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THE EFFECT OF EXTREMELY LOW FREQUENCY RADIATION ON HUMAN PERFORMANCE: A PRELIMINARY STUDY

Richard S. Gibson, et al

Naval Aerospace Medical Research Laboratory

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Richard S. Gibson
William F. Moroney

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Interest in the development of an extremely low frequency (ELF) communications system for naval use has resulted in a program to determine the effects of such fields on man. This report represents part of pilot level effort to develop a set of tests and procedures for determining whether ELF fields have any measureable effects on human memory and psychomotor functions.

Four tests were used to measure performance before, during, and after a 24-hour exposure to a low intensity magnetic field of $10 \cdot 4$ Wb/m^2 Hz. The tests used were: The Response Analysis Tester (RATER), the simplified electronic tracking apparatus (SETA), the Wilkinson Adding Task, and the Minnesota Rate of Manipulation Test (ROM). The results were analyzed at three levels: (1) a gross analysis by test type comparing the performance measures obtained before, during, and after ELF exposure; (2) a micro analysis of the trial-by-trial performance changes for each of the tests; and (3) a test session by test session analysis of performance for each of the experimental subjects.

None of the tests exhibited significant performance decrements under the gross analytical conditions. The Wilkinson Adding Task exhibited significant performance decrements during the second of two testing sessions while being exposed to the ELF radiation. One of the RATER conditions exhibited a significant improvement in performance. One subject had a significantly bad session in which his performance declined on 6 out of 7 measures; however, this performance appeared to be unrelated to other psychological or physiological data.

In view of the large number of statistical analyses performed on a limited amount of data, the few significant performance decrements must be interpreted with extreme caution. They identify techniques to be replicated in future research and nothing more. Individual differences in test performance were large, any effects due to the exposure to ELF magnetic fields were small; consequently, special consideration should be given to the possibility of using an exposure-reexposure experimental design in any future experiments.

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R. S. Gibson and W. F. Moroney

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Approved by

Ashton Graybiel, M.D.
Assistant for Scientific Programs

Released by

Captain N. W. Allebach, MC, USN
Officer in Charge

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Naval Aerospace Medical Research Laboratory
Pensacola, Florida 32512

SUMMARY PAGE

PROBLEM

Interest in the development of an extremely low frequency (ELF) communications system for naval use has resulted in a program to determine the effects of such fields on man. This report represents part of a pilot level effort to develop a set of tests and procedures for determining the effect of ELF fields on human cognitive and psychomotor functions.

FINDINGS

Four tests were used to measure performance before, during, and after a 24-hour exposure to a low intensity magnetic field of $10^{-4} Wb/m^2$ at 45 Hz. The tests used were: the Response Analysis Tester (RATER), the simplified electronic tracking apparatus (SETA), the Wilkinson Adding Task, and the Minnesota Rate of Manipulation Test (ROM). The results were analyzed at three levels: (1) a gross analysis by test type comparing the performance measures obtained before, during, and after ELF exposure; (2) a micro analysis of the session-by-session performance changes for each of the tests; (3) a test session by test session analysis of performance for each of the experimental subjects.

None of the tests revealed significant performance decrements under the gross analytical conditions. The Wilkinson Adding Task uncovered significant performance decrements during the second of two testing sessions while being exposed to the ELF magnetic field. One of the RATER conditions exhibited a significant improvement in performance. One subject had a significantly bad session in which his performance declined on 6 out of 7 measures; however, this performance appeared to be unrelated to other psychological or physiological data.

In view of the large number of statistical analyses performed on a limited amount of data, the few significant performance decrements must be interpreted with extreme caution. They identify techniques to be replicated in future research and nothing more. Individual differences in test performances were large, any effects due to the exposure to ELF magnetic fields were small; consequently, special consideration should be given to the possibility of using an exposure-reexposure experimental design in any future experiments.

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INTRODUCTION

The proposed installation of a communications system which produces an extremely low frequency field (45 to 75 Hz) of low intensity (magnetic field strength of 0.02 mT; electric field strength of 0.06 V/m) has raised questions regarding the effects of such radiation on man. The Biomedical Division of this Laboratory, under the direction of Dr. Dietrich E. Beischer, is engaged in a research program to determine whether man can be safely exposed to electric and magnetic fields in the extremely low frequency region of the spectrum below 100 Hz. This report represents a specialized subset of a much broader multiple disciplinary pilot study and is concerned with procedures to measure the effects of ELF fields on selected aspects of human performance--specifically, cognitive and psychomotor performance. A more comprehensive report with special emphasis on the physiological effects of ELF magnetic fields has been published by Beischer, Grisset, and Mitchell (2).

An earlier survey of the available literature by Beischer (1) revealed that no investigation had been performed at the same frequencies and intensities as those peculiar to the communications system under consideration. However, this survey noted some anecdotal evidence which attributes a rather ambiguously defined neurasthenic syndrome (general weakness, fatigue, laziness, sleepiness in daytime, etc.) to individuals who have had prolonged exposure to ELF. The same source also reported that decrements in performance resulting from exposure to ELF include: difficulty in concentrating, reduced memory capability, and reduced intellectual capacity. These symptoms evolved primarily from crude clinical observations based upon heterogeneous samples (e.g., electric power station workers) "naturally" exposed to undefined levels of ELF fields over uncontrolled periods of time. These symptoms were used as the basis of selecting a set of tests to examine the following variables: (1) decision-making and short-term memory; (b) coordination and dexterity in continuous and discrete modes; (c) long-term memory and concentration. Since the apparatus was to be used in an ELF magnetic field, devices (particularly CRTs) influenced by the presence of magnetic fields could not be used, nor could devices which would seriously distort the field by creating shadows or reflecting energy (large racks or consoles). All of the tests were selected on the basis that they would measure the desired psychological functions, that they would be sufficiently challenging to be sensitive to small experimentally induced performance decrements, and that they would retain these properties under conditions requiring repeated usage.

APPARATUS

Four devices were selected for use in the experiment: decision-making and short-term memory, the Response Analysis Tester (RATER); coordination and

dexterity in a continuous mode, the simplified electronic tracking apparatus (SETA); coordination and dexterity in a discrete mode, Minnesota Rate of Manipulation Test (ROM); long-term memory and concentration, the Wilkinson Adding Task (Addition). Each device and the experimental procedures employed in its use will be presented in a separate section.

Response Analysis Tester (RATER Model III). The RATER provided a mean for detecting response impairment of decision-making and short-term memory. It has been used in a number of exotic environments (4, 10, 11, 12). The RATER pictured in Figure 1 is manufactured by Convair Division of General Dynamic and is described fully in their operating instructions (7). The RATER was used to present pattern stimuli (+, ○, □, △) to the subject at the rate of one every 1.5 seconds or 40 per minute. All stimuli were presented randomly on a single plane readout display located on the subject's response unit. The subject was instructed to respond as rapidly as possible by depressing the appropriate button. Since switches on the response unit were not labeled the subject was required to memorize the appropriate response pattern which was made available to him. After the pattern had been learned the instructional material was removed. The counters on the control unit provided the following data to the examiner: number of presentations, number of responses, and number of correct responses. After each trial, the data were recorded and the counters were manually reset to zero.

An experimenter controlled delay mode was utilized to determine the effect of ELF fields on short-term memory. This delay mode required the subject to retain in memory a sequence of symbols before he responded. There are four delay mode options: zero-delay, one-delay, two-delay, and three-delay. In the zero-delay mode the subject responded to the symbol currently being presented. In the one-delay mode the subject responded to the symbol immediately prior to the symbol being presented. In the two-delay mode the subject responded to the symbol two presentations prior to the symbol currently being presented. In the three-delay mode the subject responded to the symbol presented three presentations prior to the symbol presently displayed on the screen. The more symbols he was required to keep in memory, the more difficult the task.

Simplified Electronic Tracking Apparatus (SETA). The SETA provides a compensatory tracking task which requires the subject to maintain the pointer of a zero centered meter at the null position by manipulating a control device. (Compensatory tracking tasks have been utilized in aviation and aerospace research (8) to measure decrements in performance. The device used in this experiment, see Figure 2, is a modified version of the apparatus designed by Gain and Fitts (6). In this experiment a single axis displacement joystick (a modified model 521, 2 axis joystick manufactured by Measurement Systems, Inc.) was substituted for

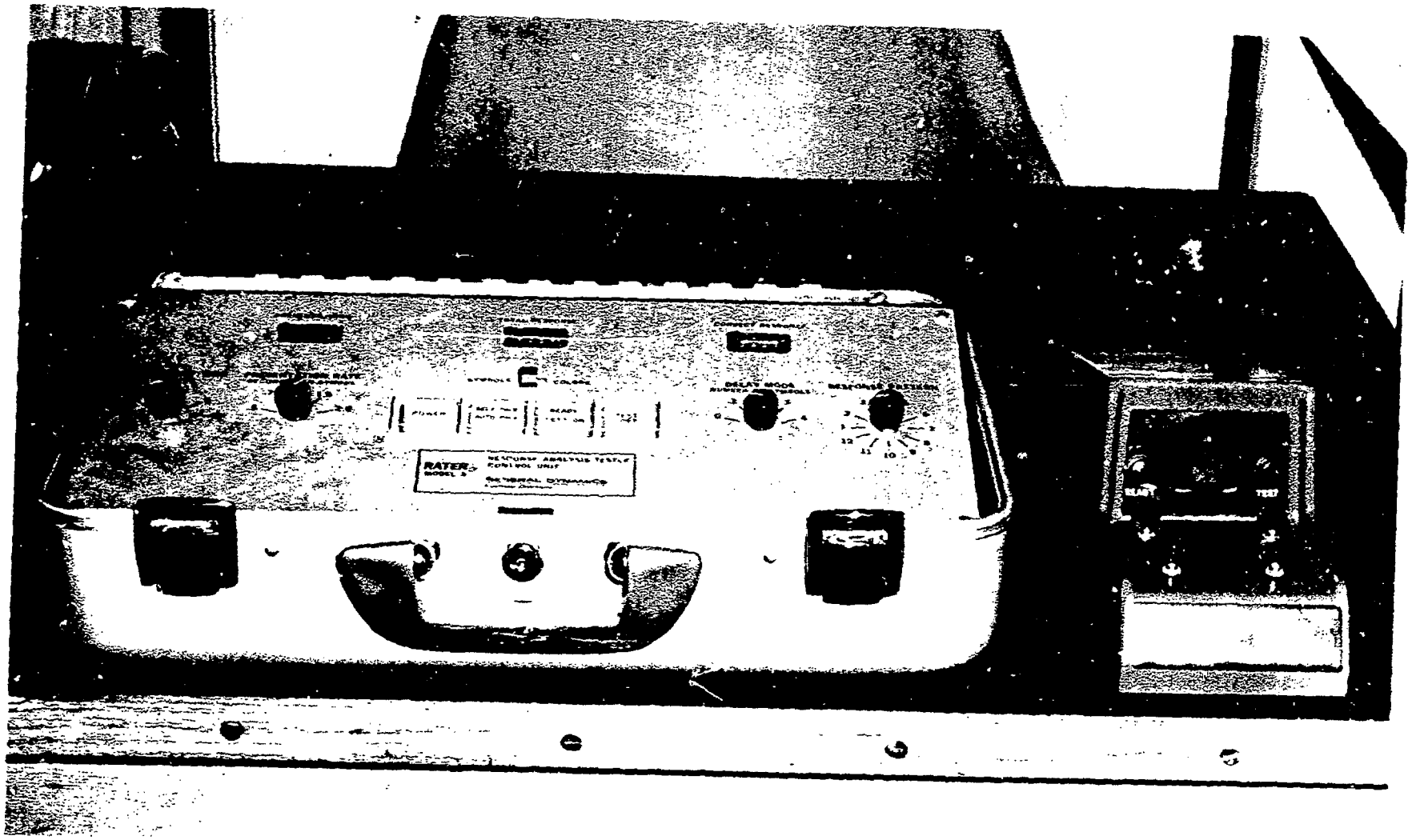

Figure 1

Response Analysis Tester, Model III (RATER)

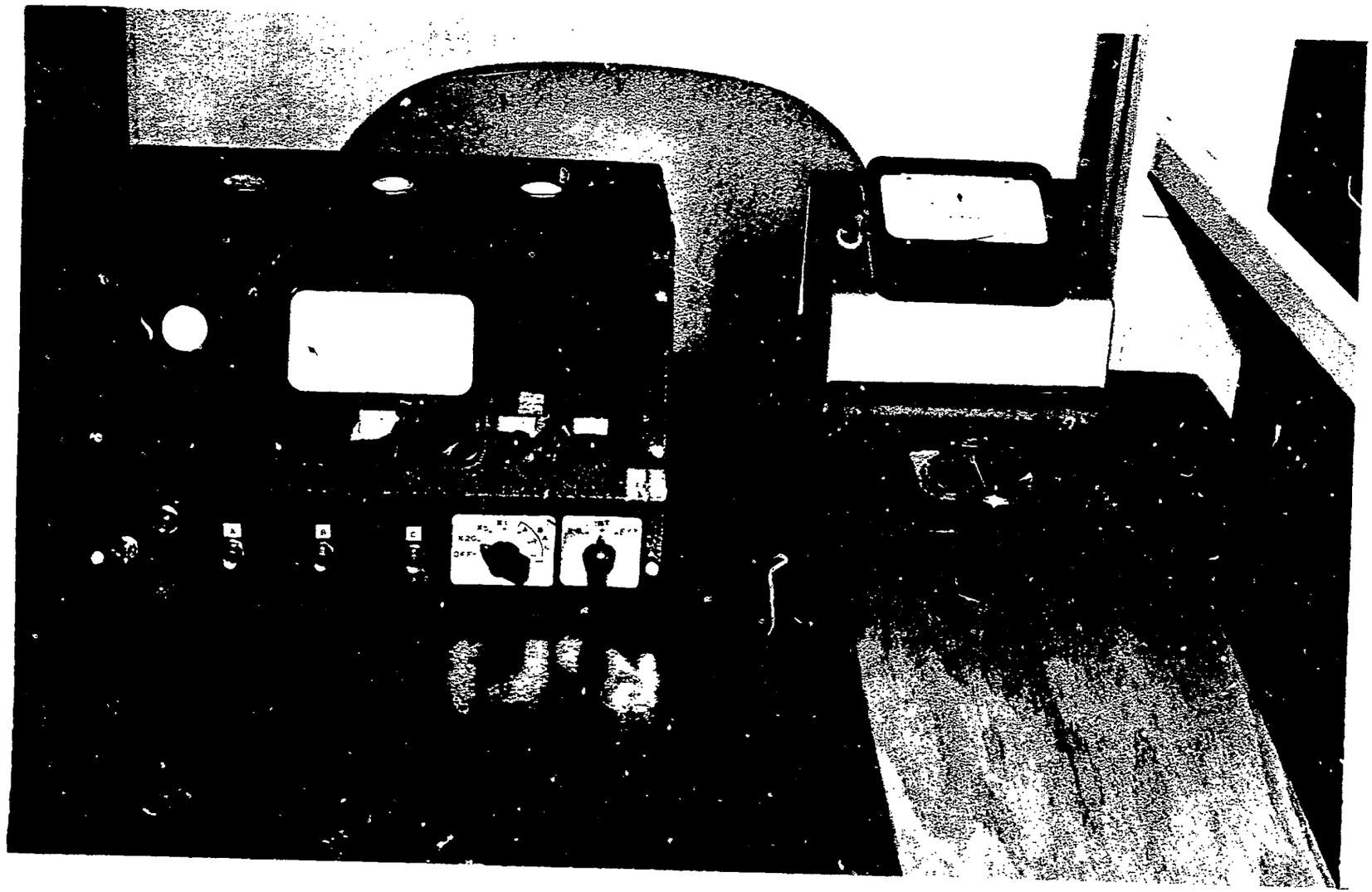

Figure 2

Simplified Electronic Tracking Apparatus (SETA)

the control device used by Gain and Fitts. The movements of the meter-pointer were induced by a voltage across a potentiometer driven by a rotary cam, which created a sinusoidal input. An analog computer determined integrated absolute error which was displayed on the experimenter's control panel. As is common practice with compensatory tracking tasks, part of the subject's error was fed back as an input to the system. The difficulty of the task was controlled by the amount of the subject's error fed back into the problem generator. An additional option provided for the reversal of the relationship between the control and the display such that inputs which formerly drove the pointer to the left would now drive the pointer to the right and vice versa.

The subject was tested under four conditions: 1) little error fed back, normal control-display relationship; 2) most error fed back, normal control-display relationship; 3) little error fed back, reverse control-display relationship; and 4) most error fed back, reverse control-display relationship.

Wilkinson Adding Task (ADDITION). The Wilkinson Adding Task was used to measure long-term memory and ability to concentrate. It has been shown to be sensitive to the effects of sleep deprivation (9). The task consists of the addition of sets of five two-digit numbers. The subject was instructed to complete correctly as many additions as possible within a one minute period. Each test session consisted of five consecutive one-minute periods. A new addition form was used for each test session.

Minnesota Rate of Manipulation Test (ROM). The ROM was used to measure the coordination of the eyes with arm-hand manipulation. The timed "Turning Test" presented in Figure 3 required the subjects to remove the blocks from the holes with one hand, turn them over with the other hand and replace them in the same holes, moving from block to block as rapidly as possible. Four trials were administered in succession with a 15-second break between trials. The amount of time required for the completion of each trial was recorded and the score assigned was the time in seconds to complete the four trials.

This test has been reported by Bourassa and Guion (3) to be heavily loaded as a manual dexterity task. Fleishman and Ellison (5) report similar findings but with lesser loadings.

Figure 3

Minnesota Rate of Manipulation Test (ROM)

SUBJECTS

The subject population consisted of eleven male volunteer subjects between the ages of 19 and 28. The six experimental subjects were all officers or officer candidates. The five control subjects included three enlisted men. Prior to commencing the experiment potential subjects were interviewed and advised of the nature of the experiment. Those still wishing to volunteer were then subjected to a rigorous physical examination to determine that all of their biological functions were within the normal range. After successful completion of the interview and physical, the subjects were introduced to each task.

PROCEDURE

Due to the size of the testing facility, and the amount of test equipment available, only two subjects could participate during each replication of the experiment; therefore, on most occasions, they commenced the practice session in pairs, and were alternately tested in blocks of trials on each of the 4 tasks. Blocks of trials for each particular task were distributed throughout the practice session. The practice schedule for the subjects is presented in Table 1.

Table 1

Practice Session for Each Subject

	No. of Blocks	No. of Trials Per Block
RATER		
Self Paced	1	2
0 Delay	1	2
1 Delay	1	2
2 Delay	1	2
3 Delay	1	2
Self Paced, 0 Delay, 1 Delay, 2 Delay and 3 Delay.	2	1
SETA		
Little error, normal control.	1	5
Most error, normal control/most error, reversed control.	3	2 to 3
ROM	2	2
ADDITION	1	1

All subjects were advised that the ELF field would be activated at some time during the experiment and that they would not be advised when the field was activated. The field was only activated for a period of 24 hours during the S's 7-day stay in the experimental area. The field was always activated on the third day. The tasks were administered in a sequence such that the two cognitive tasks (RATER and ADDITION) were always separated by one of the psychomotor tasks (SETA or ROM). The basic test administration sequence is contained in Table II. Subjects were tested twice daily--midmorning and afternoon. Each subject was tested under a different schedule. The five control subjects used the same test schedule but were not exposed to the ELF field.

Table II

Test Administration Sequence

1	SETA	ADDITION	ROM	RATER
2	ROM	RATER	SETA	ADDITION
3	RATER	ROM	ADDITION	SETA
4	ADDITION	SETA	RATER	ROM

RESULTS AND DISCUSSION

Performance on each of the tests will be discussed separately. All figures contain the data collected on ten consecutive trials. Sessions 1 through 3 represent the pre "field-on" conditions, sessions 4 and 5 are during the "field-on" conditions, and finally sessions 6 through 10 are the post "field-on" conditions. It should be noted that while sessions 3 and 4 for the control group fell within the "field on" area their data were not collected under "field on" conditions.

Response Analysis Tester (RATER). Figure 4 contains the results obtained under the four levels of task difficulty--zero, one, two and three delay (or symbols back). As expected, for both groups as task difficulty increased, performance decreased. Experience with the RATER, acquired during the practice sessions, accounts for the practically maximum performance shown by both groups under the zero delay conditions. A repeated measures analysis of variance (ANOVA) indicated that for the zero, one, and two delay conditions there were no significant practice effects, no significant differences between experimental and control groups, and no significant groups by experimental conditions interactions. Use of the Sign test to assess shifts in performance on a session-by-session basis indicated no significant differences for the zero, one, and two delay conditions.

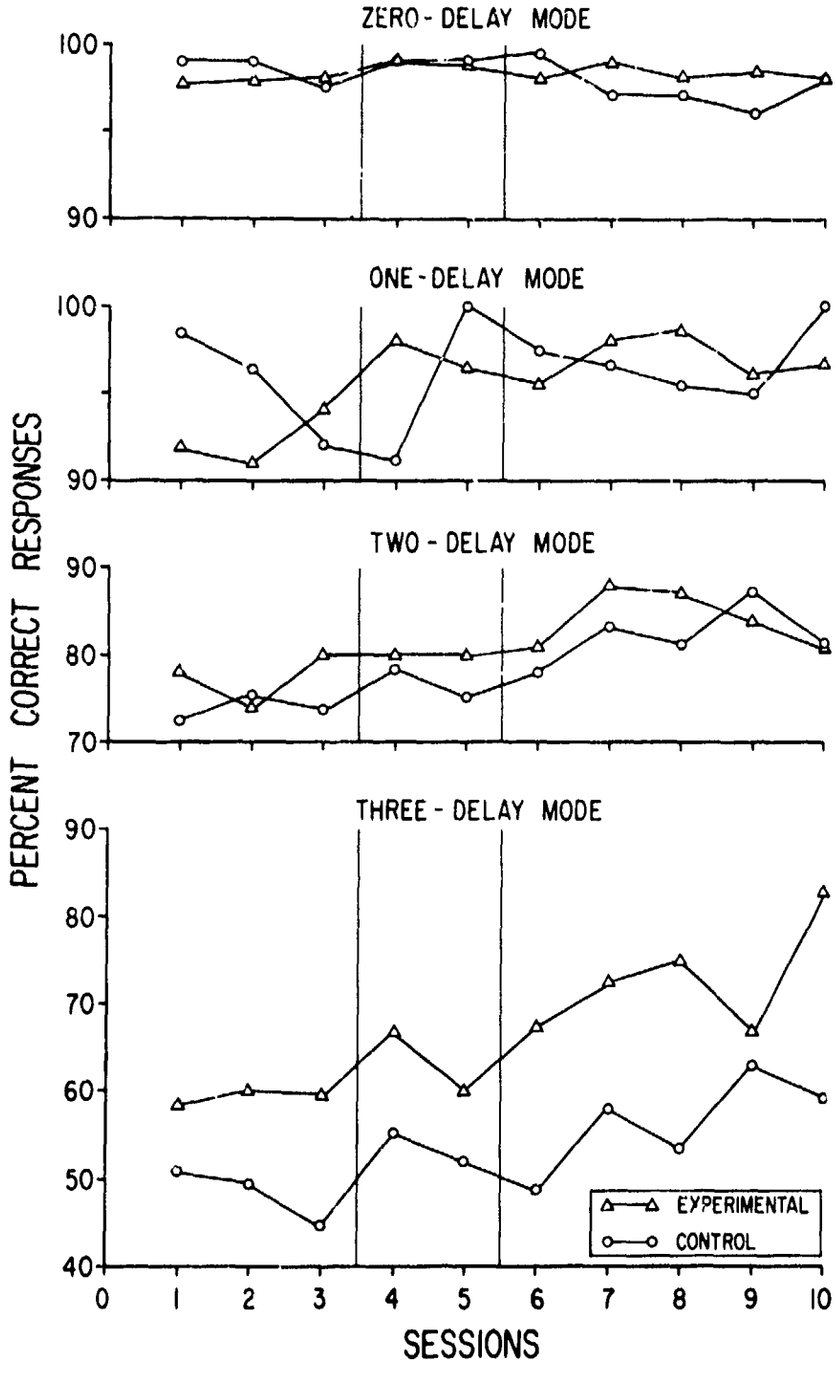

Figure 4

Per cent correct responses for the experimental and control groups performance on the RATER task under four levels of difficulty--zero, one, two, and three delay. Vertical lines separate the pre, during, and post exposure sessions.

The three delay conditions did yield some significant differences. There was a significant practice effect ($F = 170.46$, df 2/18, $p < .001$), and a significant group by experimental condition interaction ($F = 12.44$, df = 2/18, $p < .001$). While both experimental and control groups improved over time, the experimental group improved much more than the control group during the after exposure time period. The mean per cent correct for each of the groups for the before, during, and after time period, is as follows: experimental, 59.6, 64.6, and 74.6; control, 48.4, 53.6, and 58.0. Use of the Sign test to assess shifts in performance on a session-by-session basis failed to yield any significant differences.

Simplified Electronic Tracking Apparatus (SETA). While data were collected under four conditions on this tracking task only the results obtained under the most difficult conditions were selected for presentation. These data (Figure 5) were selected, because it was expected that if ELF fields were to have any effect the effects would become most apparent under the most difficult conditions--i.e., greatest amount of error fed back into the system with the control/display relationships reversed. A repeated measures ANOVA yielded no significant comparisons. Use of the Sign test to assess shifts in performance on a session-by-session basis also failed to yield any significant differences.

Wilkinson Adding Task. The number of attempted additions and the number of correct additions for each test session for both the experimental and control groups is presented in Figure 6. The number of addition attempts for the experimental subjects on each test session is presented in Figure 7. The number of addition attempts for the control subjects is presented in Figure 8. The results of a repeated measures ANOVA of the before, during, and after ELF-exposure performance indicated that the groups were different: experimental group's performance was generally superior to the control group's performance ($f = 10.92$, df = 1/9, $p < .01$). The performance of both groups improved with practice ($F = 18.95$, df = 2/18, $p < .001$). The groups by experimental condition interaction was not significant. Use of the Sign test to assess shifts in performance on a session-by-session basis indicated a significant decline in performance on the second session during the exposure period ($p = .032$) and a significant number of improvements on the first test session of the post-exposure period ($p = .032$). Six out of the six of the experimental subjects demonstrated a decline in performance on the second test session of the exposure period. By contrast the control subjects showed a mixed pattern of improvements and declines on their equivalent test session: three improved and two declined. On the first test session of post-exposure period, six out of six of the experimental subjects improved in contrast to two improvements, two declines, and one no-change in control subject performance on their equivalent test session. There seems to be no alternative to a conclusion that the experimental subjects' speed of performing additions decreased

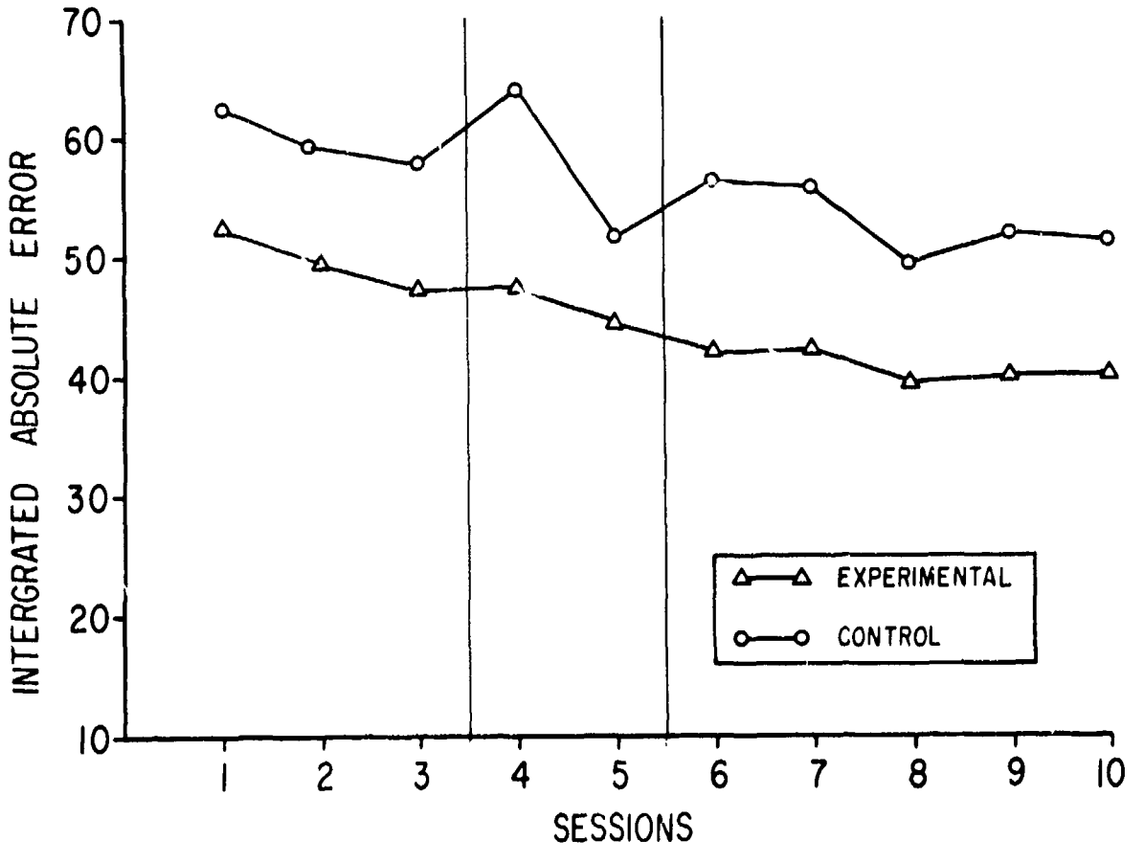

Figure 5

Performance of the experimental and control groups on the SETA across test sessions as measured by their integrated absolute error on the most error feedback, reverse control condition.

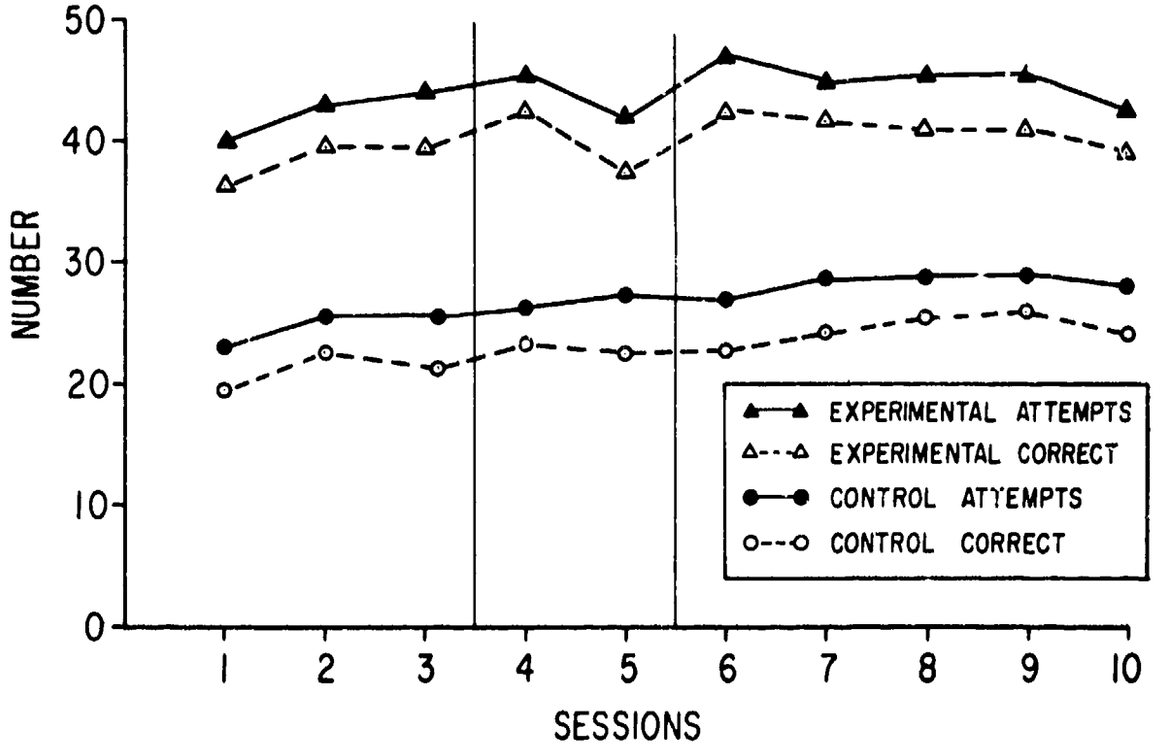

Figure 6

Performance of the experimental and control groups on the Wilkinson Adding Task across test sessions as measured by both the number of attempted additions and the number of correct additions.

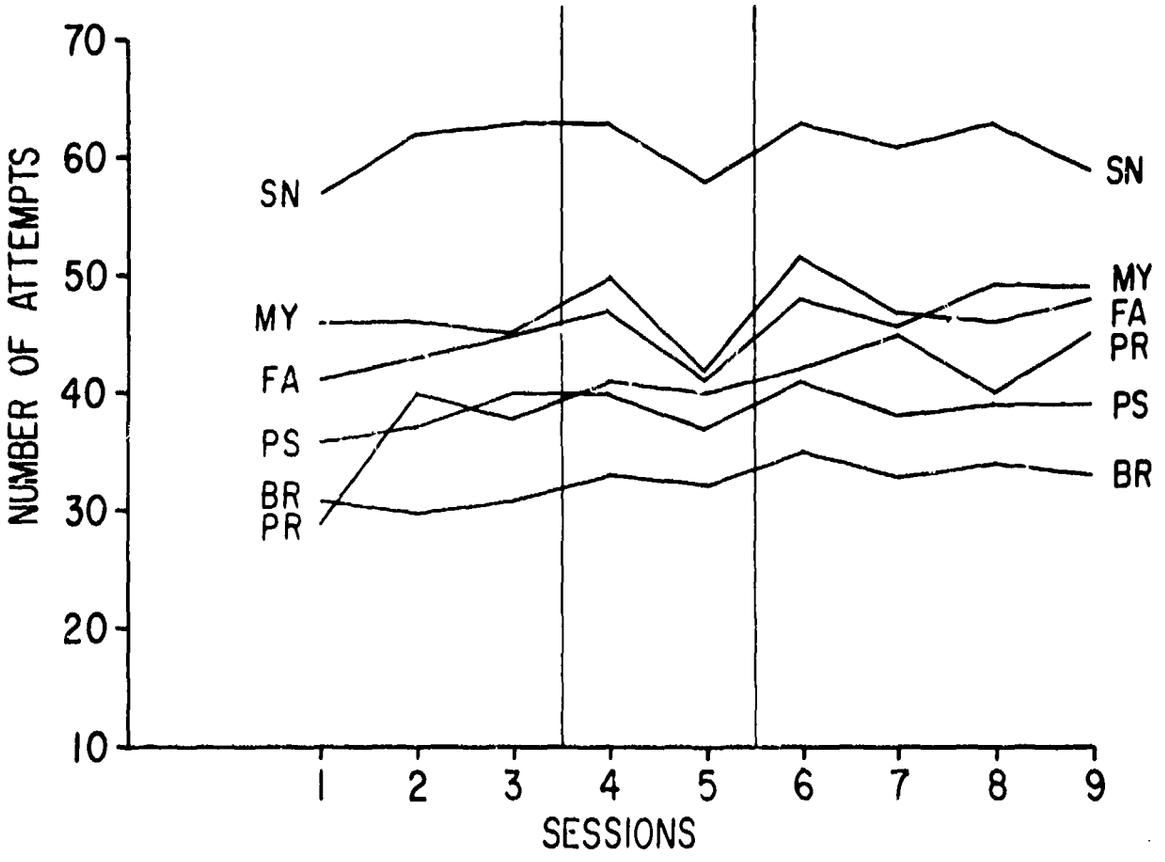

Figure 7

The number of addition attempts on the Wilkinson Adding Task across test sessions for each of the experimental subjects.

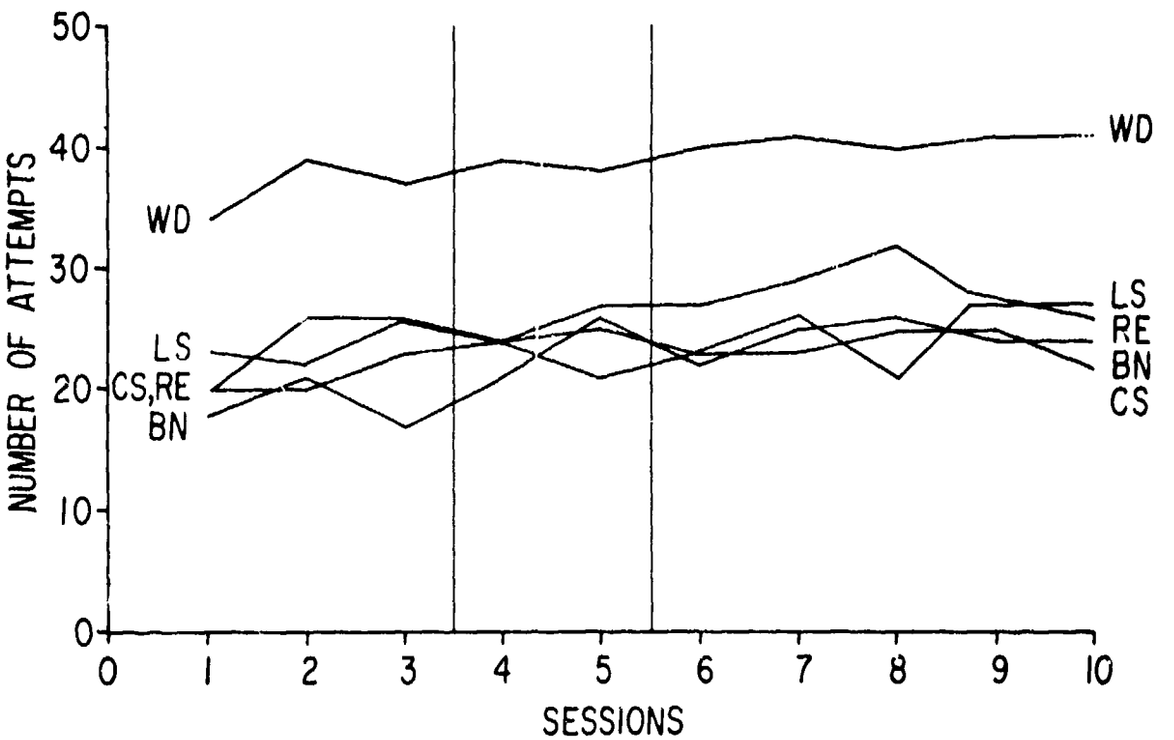

Figure 8

The number of addition attempts on the Wilkinson Adding Task across test sessions for each of the control subjects.

during their exposure to an ELF magnetic field. It should also be noted that the speed of performing additions had recovered by the time of the first test session of the after exposure time period.

Minnesota Rate of Manipulation Test (ROM). The data from the Minnesota Rate of Manipulation Test are presented in Figure 9. The repeated measures' ANOVA indicated that the subject's performance improved with practice ($F = 14.48$, $df = 2/18$, $p < .001$). Use of the Sign test to assess shifts in performance on a session-by-session basis indicated that a significant number of the experimental subjects improved on the first test session of the exposure period: six out of six subjects ($p = .032$).

Individual Susceptibility to ELF Magnetic Fields. In order to check for the possibility that there might have been an individual subject susceptibility to ELF magnetic fields that was masked by the use of group data in the preceding analyses, a review of individual performance data by test session was made. Using the Sign test to compare the test session by test session improvement or decline of a subject's performance on seven test measures, the following results were obtained. Three out of six experimental subjects did not manifest any significant improvements or declines in their performance on a test session by test session basis. Two subjects had one or more significantly good test sessions (MY sessions 2 ($p = .032$), 4 ($p = .016$), and 6 ($p = .016$); FA session 3 ($p = .032$). One subject had a significantly bad test session in which his performance declined on six out of seven test measures (BR session 7 ($p = .032$). However, since BR's one poor test session doesn't seem to be part of a more general performance trend and since it seems to be unrelated to the physiological data (2), it probably represents a chance observation unrelated to the experimental conditions.

SUMMARY

For the exposure durations and intensity levels of the ELF magnetic field used in this pilot study, human psychomotor functions appear to be unaffected. Neither of the predominantly psychomotor tests used (SETA and ROM) yielded anything of significance. Both of the predominantly cognitive tests yielded statistically significant results. The number of attempts on the Wilkinson adding task decreased during the second test session of the exposure period. The level 3 delay of the RATER showed a greater than expected increase in performance during the after exposure period. Consequently, it is recommended that both the Wilkinson adding task and the RATER should be seriously considered for inclusion in any future studies concerned with the possible effects of ELF fields on human performance.

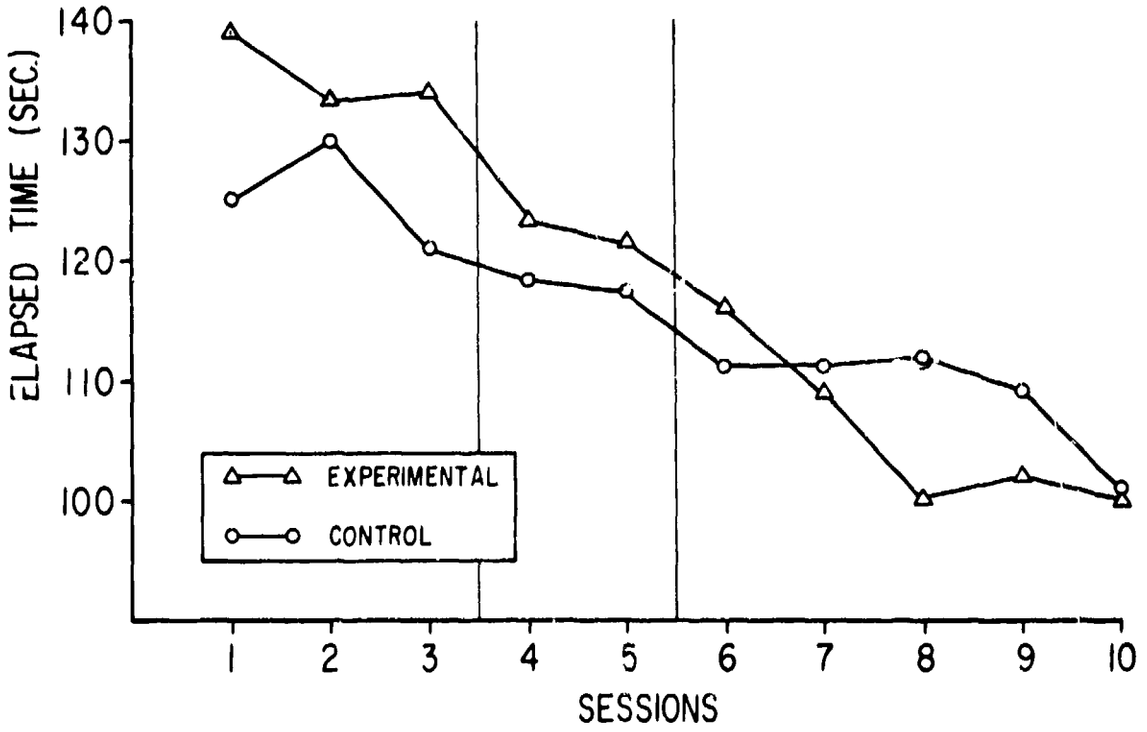

Figure 9

Performance of the experimental and control subjects on the Minnesota Rate of Manipulation Test across test sessions as measured by the amount of time required to complete the four trials within each test session.

The use of small numbers of subjects coupled with the absence of any massive experimental effects made the interpretation of the results difficult and precluded the drawing of any causal relationships between the ELF fields used and the few performance changes which were noted. Much of the doubt relating to the interpretation of these data could be resolved by using each subject as his own control in an experimental design using more than one exposure period separated by a two to three day nonexposure period.

As a final note, it should be emphasized that because of the large number of statistical analyses and comparisons performed on a limited amount of data, the few significant performance decrements reported must be interpreted with extreme caution. This study was conducted for the purpose of developing techniques for future research efforts. The few significant results should be considered as appropriate to identify techniques to be used in future research and nothing more.

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