment.

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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 U.S. Navy is currently interested in the physiological effects of non-ionizing electromagnetic radiation. This interest covers a broad range of the spectrum, including the extremely low-frequency (ELF) region used in power generation and distribution systems. Operation and maintenance personnel on these systems are often exposed to ELF fields of substantial intensity for short periods. Medical evaluation of such workers has not revealed any deleterious effects (7); however, psychophysiological studies have indicated that neuromuscular reaction time may be affected by ELF fields.

In two such studies König and Ankemüller (6) and König (5) measured reaction time in humans exposed to ELF electric fields and found that it appeared to be frequency dependent. Longer reaction times were recorded when the ambient electric field contained frequencies from 3 Hz to 6 Hz, and shorter times were recorded for approximately 9 Hz.

By exposing human subjects to magnetic fields of up to 0.2 Hz, Friedman et al. (1) showed that their reaction times were longer for the sessions in which the field was on than for the control sessions. No effects were found at frequencies of 0.1 Hz.

Hamer (4) reported an extremely small reaction-time effect on human subjects exposed to ELF electric fields at frequencies between 2 Hz and 12 Hz. He did not consider the results to be conclusive and emphasized the need for further experiments to substantiate his results.

In a more recently conducted study, Gavalas et al. (2) observed a significant difference in inter-response times for monkeys exposed to a 7-Hz electric field. No significant changes occurred at 10 Hz.

Grissett and de Lorge (3) conducted an experiment similar to those just cited in that it was directed at the instantaneous as opposed to cumulative effects of ELF fields. Three squirrel monkeys were exposed for 1-hour daily sessions to a 3-gauss magnetic field at 45 Hz. The experiment was then repeated at 3 gauss and 7 Hz. No significant changes were observed in reaction-time measurements for these subjects under either experimental condition. Two other indices of performance, reinforcement ratio and efficiency ratio, were also unchanged. It was concluded that the instantaneous effects, if present, were not sufficient to be measured by the reaction-time technique employed in the experiments.

The present study is similar to the earlier one (3) in that the same techniques were used, but the animals were exposed continuously for 42 days to a higher intensity field of 10 gauss and at 45 Hz only. The purpose of this experiment was to study the cumulative effects of the ELF field on physiological systems that participate directly or indirectly in the reaction-time response.

## PROCEDURE

### APPARATUS

A wide-angle view of the apparatus, which consisted of three separate, but identical, Helmholtz coil pairs wound on open-ended plywood boxes, is shown in Figure 1. The coils were 2-foot square, and the spacing between coils was 1 foot. The inside dimensions of the Plexiglas cages were 15.5 inches deep, 19 inches high, and 16 inches wide. An aluminum response lever  $3/8$  inch in diameter projected  $3/4$  inch into the cage through a hole 5 inches above the floor and centered on the rear wall facing one end of the open chamber. A 10-inch-square electroluminescent lamp hanging at one end of the wooden chamber, 35 inches from the cage wall, served as the stimulus light. Reinforcement consisted of Purina monkey chow pellets, each weighing 0.22 gm. Each pellet was released from a dispenser mounted above the wooden chamber and then traveled by force of gravity through a plastic tube into the cage. Recording, control, and magnetic-field generating equipment were located in an adjacent room to prevent the animals from receiving extraneous audio cues that would affect their performance.

### METHOD

The same adult squirrel monkeys, *Saimiri sciureus*, used in the previous short-term study (3) were used in the present long-term study. Since the animals were only exposed for a total of 10 hours and the results were negative in the previous study, it was permissible to use the same subjects in the present experiment in which they were exposed for 1008 hours.

The training procedure described below was that used preparatory to the previous short-term experiment (3) and is repeated here for completeness. Prior to training, these animals (one female, LE, and two males, D26 and A88) were food deprived to approximately 85 percent of their body weight and maintained at this level throughout the experiment. Their experimental weights were LE, 525 gms; D26, 920 gms; and A88, 710 gms.

In the initial phase of training, each lever depression immediately illuminated the lamp and simultaneously dispensed a reinforcement pellet. Following acquisition of that response, the procedure was changed so that the lamp was not illuminated unless the lever was depressed for 5 seconds, and a reinforcement pellet was given only when the lever was released in the presence of the light stimulus. If the lever was not released within 3 seconds from onset of the light stimulus, the stimulus was automatically terminated and no reinforcement was given. The time from lever depression to presentation of the light stimulus was then varied (1 sec to 15 sec) to improve the animals' association of reinforcement with light stimulus rather than with merely holding the lever down for a fixed period. On the seventeenth training session, this delay was fixed at 5 seconds for the duration of the experiment, and the reinforcement schedule



Figure 1

Wide-angle view of apparatus. The magnetic field was generated by a Helmholtz coil pair wound on the outside of each open-ended plywood box. The Plexiglas cages are 15.5 inches deep, 19 inches high, and 16 inches wide and are centered in the field which is directed axial to the wooden chamber. Squirrel monkeys lived in these cages throughout the experiment and were exposed continuously for 42 days to a field of 10 gauss at 45 Hz.

was changed so that it was controlled by a variable-interval tape puller. The interval in the reinforcement schedule averaged 15 seconds, with a minimum of 2 seconds and a maximum of 52 seconds.

A correct response was defined as a lever release occurring during the 3-second stimulus period. An incorrect response occurred when the lever was released prior to onset of the light stimulus, or when the lever was released after the light stimulus had been automatically terminated. If the reinforcement programmer had stopped advancing and a correct response occurred, a pellet was dispensed. The programmer would also restart when the lever was released following automatic termination of the stimulus; however, no pellet would be delivered.

While additional apparatus was being constructed to accommodate three subjects simultaneously, two 1-hour sessions were conducted to maintain the level of training. At the beginning of the present experiment each subject had worked at the task for a total of sixty-six 1-hour sessions. The present data are based on sessions 67 through 140.

Except for 5 minutes each day when the animals were weighed and their cages replaced with clean ones, they were confined within the coil system throughout the experiment. The experiment consisted of a pre-exposure control period of 23 days, an exposure period of 42 days with a magnetic field of 10 gauss rms at 45 Hz, and a post-exposure control period of 9 days. The subjects worked on the performance task for 1 hour each day during the 74-day experiment. These 1-hour sessions were held at the same time each day.

The following data were recorded: time from illumination of the light panel to lever release, number of correct responses, total responses, body weight, and food intake.

#### Performance Indices

The following three indices of performance were computed from the behavioral data: reinforcement ratio, efficiency ratio, and reaction time.

Reinforcement ratio is the average number of correct responses required to receive one pellet. This ratio is always greater than one; however, it would be theoretically possible to receive a pellet for each correct response if the interval between lever depression, which produces stimuli, is always greater than the longest time interval of the variable-interval reinforcement schedule.

Efficiency ratio is defined as the ratio of correct responses to the total number of responses for one session. The stability of these parameters is directly related to the constancy in rate and manner with which the animal performs the task.

Reaction time is defined as the interval between onset of the light stimulus and release of the lever for all correct responses. The physiological and psychological factors affecting the absolute value of these measurements have not been quantitatively evaluated. The same measurements for human subjects approach the theoretical limit based on neural-conduction velocities, synaptic delays, and contraction time of myofibrils, while the measurements for squirrel monkeys are approximately ten times longer. The differences in these measurements arise from the fact that a human subject can be verbally instructed to strive for a minimum time delay and can easily understand such a concept while the animal must learn by trial and error and the reinforcement schedule must favor shorter delays. As learning progresses, the mean and variance approach values which vary widely among subjects, but for a given subject become reasonably stable. The mean and variance for each session and the session-to-session stability of these reaction-time measurements throughout the pre-, per-, and post-exposure periods are the parameters by which the effects of the ELF magnetic field on reaction time are examined.

## RESULTS AND DISCUSSION

In the precontrol period, the reinforcement ratio (Figure 2) for subject LE was quite stable, while the efficiency ratio (Figure 2) for this period increased steadily from 0.47 to 0.85 and then decreased and appeared to level off at about 0.7. Although this change in efficiency ratio cannot be explained, it is consistent with the subject's previous performance. In a previous experiment (3), her efficiency ratio increased from 0.3 at the beginning of the experiment to 0.67 at the end of the postexposure period.

These long-term changes in efficiency ratio for LE were generally quite orderly, with small changes between sessions. In the present experiment the mean value leveled off, but the changes between sessions were large and very erratic. The beginning of this erratic behavior correlated in time with onset of the exposure period. For the first two sessions immediately after termination of the field, this subject would not touch the lever of the apparatus. She would sit in one corner of her cage, scanning her environment in an apprehensive manner. When she finally resumed work on the third day of the postexposure period, the efficiency ratio was lower than for any previous session. This animal has a history of such behavior when some aspect of her environment is changed. In this case, the change could have been the abrupt cessation of the slight 45-Hz hum generated by the coils. The erratic variation in efficiency ratio during the exposure period cannot be adequately explained. This kind of variation in the exposure period did not occur for the reinforcement ratio or for reaction time (Figure 2). Although some variation in reaction time did occur, it was gradual and did not correlate with exposure.

The performance indices for subject D26 (Figure 3) were reasonably stable throughout the experiment. There were no indications at the onset, during, or at the termination of exposure to indicate a magnetic-field effect.

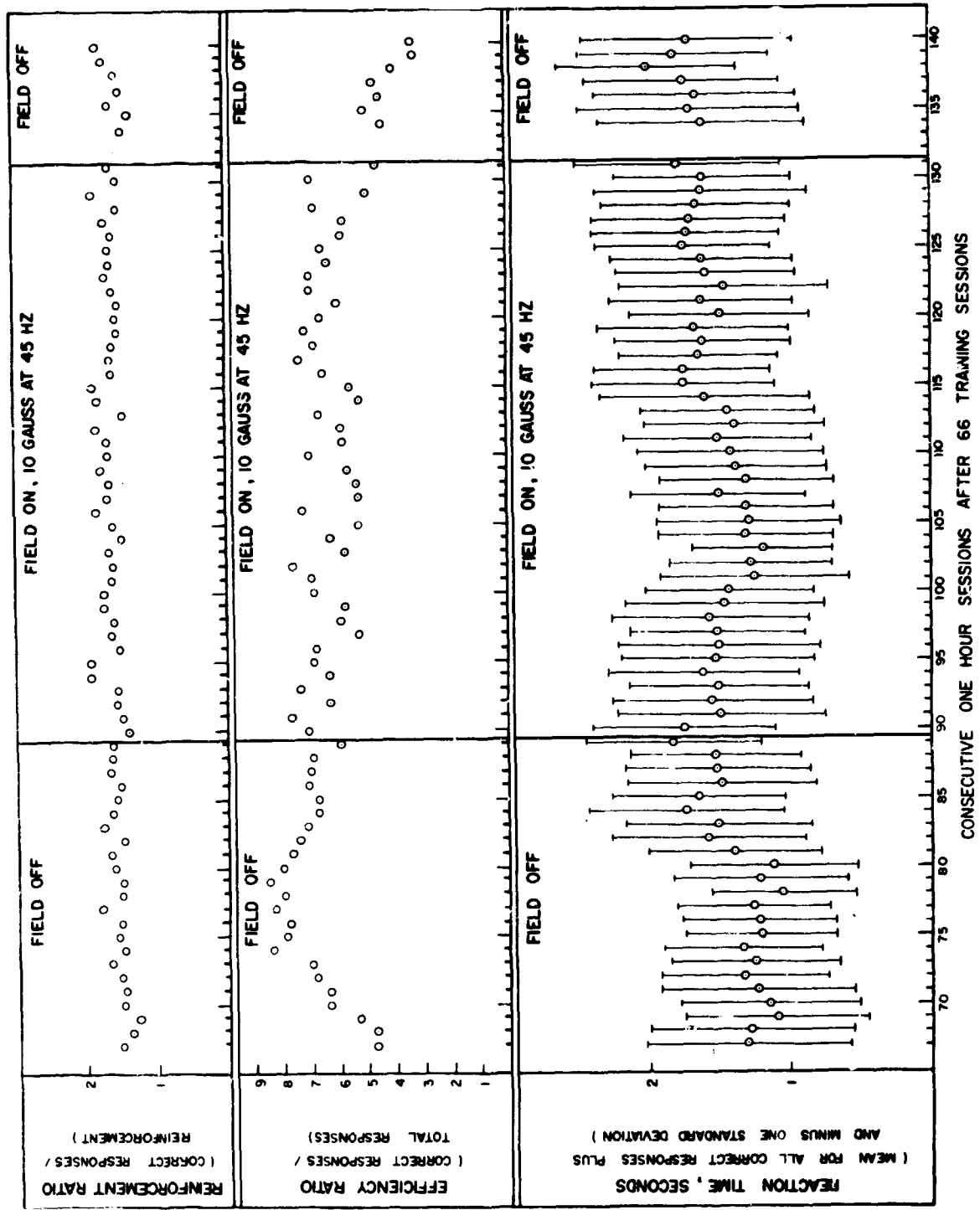


Figure 2

Performance Data for Subject LE

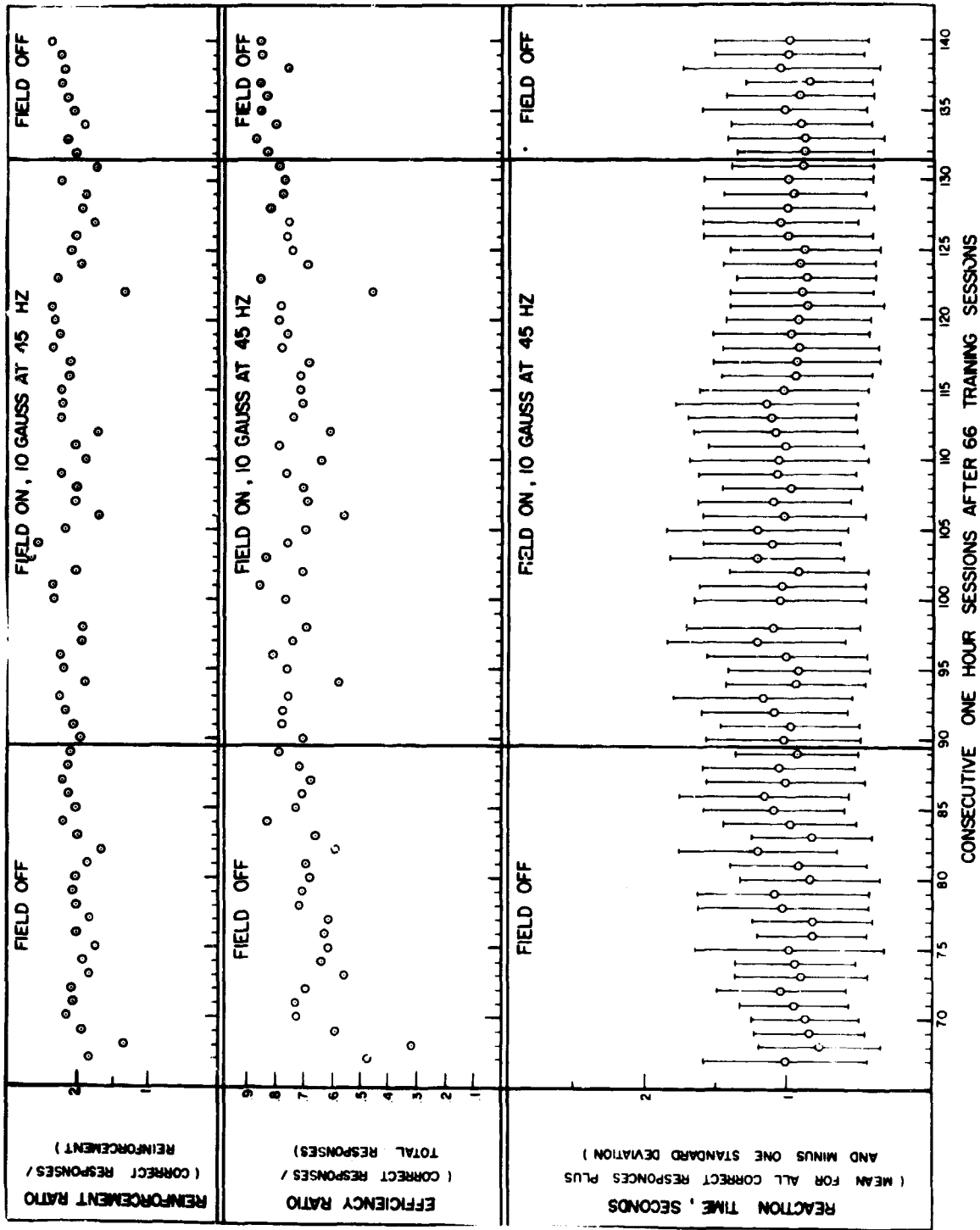


Figure 3  
Performance Data for Subject D26

Subject A88 displayed a consistent trend in all indices throughout the experiment. The reinforcement ratio and the efficiency ratio increased steadily while the reaction time decreased (Figure 4). A magnetic-field effect was not indicated.

In addition to the performance measurements, the animals' food and water intake and body weight were carefully measured. The ratio of food intake to body weight gradually decreased throughout the experiment for two subjects. For LE the ratio decreased from 4.3 per cent to 3.2 per cent, and for A88 the decrease was from 3.5 per cent to 2.6 per cent. This decrease could have been caused by a slow decrease in physical activity. The animals were not only confined, but they were also isolated from visual contact with other animals. This was a considerable change from their previous housing condition, in which they were confined to wire cages adjacent to other squirrel monkeys. The food intake and body weight for D26 were very unstable, and trends similar to those described for the other subjects could not be established.

In conclusion, the central-nervous-system performance as measured by this particular task appears to be insensitive to the specific magnetic-field conditions applied in this experiment. Trends appearing in the data plots could not be correlated with the time course of exposure except in the case of the increased variability of efficiency ratio for subject LE during the exposure period; in this case, the erratic behavior caused by the 45-Hz hum in the coil windings is an alternate and very plausible explanation. The metabolic effects should be further investigated; however, the data in the present experiment showed no immediate changes in trend at the onset or termination of exposure, which means that reduced activity associated with isolation gives a better time-base correlation with observed trends than exposure to the ELF magnetic field. These results indicate that if a physiologically significant ELF effect exists, it is probably quite subtle and will therefore require a broad range of very sensitive experiments to properly evaluate the long-term effects of the ELF environment.

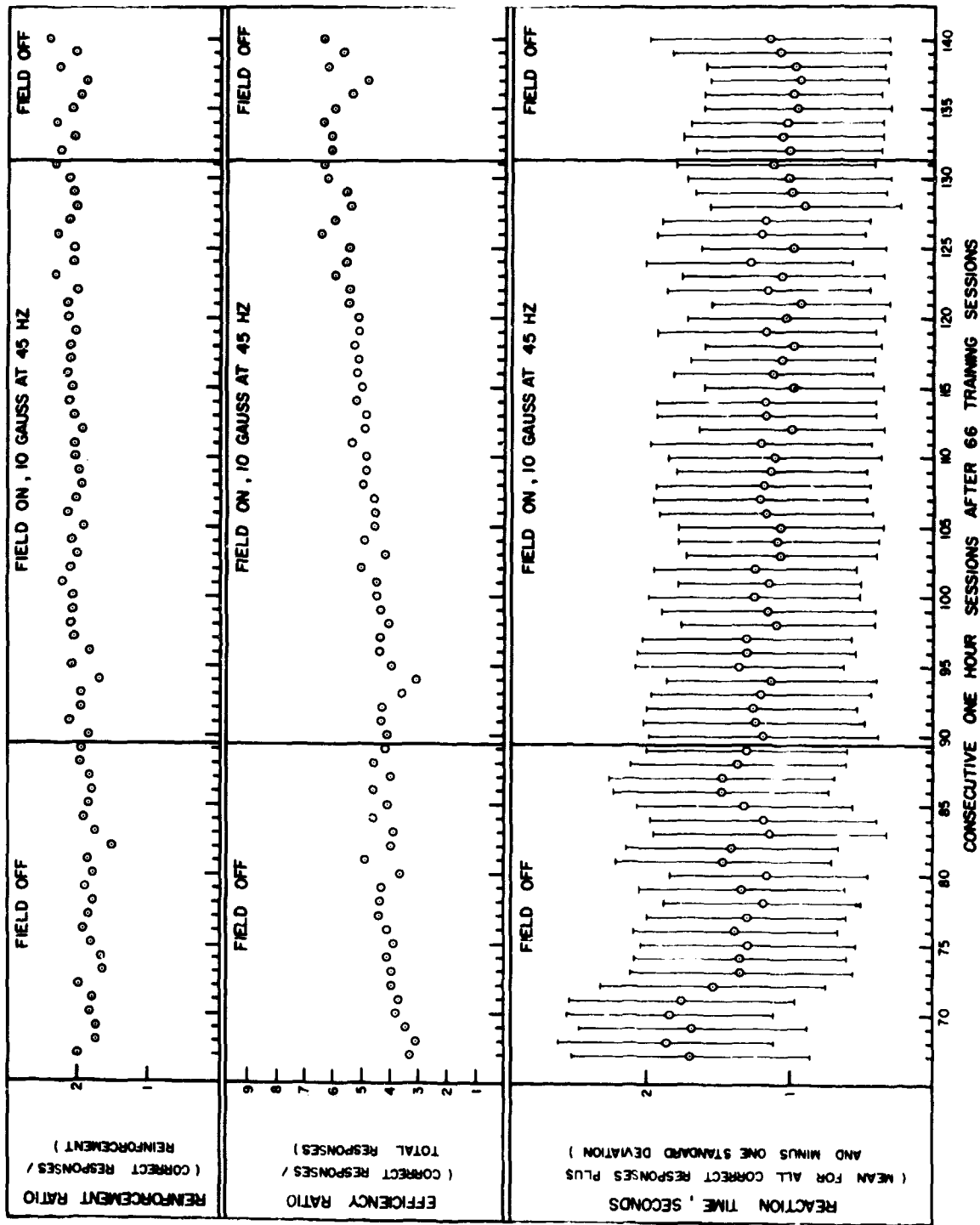


Figure 4

Performance Data for Subject A88

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