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RESEARCH WITH THE PRIMATE EQUILIBRIUM PLATFORM IN A RADIATION ENVIRONMENT

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FOREWORD

The Primate Equilibrium Platform described in this paper was developed by Systems Research Laboratories, San Antonio, Tex., under contract No. AF 41(609)-2724 and task No. RMD1067 (571003). The work was accomplished from January 1967 to September 1967 and was monitored by Donald J. Barnes (then lieutenant), Radiobiology Division, USAF School of Aerospace Medicine. The paper was submitted for publication on 13 May 1968.

The animals involved in this study were maintained in accordance with the "Guide for Laboratory Animal Facilities and Care" as published by the National Academy of Sciences-National Research Council.

The author is indebted to G. Carroll Brown for technical assistance and to Jerry F. Ferguson, James L. Frierson, and Henry J. Bicehouse for the many laborious hours they spent in the training of the primates.

This report has been reviewed and is approved.

George E. Schafer

GEORGE E. SCHAFER
Colonel, USAF, MC
Commander

ABSTRACT

A revised Primate Equilibrium Platform (PEP II) was designed and constructed to further investigate the effects of pulsed ionizing radiation on the equilibrium function. Twenty rhesus monkeys were trained to maintain a platform-horizontal position (± 15°) by the manipulation of a "joy stick."

The experimental animals were transported to the Fast Burst Reactor (FBR) at White Sands Missile Range (WSMR), N. Mex., and were irradiated at that facility. Thirteen of the primates received an approximate midhead dose of 1,000 rads, and 6 received an approximate midhead dose of 2,500 rads. One animal was omitted from the final results owing to a technical problem.

After irradiation, 13 animals were tested for 1 hour and the remaining 6 animals were tested for 3 hours, as these were actually two separate experiments 4 months apart. The major dependent variable was the time spent on "horizontal" per trial.

Results demonstrated a definitive dose-level effect in the occurrence of early performance decrement. The operational significance of this finding, as well as the recovery phenomenon seen in all cases, indicates the importance of continued research in this area.

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I. INTRODUCTION

As nuclear weaponry becomes more advanced and particularly as it becomes more available, knowledge of radiation environments increases in importance. Also, as the probability of needing such knowledge for military planning increases, basic research must of necessity be replaced by, or at least subordinated to, research designed to more practical and probable ends. The scientist, while pursuing an understanding of basic processes, must strive to formulate generalizations which have applied value to actual situations even if such generalizations are based upon scanty evidence. A complete and detailed understanding of the effects of irradiation upon an embryo or upon chromosomal structure is a goal of great importance to the geneticist, but is all but worthless to the field commander whose men are deployed in a nuclear environment. Likewise, for the behavioral scientist, while it is intriguing to determine that chronic irradiation of a primate colony affects the social interaction between members of that colony, this knowledge adds little to the solution of the field commander's immediate dilemma.

The approach taken by this laboratory to a solution of these problems is direct and as closely tied to operational reality as possible. Analysis of mission profiles yields knowledge of behavior expected of military personnel. Categorization of this behavior into its cognitive and psychomotor aspects and the determination of the relative levels of complexity involved in each, provide a working framework. The application of these criteria to tasks devised for experimental subjects (primates) bridges the gap between the laboratory and the field.

Although rhesus monkeys cannot perform those tasks expected of military personnel, their behavior can be categorized in an analogous manner and subsequent predictions will aid in establishing the relationships between these categories of behavior and the effects of irradiation.

This paper reports on two very similar experiments conducted at the Fast Burst Reactor, White Sands Missile Range, N. Mex., with a total of 20 monkeys *(Macaca mulatta)* trained to the Primate Equilibrium Platform (PEP). The PEP, discussed in a previous paper by this author (1), was modified in order to refine stimulus control within the system for the present experiments. The initial PEP (PEP I) was controlled entirely by the primate, each response being an overcorrection of the response immediately preceding it. Also, the manipulandum (i.e., "joy stick") was mounted to the primate's right; this position was somewhat unwieldy for the monkey.

II. DESIGN OF PRIMATE EQUILIBRIUM PLATFORM

A new and upgraded Primate Equilibrium Platform (PEP II) was utilized in these experiments (fig. 1). The PEP II was constructed with the "joy stick" mounted directly in front of the primate in order to decrease training time and to increase similarity and

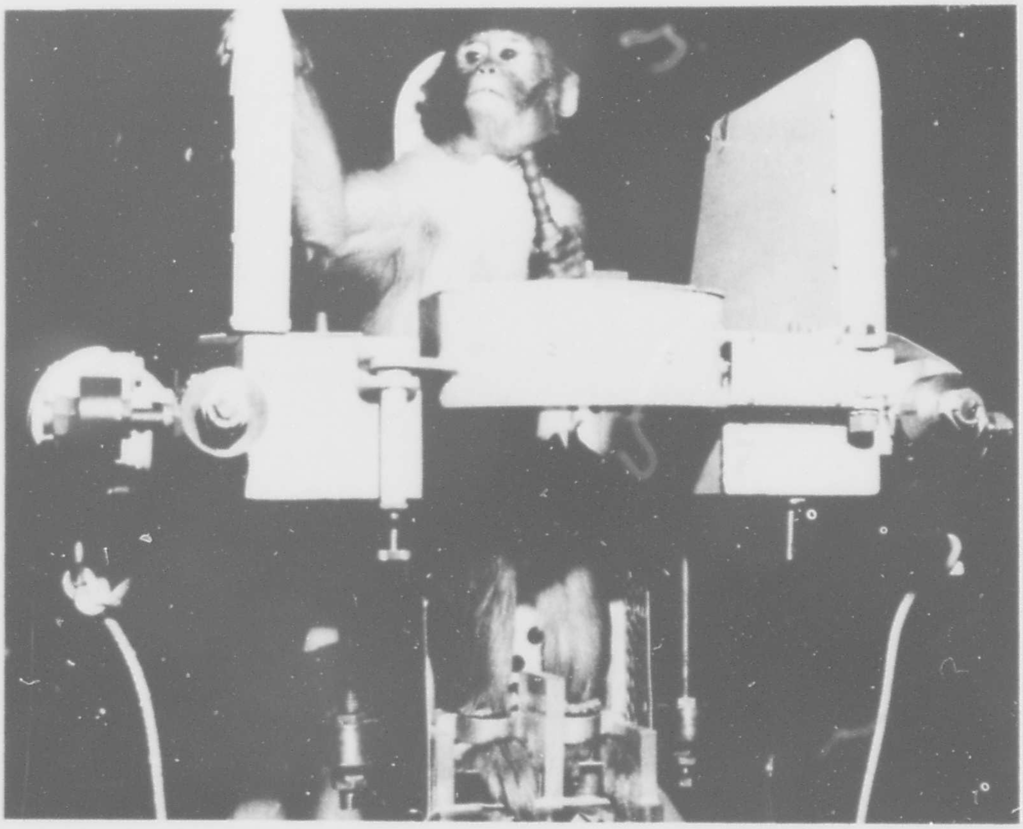

FIGURE 1

Primate seated in PEP II.

subsequent comparability of responses in any direction. The PEP II also incorporated significantly stronger motors in each axis, causing the platform to alter its position very quickly upon movement of the "joy stick." The most important change between PEP I and PEP II was the addition of stimulus-input programing contingencies. The PEP II can be programed either manually by the experimenter, through two Hewlett-Packard function generators (one for each mode), or through a taped program from an Ampex SP100 magnetic tape recording unit. Rather than maintaining the horizontal position by responding to overcorrections, the primate must "track" the incoming signals to the platform. This task has been categorized as highly complex in terms of its psychomotor components.

The PEP II is monitored by a 7-channel Ampex magnetic tape recorder. Channels 1, 2, and 3 are used to record, in analog form, the input signal to the platform, the primate's response to the stick (stick movement), and platform movement (position in space) in the pitch mode, respectively. Channels 4, 5, and 6 are utilized in measuring the same parameters in the roll mode. Channel 7 is free for voice monitoring by the experimenter. A separate monitoring unit of digital logic (Behavioral Research Systems) records the time-off-horizontal for each trial.

The input signals can be varied with respect to (1) amplitude, (2) frequency, and (3) waveform. Either the sinusoidal, square, or triangular waveform can be generated by the function generators for each mode individually. Differential waveforms for each mode are therefore possible. By altering waveforms, frequencies, and amplitudes of signals, it is relatively simple to present the primate with an unpredictable task. While this task is certainly a basic approximation of man's probable behavior in a weapons system, it appears more germane to behavioral extrapolation than do many of the more traditional behavioral schedules.

The PEP is projected for use in several experiments to obtain a relatively large number of subjects at various radiation levels and under varying experimental conditions, these factors to be determined by mission analysis. A desired advantage of the PEP and this type of research concerns its deviation from the usual all-or-none responding, in the sense that close control of stimulus input and precise recording of response contingencies may interact to yield data reflecting subtle changes in behavior as well as the more dramatic and debilitating effects of pulsed ionizing radiation. Certainly the concepts employed in this type of experimentation are relevant to the applied prediction of postirradiation behavior in that the particular cues utilized by the subject in the performance of this task are vital ones to mission accomplishment for man.

Preliminary analyses of mission profiles demonstrate the necessity of examining postirradiation behavior for a period up to and including 12 hours. Although early research with the PEP, as well as the results contained herein, does not encompass such a lengthy postirradiation observational period, future plans are to extent observations up to and including 12 hours postirradiation with work-rest cycles programed on the basis of mission analysis.

III. MATERIALS AND METHODS

Subjects

Experiment 1. Fourteen adolescent rhesus *(Macaca mulatta)* monkeys drawn from the animal colony maintained by the USAF School of Aerospace Medicine were chosen at random and trained to criterion level on negative reinforcement. This group included 6 females and 8 males. One female was dropped from the final experimental results because of a technical problem (reactor preignition). The final subject group, therefore, was composed of 8 male and 5 female monkeys, weighing between 7 and 9 pounds.

Experiment 2. Six rhesus monkeys chosen in the manner described above and trained in an identical fashion were utilized in the second of the two experiments reported herein. All 6 of the monkeys were females, and their weights ranged between 6 and 8 pounds.

Materials

The basic equipment employed in this study was a PEP designed and constructed by Systems Research Laboratories (SRL) and supplementarily programed with solid state circuitry manufactured by Behavioral Research Systems (BRS). The task for the primate was to "pilot" the platform by manipulating a "joy stick" and to thereby maintain a relatively horizontal position. The PEP II allows variation in deviation from the horizontal position as a criterion. In the studies reported here, the shock angle was set at a 15° deviation from the horizontal.

Negative reinforcement was automatic when the deviation from the horizontal was greater than 15°. Platform speed was constant for all animals at approximately 90° rotation per 3 seconds—e.g., from 45° pitch forward to 45° pitch backward. The shock level was constant for all subjects at 10 ma. at 280 volts. The shock was delivered to the soles of the primate's feet by means of a spring-loaded footplate adaptable to the training couch.

The primate couch (fig. 2) was of aluminum construction and restrained the primate at three points: (1) neck, (2) waist, and (3) ankles. The couch held the primate in an upright seated position with his arms and hands free at all times.

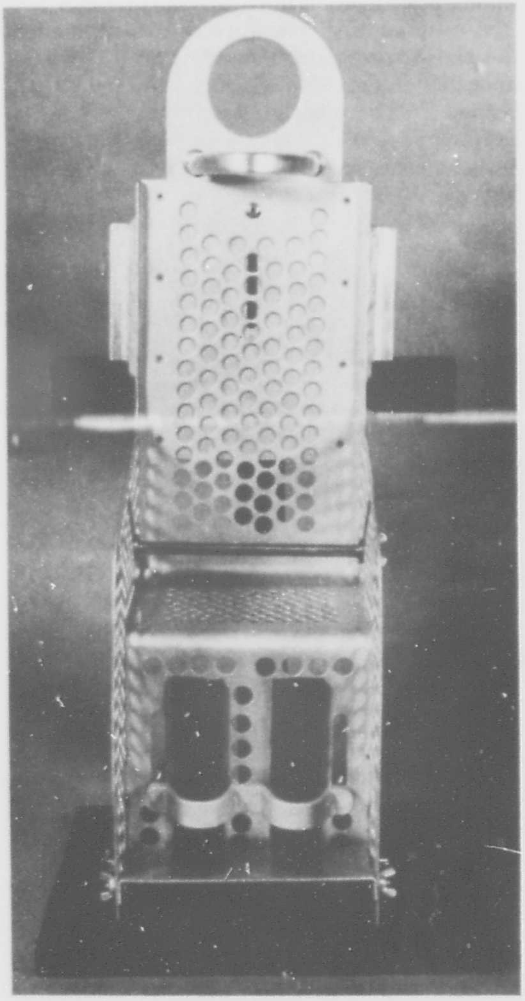

FIGURE 2
Primate restraining couch.

Procedure

Each primate was adapted to restraining couches for a minimum of 4 hours before conditioning. Conditioning procedures were identical to those described in an earlier paper (1).

The training of the 14 primates utilized in experiment 1 was continued until each primate could maintain platform-horizontal for 1½ hours of continuous performance. A measure was taken every 5 minutes, and performance of less than 99% efficiency during any one trial marked the animal as untrained. When the criterion level was reached, each primate was maintained at this level until the experimental procedure was completed.

In the second experiment reported, the 6 primates were trained to maintain platform-horizontal for 3½ hours without a rest period. Data were also gathered on these primates every 5 minutes, and the criteria for training were identical to those used in experiment 1. Subjects in both experiments performed for 30 minutes prior to irradiation and for 1 hour (experiment 1) or 3 hours (experiment 2) after irradiation. Subtle changes in time attributable to fatigue effects were noted during early training but were not significant at any time, and fatigue was felt to be a negligible factor influencing the final results.

In experiment 1, all animals were trained to a constant amplitude, a frequency of 0.3 Hz per second in the pitch mode and 0.4 Hz per second in the roll mode. The only change in experimental conditions between the two groups was the different type of wave used in training. The 14 animals in experiment 1 were trained to the square-wave input and tended to respond with quick sporadic movements to the stimulus input. Subjects in experiment 2 were trained to the same amplitudes and frequencies but to the sine wave rather than to the square wave. They moved more smoothly, were trained more quickly, and showed fewer effects of fatigue during early training. The 6 animals in experiment 2 were required to perform for a significantly longer period after irradiation and were therefore subjected to longer training-baseline runs which could have served to provide more stable behavior during the 1-hour postirradiation period, although this was not reflected by the data.

The subjects in experiment 1 were randomly divided into two groups of 7 animals. One group received an average midhead dose of 1,000 rads, while the 6 animals in the second group (1 animal was omitted because of reactor preignition) received an average midhead dose of approximately 2,500 rads. The 6 animals in experiment 2 all received an average midhead dose of 1,000 rads. The neutron-to-gamma ratio for both experiments approximated 6 to 1.

In an attempt to obtain further observational data, 2 subjects in experiment 2 were exposed to a second burst after the 3-hour postirradiation period. Their performance after the initial radiation was excellent and at no time differed significantly from baseline performance. Perhaps surprisingly, this performance was maintained at the same high level after a second dose of 1,000 rads. These 2 subjects were followed for 1 hour after the second burst and were then removed from the experimental apparatus.

Reactor environment

The Fast Burst Reactor at White Sands Missile Range was utilized for these experiments. This facility delivers a pulsed ionizing dose within a 40-μsec. half-width. For a more specific technical description of this reactor, the reader may refer to the "Nuclear Effects Laboratory Technical Report on Radiation Facilities," published at White Sands in December 1963.

The Equilibrium Platform was placed on a stand in order to position the subject's head in a direct line with the center of the fuel element. The electrical power to the Equilibrium Platform was controlled by the reactor operator in order to insure minimum movement at the moment of burst. Power was on within 1 second of the actual burst.

Each burst is accompanied by a rather loud and sharp explosive report. A tape recording was made of the entire burst procedure at 1 m. from the reactor and was part of the animal's adaptation during training. Although the recording was rather loud and created a chaotic auditory environment, this noise had no noticeable effect upon any of the primates either during training or during the actual experiments.

Dosimetry

Dosimetry measurements were made by Edgerton, Germeshausen, and Grier, Inc., Santa Barbara Laboratory, Calif., by the Radiobiology Division of the USAF School of Aerospace Medicine, and by White Sands Missile Range.

IV. RESULTS

Experiment 1

Figure 3 demonstrates the average pre- and postirradiation response of all animals in experiment 1. A significant early performance decrement followed by complete recovery was observed in 4 of the 6 subjects receiving an approximate midhead dose of 2,500 rads. The remaining 2 subjects in this group demonstrated a slight but insignificant increase in response variability, but maintained criterion performance throughout the 1-hour postirradiation period. The mean time-on-horizontal per 5-minute period appeared to be the most meaningful measure of general functional capability.

For the 1,000-rad group in experiment 1, only 1 subject out of 7 demonstrated a significant early performance decrement after irradiation. Although this animal's data, in conjunction with the remaining 6 animals, had a major effect upon the mean scores, figure 3 demonstrates graphically the close correspondence between baseline and postirradiation behavior of this group. Omission of the single "nonresponder" from postirradiation data yielded no distinguishable differences between baseline and postirradiation curves.

Experiment 2

The time-on-horizontal curves for the 6 subjects in this experiment administered 1,000 rads midhead are shown in figure 4. Again, a single subject demonstrated an early performance decrement which was very transitory but highly debilitating for a short period of time. Inclusion of the performance of this subject caused the drop noted in the postirradiation curve, which does not appear without the

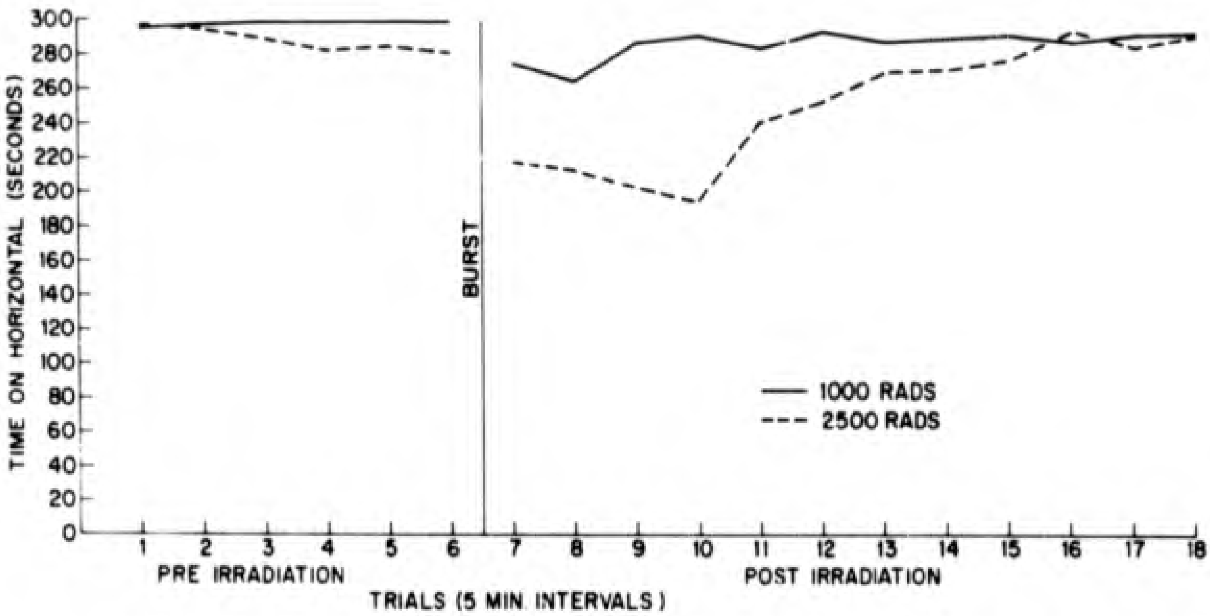

FIGURE 3

Experiment 1. Mean time-on-horizontal per trial (5 minutes).

scores obtained on this single "nonresponder." Even so, the mean curve does not appear to differ from the preirradiation curve.

Because of the relatively small number of subjects per group, the data for both experiments were combined in order to accomplish a chi-square test for significance of difference in number of "responders" (those subjects which did not demonstrate a significant deviation from baseline performance at any time throughout the 1-hour postirradiation period) and "nonresponders" (those subjects demonstrating a significant diminution of performance during any given time period). The difference was significant between dose levels ($P < .05$). This grouping assumes an equality between all subjects receiving 1,000 rads midhead, which is valid except for the difference in signal input. As the performance, both pre- and postirradiation, of the subjects in these groups closely corresponded and since the task remained almost identical, this assumption is felt to be justified in order to gain a broad perspective of the data.

The chi-square matrix therefore is as follows:

	1,000 rads	2,500 rads
Nonresponders	2	4
Responders	11	2
Total subjects	13	6

V. DISCUSSION

The results of the two experiments reported herein, as well as the data gained on an earlier study with the PEP (1), demonstrate a striking difference in response to doses of 1,000 rads and 2,500 rads. At the lower dose level, it appeared that only a small percentage of subjects were severely affected and then for only very short periods of time, whereas the higher dose level of 2,500 rads appeared to effect a more general and severe degradation of performance. The obvious differences noted between these dose-level responses provide a definition for both the threshold and the relative upper limit of radiation effects upon this particular behavior.

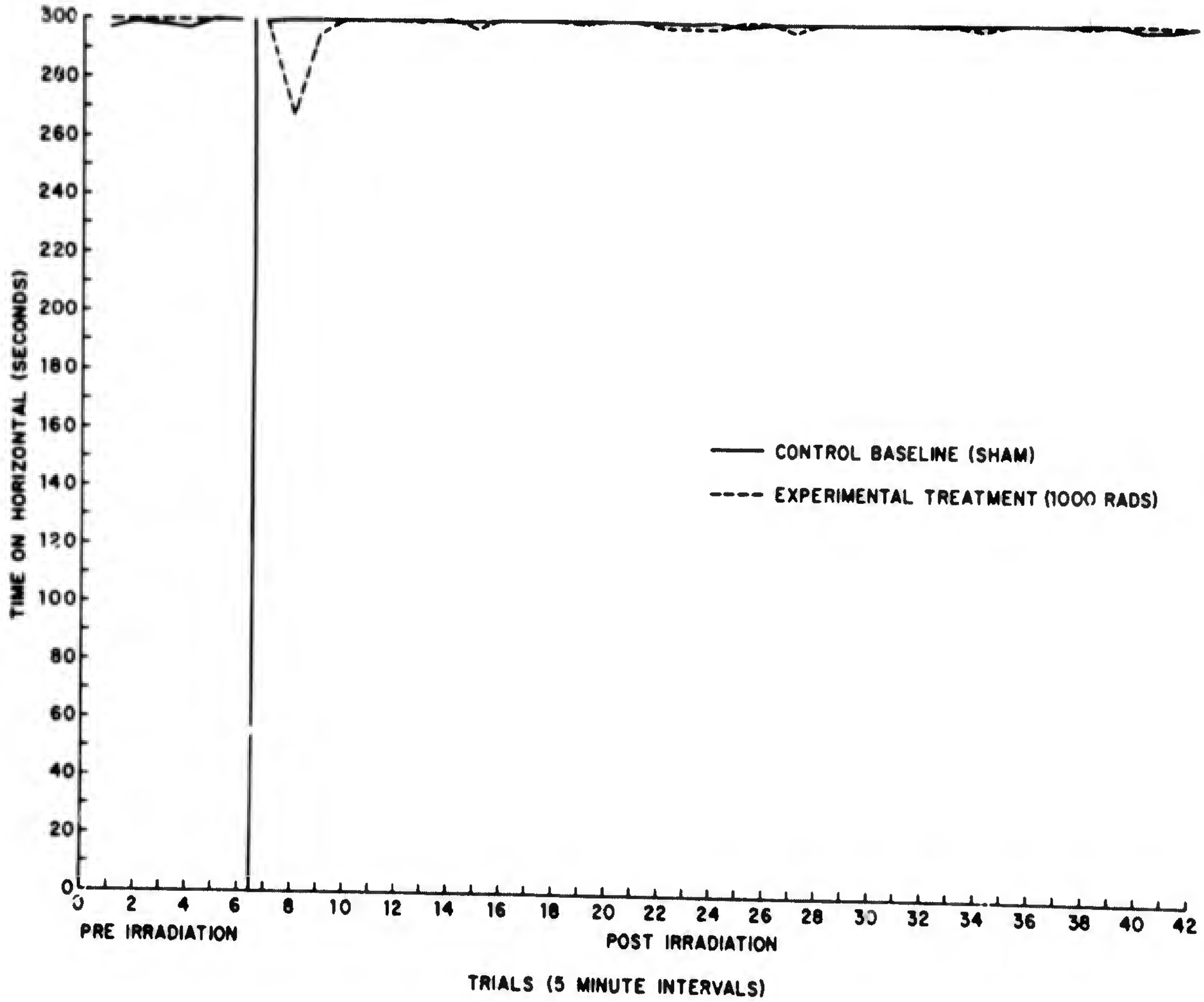

FIGURE 4

Experiment 2. Mean time-on-horizontal per trial (5 minutes).

The mechanism of damage in the demonstration of performance decrement with the PEP is of some interest. Pilot studies have suggested that the integrity of the visual modality is practically, if not entirely, unnecessary for the maintenance of performance capability on the PEP. To investigate this hypothesis, a group of primates trained to perform under a hood will be subjected to radiation to differentiate between their postirradiation response and that of primates performing as did the subjects in this paper.

Experiments projected for the more distant future include the increase of stimulus input, the lengthening of the postirradiation observational period, and the addition of tasks to the primate's basic task of maintaining a horizontal attitude. As the PEP is indirectly analogous to a "tracking" task, an experiment is planned to investigate the effect of radiation upon the identical response to a visual stimulus. Primates seated in the PEP will be faced with an oscilloscope which will provide the means of stimulus presentation. The PEP will be locked on horizontal. The primate's response to the "joy stick" will be to the visual stimulus alone and will correspond in the dimensions of frequency and amplitude to the response required of the subjects in this paper. By examining the primate's postirradiation response to this task, the effects of irradiation on differential perceptual functioning can be evaluated.

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