EFFECTS OF 50 HZ INTERMITTENT MAGNETIC FIELD EXPOSURE ON HUMAN PERFORMANCE AND CARDIOVASCULAR RESPONSE

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ABSTRACT

One hundred subjects (aged 18-48 years) were exposed and sham exposed to a 100 μT intermittent magnetic field, modulated sinusoidally at 50 Hz. To examine the effect of field exposure on performance, a two alternative forced-choice duration discrimination task with 3 levels of difficulty was used. Cardiovascular response was also assessed using measures of blood pressure and pulse rate. A number of factors were incorporated into the experiment with the aim of increasing sensitivity above that of past research. In particular, the experiment's statistical power was increased using several techniques (e.g., large sample size and a repeated measures design). Also, intermittent exposure was used instead of continuous, and the conditions of exposure were optimised using field parameters specified by parametric resonance theory. To measure performance during exposure, the subjects' task on each of 150 trials was to decide which of two sequentially presented light flashes had the longer duration. The base duration was 50 ms and the alternative durations were 65, 100, or 125 ms. Both reaction time and percentage of correct responses were recorded for each subject. Total exposure time lasted approximately 9 minutes. Blood pressure and pulse were measured for a minimum of 5 minutes, both before and after exposure and sham exposure. The results showed that compared to sham exposure, real exposure decreased reaction time on the hardest level of the performance task. No reliable field-related effects were observed with percentage of correct decisions or the measures of cardiovascular response. The difficulty of making comparisons with similar studies was discussed along with the need for future magnetic field research to be designed with maximum experimental sensitivity in mind given that small effects are likely.

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INTRODUCTION

Overview

Over the last 50 years there has been a marked increase in the generation, transmission, distribution and use of electricity and as a consequence we now experience greater exposure to extremely low frequency (ELF) electromagnetic fields (EMFs). With the increased levels of exposure, research into possible health and biological field effects has undergone rapid growth (Gamberale, 1990). In a recent review of this area, Wood (1993) suggested that some epidemiological studies indicate that exposure may be associated with a twofold increase in certain cancers. However, the National Radiological Protection Board (NRPB, 1992) extensively reviewed the literature and concluded that the results of both epidemiological and experimental studies were at the time of investigation inconclusive. Nevertheless, they do concede that this area of research is of "sufficient importance to warrant further investigation" (p. 44). Furthermore, Trans Power, the company that controls the distribution of electricity in New Zealand, has recently acknowledged that some research shows a possible link between EMFs and adverse health effects (Power Line, 1994). What is more, electromagnetic sensors suitable for home use are now being marketed to the general public (e.g., the Electrosensor, Model ES9000, Sonic Technology Products, Inc.). These facts are indicative of the growing interest and concern, shared by the public and researchers alike, over the possible effects of EMFs.

Both the review by the NRPB (1992) and Wood (1993) suggested that there is evidence, although often inconsistent, that exposure to power frequency fields may produce several biologically important results. Wood stated that "these include a) alteration in cell membrane Calcium dynamics, b) reduction in night-time pineal melatonin levels in rodents, c) the incidence of abnormalities in chicken embryos, d) the rate of RNA transcription in cultures of human cancer (and other) cells and in alterations in human heart rate and aural responses" (p.1). However, while the evidence of biological effects is continually growing, there are many fundamental problems in this area of research yet to be resolved. One of the more pressing problems is to find a mechanism by which weak ELF fields may interact with human or animal tissue at the cellular level. This problem has generated considerable interest and research, and while one or two plausible mechanisms have been proposed there is as yet no generally accepted theory (see Wood, 1993).

In contrast to cellular level research, there are relatively few well controlled studies on the effects of weak EMFs on humans at the behavioural level. What research there is points to at least some evidence of field-induced changes in performance (e.g., Cook, Graham, H. D. Cohen, & Gerkovich, 1992; Graham, Cook, H. D. Cohen, & Gerkovich, 1994). However, the few studies that have been done are difficult to compare and draw meaningful conclusions from, primarily because a wide variety of field intensities, frequencies, and experimental protocols have been used. Moreover, little attention has been paid to whether the experimental designs used by researchers to date have been sensitive enough to detect real field-related effects, if they exist. The present study was specifically designed to address the latter issue in an

investigation of the effects of a 50 Hz magnetic field on visual duration discrimination.

The Nature of Electromagnetic Fields

The flow of electric current produces a magnetic field, while the voltage on a current-carrying wire produces an electric field around it. The greater the current the stronger the magnetic field, and similarly, the greater the voltage the stronger the electric field (National Radiation Laboratory, 1994). Further information on the sources and nature of EMFs can be found in Nair, Morgan, and Florig (1989), and Tenforde and Kaune (1987).

Electromagnetic field frequencies under 300 Hertz (Hz) are described as ELF. Frequencies under 30 Hz are described as sub-extremely low frequency, but in EMF research this distinction is rarely made. Transmission line power frequencies (i.e., 50 or 60 Hz) are the most common source of ELF field exposure. (See Table 1 for a complete list of EMF frequencies and some sources of exposure.)

Magnetic field exposure may be characterised in any one of three ways. First, it may be expressed in terms of magnetic field strength, **H**, measured in the Systeme Internationale (SI) unit, amperes per metre (A/m). However, with regard to human and animal exposure, it is more common to find the field strength expressed in terms of magnetic flux density, **B**. In SI units, **B** is expressed in Tesla (T) or microTesla (μT). In a vacuum, **B** and **H** are directly related by $\mathbf{B} = (4\pi \times 10^{-7})\mathbf{H}$.

Table 1
Electromagnetic fields and their sources.

Frequency	Wavelength	Description	Band	Sources
0 Hz		Static		Earth's field Magnets, DC supplies
		Sub-extremely low frequency*	SELF	
30 Hz	10 000 km			Electric power lines and cables. Domestic and industrial appliances
50 Hz	*6 000 km*	Extremely low frequency	ELF	
300 Hz	1 000 km			
		Voice frequency*	VF	Induction heaters
3 kHz	100 km			
		Very low frequency	VLF	Television sets Visual display units
30 kHz	10 km			
		Low frequency	LF	AM radio
300 kHz	1 km			
		Medium frequency	MF	Induction heaters
3 MHz	100 m			
		High frequency	HF	RF heat sealers
30 MHz	10 m			
		Very high frequency	VHF	FM radio
300 MHz	1 m			
		Ultra high frequency	UHF	Cellular telephones Television broadcast Microwave ovens
3 GHz	10 cm			Radar
		Super high frequency	SHF	Satellite links Microwave communications
30 GHz	1 cm			
		Extra high frequency	EHF	Point-to-point links
300 GHz	1 mm			
		Infrared		

Note. From *Electromagnetic Fields and the Risk of Cancer: Report of an Advisory Group on Non-ionising Radiation.* (p. 5), by National Radiological Protection Board, 1992, Chilton, England: National Radiological Protection Board. Copyright 1992 by National Radiological Protection Board.

However, the older centimetre, gram and second (cgs) unit, **B**, expressed in Gauss (G), is still used by some authors. It is also worth noting that Tesla and Gauss are directly related such that 1.0 T = 10,000 G. In addition, flux density is usually reported as the root-mean-square (rms) value, but waveform amplitude and peak-to-peak values are also used. In the present thesis all magnetic fields are reported as rms flux densities in SI units, unless otherwise stated. To help understand flux density, Koch, Koch, Martin, and Moses (1993) provided the following description: "Flux density may be visualised as a series of parallel closed lines arranged about a current-carrying conductor or leaving a magnetic field source, passing through space, and returning to the source; the density of the lines in space is a measure of the flux density of the field" (p. 617-618). Field strength drops sharply as the distance from the source increases, because the strength is inversely related to the square of the distance from the current-carrying system (Koch et al., 1993). In contrast to magnetic field strength, electric field strength is generally only expressed in the SI units, volts per meter (V/m) or kilovolts per meter (kV/m).

Prior research conducted in laboratory settings has generally used coil pairs to produce homogeneous EMFs. In the classic Helmholtz configuration, the coils (either square or circular) are positioned such that the distance between the coils is approximately equal to the radius. This design produces homogeneous fields, but only in systems of relatively small volume (Kirschvink, 1992). In larger volumes improved designs using three, four, or five coils provide better uniformity (e.g., see Kirschvink, 1992).

Typically, humans experience intermittent EMF exposure arising from a variety of sources that use electrical energy (NRPB, 1992). For example, overhead transmission lines, household wiring, and electrical appliances all produce EMFs to varying degrees. Table 2 contains a list of examples of sources and field strengths to which people are exposed. Recently, the International Commission on Non-Ionizing Radiation Protection (1993, cited in National Radiation Laboratory, 1994) confirmed guidelines for 50/60 Hz occupational and general public exposure. Accordingly, short-term occupational exposure to electric fields up to 30 kV/m, and magnetic fields of 5000 μT is considered permissable. For the general public, short-term exposure to electric fields up to 10 kV/m, and magnetic fields up to 1000 μT is permissible. However, while the characteristics of EMFs are well known and some attempt has been made to define safe limits, the appropriate dose-response relationship remains unclear.

Relations Between Dose and Response

The dose-response question poses a serious problem for the whole area of EMF research. To this end, researchers have recently concentrated on possible "effects functions" or relations between exposure and field effects (see Morgan & Nair, 1992, for a review). In 1991, leaders in the bioelectromagnetic research community participated in a questionnaire and workshop designed to assess alternative effects functions (Morgan & Nair, 1992). The traditional effects function states that an effect is proportional to the product of field strength and time spent in the field. However, a dissatisfaction with this view apparently led to the

Table 2

Examples of electromagnetic field sources and field strengths to which people are exposed.

Exposure condition	Electric field strength	Magnetic flux density
Environmental — natural fields		
Static, fair weather	120-150 V m^{-1}	50 μT
Static, stormy weather	10 kV m^{-1}	50 μT
Environmental — human activities		
50 Hz, 400 kV power line, midspan	10 kV m^{-1}	40 μT
50 Hz, 400 kV power line, 25 m from midspan	1 kV m^{-1}	8 μT
500-1600 kHz, 100 m from AM broadcast antenna	20 V m^{-1}	—
27 MHz, 4 W CB radio, 12 cm from antenna	100-600 V m^{-1}	0.25-1.0 μT
470-854 MHz, TV broadcast, maximum within 1 km of TV mast	3 V m^{-1}	0.1 μT
Home/work related		
Static, 30 cm from TV/VDU	0.5-10 kV m^{-1}	—
50 Hz, ambient, distant appliances	1-10 V m^{-1}	0.01-1 μT
50 Hz, 30 cm from appliances	10-250 V m^{-1}	0.01-30 μT
3 cm from appliances	—	0.3-2000 μT
50 Hz, 0.5-1 m from induction furnaces	—	100-10 000 μT
50 Hz, substations etc	10-20 kV m^{-1}	Few hundred μT
15 kHz, 30 cm from TV/VDU	1-10 V m^{-1}	Up to 0.2 μT
0.15-10 kHz, 0.1-1 m from induction heaters	—	15-1250 μT
250-675 kHz, at operator positions from induction heaters	2-100 V m^{-1}	0.2-22 μT
10-80 MHz, 15 cm from dielectric heaters	20-800 V m^{-1}	0.1-1.1 μT
27-450 MHz, 5 cm from low power mobile antennas	200-1350 V m^{-1}	—
470-854 MHz, TV aerial riggers	30-300 V m^{-1}	0.1-1.3 μT
		Power flux density
2450 MHz, 50 cm from microwave oven leaking at emission limit	14 V m^{-1}	0.5 W m^{-2}
2.82 GHz stationary ATC radar, off axis at 100 m	8 V m^{-1}	0.16 W m^{-2}
14 GHz satellite station off axis at 100 m	0.4 V m^{-1}	0.0004 W m^{-2}

Note. From *Electromagnetic Fields and the Risk of Cancer: Report of an Advisory Group on Non-ionising Radiation.* (p. 11), by National Radiological Protection Board, 1992, Chilton, England: National Radiological Protection Board. Copyright 1992 by National Radiological Protection Board.

development of the questionnaire and subsequent workshop. Morgan and Nair reported that the questionnaire and workshop evaluated seven alternative effects functions:

> 1) effect proportional to time-average of field strength; 2) effect proportional to cumulative field strength, or some function of field strength; 3) effect is binary in field presence, (i.e., only dependant on presence, or absence of field); 4) effect depends upon "switching," that is, the number of times the organism experiences a sudden (in time $\leq \tau$) change in field strength...; 5) effect occurs only within field-strength window(s); 6) the effect occurs only within frequency windows, and in combination with one or more of the preceding; 7) the effect requires the presence of additional external agent(s). (p.338)

Morgan and Nair (1992) suggested that the results of the questionnaire and workshop clearly showed that none of the effects functions described above could be ruled out. Many researchers agreed that greater emphasis should be placed on examining frequency and intensity windows, and switching of the fields. There was strong agreement that these "resonant windows" and the presence of direct current (DC) fields were relevant attributes of effects functions for calcium-ion efflux. However, there was little consensus on the effects functions for the behavioural and nervous system. The majority of the experts thought that frequency windows, cumulative fields, and the role of DC fields were irrelevant, although about a third thought the behavioural literature was consistent with these effects functions. Most of the experts thought that the behavioural literature was consistent with or supported intensity

windows and switching. Nevertheless, again, about a third of the experts thought the literature did not support these effects functions. Morgan and Nair suggested that during the workshop several discussions took place on whether resonant windows would persist at the physiological or behavioural level, although no consensus was reached.

The questionnaire and workshop also assessed the extent to which six major literature categories provide support for the occurrence of four possible health consequences. One of these consequences had the title "Neurological and Behavioural Effects". The results showed that the vast majority of the experts thought the literature on calcium efflux, endocrine functions, reproduction and growth, and behavioural and nervous systems were either consistent or supported neurological and behavioural effects. The literature on cell signalling and biosynthesis produced mixed results, while the literature on immune function was thought by all to be irrelevant to neurological and behavioural effects (Morgan & Nair, 1992).

Recently, some investigators have suggested that the effects function may differ for different endpoints (Graham et al., 1994). In other words, the relationship between dose and response may depend on the variable measured. Clearly, much more research is needed before this issue is resolved. Stemming from the dose response issue is the question of the mechanism through which EMFs interact with biological tissue. Here again, several authors have concluded that more than one mechanism of interaction is likely, given the wide variety of biological effects (Graham et al., 1994; Wilson, Hansen, & Davis, 1994).

Mechanisms of Interaction

To understand how magnetic fields may produce behavioural, physiological, or health-related effects, it is essential to first understand the "fundamental interaction mechanism" (Nordenson, Mild, Andersson, & Sandstrom, 1994). Mechanisms of interaction have received considerable attention, most recently by Blackman, Blanchard, Benane, and House (1994). As indicated in the preceding section, effects functions involving resonant windows have generated substantial interest and debate. One attempt to develop a potential interaction mechanism involving resonance windows is the parametric resonance model.

It has been reported that changes in learning rate in rats (Thomas, Schrot, & Liboff, 1986), in ion flux through cell membranes (Blackman, Benane, House, & Elliot, 1990; Liboff, Smith, & McLeod, 1987), in cell motility (McLeod, Smith, Cooksey, & Liboff, 1987), and in calcium signalling in lymphocytes (Yost & Liburdy, 1992) in the presence of an ELF magnetic field are the result of a "resonant interaction" between biological material and the applied field. This effect requires the presence of a DC (i.e., static) magnetic field (comparable with the geomagnetic field) modulated by a parallel, alternating current (AC; i.e., time-varying) magnetic field of about the same magnitude and of a specific frequency (Male, 1992). The specific frequency of the AC field is proportional to the strength of the DC field (B) and the charge-to-mass ratio (q/m) for certain ions (e.g., calcium). The so-called cyclotron-resonance frequency, f_c, is given by the equation:

$$f_c = 1/2\pi \ (q/m) \ (B_{DC}) \qquad (1)$$

where q is the charge of the ion, m is the mass of the ion, and B_{DC} is the flux density of the DC magnetic field. The specific intensity of the AC field that produces the greatest effect can be found from a Bessel function response curve (see Yost & Liburdy, 1992). Several investigators have used the theory to develop a model of interaction (e.g., Lednev, 1991; Male, 1992). The parametric resonance model assumes that an AC magnetic field aligned with a DC magnetic field will affect the probability that a particular ion remains bound to its protein. This in turn affects the probability that the protein will carry out its ion-dependent biological function (Male, 1992). Generally, research in this area has concentrated on calcium ions. However, as noted by Lednev (1991), the conditions for the resonance phenomenon may be fulfilled for ions other than Ca^{2+}. Nevertheless, recent research involving humans (Graham et al., 1994) has pointed to the importance of calcium in cardiovascular effects. Specifically, these authors suggested that EMF exposure has its greatest impact during the repolarization phase of the cardiac cycle--a time when changes in calcium ion flux are most likely to produce effects.

The parametric resonance model raises the possibility that only some combinations of the geomagnetic and applied AC field may produce effects thereby offering a plausible reason for the often inconsistent results found in EMF studies. Furthermore, Polk (1991) concluded that there is at least some evidence that biological effects depend on a DC magnetic field in conjunction with an AC magnetic field. Nevertheless, the parametric resonance model has come under some criticism (see Adair, 1992, for further discussion). Perhaps the most serious criticism is that the model violates basic physical principles. Still, by following

the parametric resonance model researchers may "maximise the utility of the results" (Blackman et al., 1990). At the very least, it is important that future investigators measure and report the direction and the magnitude of the DC magnetic field (Polk, 1991) to allow a better understanding of possible mechanisms of interaction.

ELF Fields and Human Physiology

Several authorities have concluded that any interaction between biosystems and EMFs is most likely to occur within the brain and nervous system. Some physiological effects seem to support this view. However, before reviewing these effects it should be noted that most field-related effects involving human physiology come from the Midwest Research Institute (MRI). For nearly 10 years researchers at MRI have conducted experiments examining the effects of exposure to 60 Hz electric and magnetic fields on human physiology and performance. All experiments have used a sophisticated double-blind protocol in an attempt to avoid subject or experimenter bias. The "Human Exposure Test Facility" at MRI has been described in detail elsewhere (see H. D. Cohen, Graham, Cook, & Phelps, 1992). Essentially, the facility was designed to produce uniform, corona-free, 60 Hz electric and magnetic fields. Inside the facility both temperature and humidity are controlled and a system of hardware and software interlocks mask all field-related cues. To generate the magnetic field (of up to 40 μT) two sets of three Helmholtz coils, positioned in both the vertical and horizontal axes, surround the exposure chamber. A parallel-plate system positioned

above and below the exposure chamber is used to produce an electric field of up to 16 kV/m.

The most consistent physiological effect (at MRI) has been a significant ($p < .05$) increase in cardiac interbeat interval (i.e., slowing of heart rate) during real exposure (9 kV/m, 20 μT) when compared to sham exposure (Cook et al., 1992; Graham & H. D. Cohen, 1985; Graham et al., 1994; Maresh, Cook, H. D. Cohen, Graham, & Gunn, 1988). Cook et al. suggest that this effect may be a reflection of more important changes occurring in other parts of the cardiovascular system. However, further study is needed to support this hypothesis. Interestingly, the strongest effect occurred when heart rate was measured during rest compared to during task performance (Graham & H. D. Cohen, 1985) or physical exercise (Maresh et al., 1988). Graham and H. D. Cohen speculate that this may be due to motivational influences or task demands obscuring field effects. Research at MRI has indicated that field-related effects may occur both during exposure and immediately after exposure to a 9 kV/m, 20 μT combined electric and magnetic field, but not for stronger (12 kV/m, 30 μT) or weaker (6 kV/m, 10 μT) fields. In support of the heart rate effects observed at MRI, Korpinen, Partanen, and Uusitalo (1993) using field research techniques as opposed to laboratory methods, observed that exposure to EMFs produced by transmission lines (0.14 to 10.21 kV/m, 0.001 to 15 μT) was associated with decreased heart rate in their subjects. In a subsequent field study, Korpinen and Partanen (1994) found no field-induced heart rate effects with weaker fields (3.5 to 4.3 kV/m, 1.4 to 6.6 μT). In contrast to heart rate, other cardiovascular measures such as temperature and blood pressure (BP)

have not been found to be affected by field exposure (Cook et al., 1992; Sander, Brinkmann, & Kuhne, 1982, cited in Gamberale, 1990).

Another consistent physiological effect involves event-related brain potentials (ERPs). Analysis of changes in latency and amplitude of the positive and negative ERP components can provide information about various cognitive activities involved in stimulus selection, information processing, and decision making (Graham & H. D. Cohen, 1985). More specifically, the amplitude of the P300 component is thought to be related to higher cognitive stimulus processing and evaluation. Results have shown that the amplitude of the P300 component decreases after the performance of a task, but field exposure significantly ($p < .05$) reduces this effect (Graham & H. D. Cohen, 1985) and in some cases even reverses it (Cook et al., 1992). In addition, the latency of the emergence of the P300 component tends to be greater during and after real exposure compared to sham exposure (Graham & H. D. Cohen, 1985; Graham et al., 1994). The latency of the P300 component is thought to reflect the process of stimulus evaluation (Graham & H. D. Cohen, 1985). Cook et al. suggested that the effects seen with the ERP components point to a field-related interference effect, and that disruption of cognitive processes through field interference would most likely affect stimulus evaluation and decision making.

Consistent results have also been found by examining EEG patterns during exposure. Lyskov et al. (1993) showed that intermittent exposure to a 1260 μT magnetic field caused changes in EEG patterns when compared to continuous or control conditions. Specifically, intermittent exposure caused a reduction in both delta and theta activity and an

increase in alpha activity, which Lyskov et al. interpreted as indicative of enhanced relaxation. This effect was accompanied by an increase in frontal lobe beta activity, which was interpreted as indicative of psychomotor activation. Other research has also reported that magnetic fields may produce alterations in EEG patterns (Bell, Marino, & Chesson, 1992, cited in Graham et al., 1994; Levillain & Picat, 1985, cited in Lyskov et al., 1993).

In summary, there appears to be enough evidence to suggest that EMFs can induce alterations in both heart rate and EEG activity. However, the evidence is less clearcut for the effects of EMFs on human performance, which has rarely been studied under well controlled conditions.

ELF Fields and Human Performance

The earliest published research specifically examining the effects of ELF magnetic fields on human performance appears to have been carried out in the U.S.A. by Friedman, Becker, and Bachman (1967). They investigated the effects of a magnetic field on a standard, relatively uncomplicated, psychomotor task, simple reaction time (RT). RT is operationally defined as the time between the onset of a stimulus and the beginning of an overt response (Coren, Ward, & Enns, 1994). In one of Friedman et al.'s experiments a within-subjects, counterbalanced design was used with 12 male subjects, each of whom participated in three conditions: no field (control), 0.1 Hz, and 0.2 Hz. During each condition subjects participated in two practice trials followed by 50 experimental trials (with 5 s between trials) with each condition separated by more

than 24 hrs. The sinusoidally modulated field was produced with Helmholtz-type coils producing a field strength reported by Friedman et al. as "5-11 gauss" (p.949), which is equivalent to 500-1100 μT. Results showed that the 0.2 Hz field produced significantly slower RTs compared to the control and the 0.1 Hz conditions. Friedman et al. then reproduced these results with 12 female subjects.

Since Friedman et al. (1967), relatively little published research has been conducted examining the effects of EMFs on human performance. Gamberale (1990) referred to a Swedish study by Johansson, Lundquist, Lundquist, and Scuka (1973). Few details were given by Gamberale except that subjects were exposed for three hours to a combined 20 kV/m electric and 300 μT magnetic field of 50 Hz. Gamberale suggested that no field-related effects were found involving RT or the "...performance of other psychomotor and cognitive tasks" (p. 53). Similarly, Sander et al. (1982, cited in Gamberale, 1990) found no effects involving the performance of psychomotor tasks. In this case subjects were exposed for one week (4 hrs per day) to a combined 20 kV/m electric and 5000 μT magnetic field. In the mid-1980s MRI presented the results of their screening study which incorporated a number of human performance measures examining EMF effects.

The MRI's screening study (Graham & H. D. Cohen, 1985) may have been the first to evaluate field effects on humans under double-blind control conditions. Twelve men experienced both real exposure to a combined 9 kV/m electric and 20 μT magnetic field of 60 Hz frequency, and sham exposure. All subjects were given real exposure on two separate days and sham exposure on a further two days. Exposure

consisted of two 3 hr periods separated by a 30 min lunch break. To counterbalance the order of exposure Graham and H. D. Cohen exposed half of their subjects in the order of real-sham-sham-real, while the other half were exposed to the sham-real-real-sham order.

The screening study evaluated field effects using many performance measures. Some of these measures appeared to be affected by the field, but the majority indicated no reliable field-related effects. Kirk (1968) stated that the more statistical comparisons performed in an experiment, the greater the probability that one or more will show spurious significance. Therefore, because Graham and H. D. Cohen (1985) did not correct for multiple tests, care should be taken in interpreting their results. Nevertheless, given the elusive nature of EMF effects and the scarcity of published research involving humans, the fact that their study obtained several field-related effects across several measures of performance is worthy of elaboration.

Specifically, Graham and H. D. Cohen (1985) used a signal detection task that had subjects make 200 discrimination trials before, during, and after real or sham exposure. On every trial subjects saw two light flashes and had to decide whether the second flash was longer or shorter than the first. They recorded RT for judgements made when the second flash was longer and for judgements made when the second flash was shorter. The results showed that RT for the latter performance was faster (p = .11) during real exposure (M = 972 ms) compared to sham exposure (M = 1029 ms). Interestingly, immediately after the session ended, the effect was reversed with RT slower after real exposure (M = 1007 ms) compared to sham exposure (M = 947 ms). The investigators

also used a selective attention task designed to measure both simple and more complex decision making under time pressure. The results showed evidence that simple decision making accuracy was enhanced (p = .07) during real exposure compared to sham exposure. Another task used was the paced auditory serial addition task (PASAT), which measures auditory information processing and integrated memory functioning. Measures taken from this task may include various types of errors. The only field-related effect involved one type of error, where subjects made significantly (p = .05) more errors during the start and at the end of real exposure compared to the same times during sham exposure. A time perception task was also used where subjects had to estimate the passage of both 5 and 10 s intervals. The results indicated that for the estimation of the 10 s interval, the percentage of correct responses appeared to be higher (p = .10) during real exposure (87%) than during sham exposure (80%). Finally, performance on the Wilkinson addition task appeared to be affected by exposure. That is, subjects attempted fewer additions (p = .09) during real exposure (65) compared to sham exposure (67).

Some five years after MRI's initial screening study, the same investigators attempted to replicate the results of that first study (Cook et al., 1992). A group of 18 male subjects were exposed (9 kV/m, 20 μT) and sham exposed in the same counterbalanced order as used in the screening study. Again, the researchers employed a variety of performance measures, some being new to the replication study and some of the original measures being left out. In particular, the PASAT and signal detection tasks were not used, which is unfortunate as the screening study indicated that exposure may have affected these performance measures. Nevertheless, the study did use the time

perception task and the Wilkinson addition task, but the researchers were unable to reproduce the effects seen in the screening study.

In addition, Cook et al. (1992) used a choice RT task (similar to the selective attention task used in the screening study) to measure low level decision making under time pressure. As in the selective attention task, the results showed that subjects were significantly (p = .05) more accurate during real exposure (1.97 errors) compared to sham exposure (3.22 errors). However, the results showed that this effect only occurred after 4 hr of cumulative exposure. Additionally, the investigators used an interval production task to measure whether a subject could produce a consistent series of motor responses. The results indicated that subjects speeded (p = .06) up their rate of responding when exposed to the real field compared to the sham field.

Recently, MRI conducted another study (Graham et al., 1994) using several performance measures. Eighteen male subjects participated in two 6 hr exposure sessions. All subjects were sham exposed in one session. In the other session, 6 subjects were exposed to a combined 6 kV/m, 10 μT field, 6 subjects to a combined 12 kV/m, 20 μT field, and 6 subjects to a combined 12 kV/m, 30 μT field. Order of exposure was counterbalanced for each group. An auditory signal detection task provided RT data.

The results showed that those subjects exposed to the weakest field (i.e., 6 kV/m, 10 μT) produced significantly (p = .03) slower RT *after* real exposure than *after* sham exposure (approximately 12% slower). This result was also found in the screening study. However, unlike the

screening study (which found effects using a visual signal), no significant differences were found during exposure. Field-related effects were also found using a differential reinforcement of low response rate (DRL) task. Those subjects exposed to the weakest field were significantly (p = .03) less accurate after the real field compared to after the sham field (13.2% less accurate). As with the signal detection task, no reliable differences were found during exposure (only after exposure), or for the groups exposed to higher field strengths. Graham et al. (1994) concluded that their behavioural results taken together with the effects they found involving human physiology indicate that there exists a nonlinear relationship between field strength and response. Furthermore, they suggest that the relationship between dose and response may differ for different endpoints.

Research has also been undertaken in Russia where Lyskov et al. (1993) exposed subjects (9 male and 11 female) to either an intermittent or a continuous 45 Hz, 1260 μT magnetic field. All subjects received one hour of both real and sham exposure. Results showed no direct field-related effects on simple RT. However, those subjects who received real intermittent exposure first learned significantly more slowly than those subjects who received the sham exposure first.

Recently, a research programme was initiated in New Zealand in the Department of Psychology at Massey University (Podd, Whittington, Barnes, Page, & Rapley, in press). The programme was set up specifically to examine ELF magnetic field effects on human performance. The first experiment began by attempting to replicate the work of Friedman et al. (1967). Friedman et al.'s study was of interest

for several reasons. First, the results showed that an ELF magnetic field directly affected simple reaction time (RT), a result that has not been found in several studies since then (e.g., Cook et al., 1992; Graham & H. D. Cohen, 1985; Lyskov et al., 1993). Second, these effects occurred in a near DC field - just 0.2 Hz. Yet a 0.1 Hz field produced no effects. Third, it appeared that before Podd et al. there had been no attempt to replicate independently these important results.

Podd et al. (in press) first attempted to partially replicate Friedman et al. (1967) in a double-blind experiment using a within-subjects, counterbalanced design with 12 subjects (8 males and 4 females). Subjects were exposed to a homogeneous, sinusoidally modulated magnetic field of 1000 μT produced by Helmholtz configured coils. Each subject experienced all three conditions (no field, 0.1 Hz, and 0.2 Hz); one condition over each of three consecutive days at the same time each day. In each condition, subjects participated in 50 warmup trials followed by 150 experimental trials of a simple visual RT task. Results showed no significant differences between conditions. Thus, the findings of Friedman et al. were not supported.

Podd et al. (in press) followed Friedman et al. (1967) closely with respect to the coil configuration, the magnetic field strength and frequency, the number of subjects used, and the experimental design. However, several changes were made in an attempt to increase experimental sensitivity. That is, the number of practice trials was increased from 2 to 50, and the number of experimental trials from 50 to 150. Despite increasing the number of trials the actual exposure duration was similar to Friedman et al. because the time between trials was

reduced. Podd et al. also ran subjects through each condition with exactly 24 hours between conditions to control for possible circadian effects (whereas Friedman et al. only reported a minimum of 24 hours between conditions). The aim behind these changes was to increase sensitivity by decreasing error variance. In retrospect, it is difficult to see how increasing the number of trials could have interfered with Podd et al.'s chances of obtaining a magnetic field effect. However, it is possible that the faster rate of responding required by their subjects compared to Friedman et al.'s subjects may have affected the results.

In Podd et al.'s (in press) second experiment, the authors again attempted to replicate Friedman et al.'s (1967) finding by using a 0.2 Hz condition. However, to maximise the chance of finding an effect the parametric resonance model was used to create the conditions of exposure that would theoretically produce the maximal effect. Following the logic of the parametric resonance model, Podd et al. reduced the field strength to 100 μT, included a 43 Hz condition, and oriented the applied AC field parallel to the earth's DC field. Nevertheless, Podd et al. found no field-related effect on simple RT. Therefore, their results provided no support for Friedman et al.'s results or the parametric resonance model. However, this should not be seen as especially damaging to the model as it makes no claims about the effect of magnetic fields at the macro-behavioural level. It is possible that simple RT is just not sensitive to changes that may be occurring at the cellular level.

EMF research has produced inconsistent behavioural results. Nevertheless, it is interesting to note that of the effects that have been found some have shown performance enhancement while others have

shown performance decrement. Furthermore, this effect appears to depend on when performance was measured. For example, performance appears to have been improved for selective attention and signal detection during real exposure (Cook et al., 1992; Graham & H. D. Cohen, 1985). In addition, Lyskov et al. (1993) suggested that their results indicated exposure was accompanied by increased psychomotor activation in the frontal lobe. However, immediately after real exposure a decrement in performance was reported for a signal detection task (Graham & H. D. Cohen, 1985; Graham et al., 1994). Cook et al. (1992) suggested that other authors have interpreted decrements in performance as indicative of field-induced fatigue. In contrast, improved performance has been interpreted as evidence of field-induced excitation. Unfortunately, little published research has measured performance before, during, and after exposure, which makes it difficult to clarify this issue.

Table 3 summarises the major studies and their findings related to the physiological and performance effects for humans exposed to EMFs. The scope of the present thesis does not allow for a comprehensive review of all EMF literature which would include cellular and animal experiments (see Wood, 1993, and Tenforde, 1986, respectively, for reviews) and epidemiological studies. However, it should be made clear that while EMF research has produced a number of field-related effects, overall these effects are rather inconsistent. This is especially true at the cellular level. At the whole animal level the lack of research makes it difficult to draw meaningful conclusions. Moreover, the current level of knowledge is insufficient to determine whether or not field-related effects from different laboratories can be directly compared. There are at least two important reasons for this problem.

Table 3

Summary of human behavioural and physiological effects of exposure to time-varying, ELF magnetic fields.

Author(s)	Exposure Conditions[a] and n per group	Field-induced Effects
Bell et al. (1992)[b]	60 Hz, 78 μT	Alterations in EEG patterns
Cook et al. (1992)	60 Hz, 9 kV/m and 20 μT, 6 hr exposure, n = 18	Less errors in a choice RT task, slower heart rate, and changes in cognitive processing
Friedman et al. (1967)	0.1 or 0.2 Hz, 500-1100 μT, 5 min exposure, n = 12	Increased RT during 0.2 Hz field
Graham & Cohen (1985)	60 Hz, 9 kV/m and 20 μT, 6 hr exposure, n = 12	Slower heart rate and changes in cognitive processing
Graham et al.(1994)	60 Hz, 6 kV/m and 10 μT, 9 kV/m and 20 μT, 12 kV/m and 30 μT, 6 hr exposure, n = 18	Medium field slowed heart rate and affected cognitive processing. Weakest field increased RT and decreased accuracy
Johansson et al.(1973)[c]	50 Hz, 20 kV/m and 300 μT, 3 hr exposure	No significant performance effects
Korpinen & Partanen (1994)	50 Hz, 3.5-4.3 kV/m and 1.4-6.6 μT, 1 hr exposure, n = 41	No effect on heart rate
Korpinen et al.(1993)	50 Hz, 0.2-10.2 kV/m and 1.1-15.4 μT, 30 min to 4 hr exposure, two groups of n = 26 & 27	Small decrease in heart rate
Lyskov et al.(1993)	Intermittent 45 Hz, 1026 μT, 1 hr exposure, n = 10	Learned more slowly; affected EEG patterns
Maresh et al.(1988)	60 Hz, 9 kV/m and 20 μT, 2 hr exposure, n = 11	Slower heart rate
Podd et al.(in press)	0.1, 0.2 and 43 Hz, 100 and 1000 μT, 5 min exposure, n = 12	No significant performance effects
Sander et al.(1982)[c]	50 Hz, 20 kV/m and 5000 μT,	No cardiovascular or performance effects

[a]The magnetic fields were sinusoidally modulated unless otherwise indicated. [b]Cited in Graham et al. (1994). [c] Cited in Gamberale (1990).

First, some research has used a combination of electric and magnetic fields (e.g., experiments conducted at MRI), while other research has used continuous (e.g., Podd et al., in press) or intermittent (e.g., Lyskov et al., 1993) magnetic fields. These variations are problematic because each component may affect an organism differently (Lai, Carino, Horita, & Guy, 1993). Additionally, field flux densities have ranged from relatively small (e.g., research at MRI) to relatively large (e.g., Lyskov et al., 1993). Even when dose-response was studied (e.g., Graham et al., 1994), the range of field strengths examined was limited (i.e., 10-30 μT), thus providing little clarification of the problem.

Above all else, little attention has been paid to experimental design sensitivity. The concern here is that much of the research performed to date may have had little chance of detecting field-related effects even if they are real. The present study was designed with the issue of design sensitivity, especially the aspect of statistical power, very much to the fore. Afterall, on intuitive grounds one would expect the effects of magnetic fields (to the extent that they are real) on human performance to be very small. Therefore, it is of paramount importance to have a high degree of experimental sensitivity and, indeed, to pay attention to all stages of the research programme where statistical power may be increased.

Design Sensitivity and Statistical Power

Lipsey (1990) characterised the major issues concerning the sensitivity of an experimental design by the following six factors:

a) Effect size: The magnitude of the "real" effect to be detected.
b) Subject heterogeneity: Individual differences among members of the relevant population on the independent variable of interest.
c) Sample size: The size of the sample taken from the population to constitute the experimental groups.
d) Experimental error: Procedural variation in the way members of the experimental groups are treated during the research.
e) Measurement: Muted or inconsistent response of the measurement instrument to the outcome of interest.
f) Data analysis: The inherent power of the statistical data analysis technique employed to test the difference between experimental groups. (pp. 14-15)

The sensitivity of an experimental design can be assessed using the technique of statistical power analysis. Statistical power is the probability of detecting an effect given that one really exists. In another sense, the power of a statistical test is the "probability that it will result in the conclusion that the phenomenon exists" (J. Cohen, 1977, p. 4). J. Cohen is generally credited with making the technique of statistical power analysis widely available to psychological researchers through his handbook, "Statistical Power Analysis for the Behavioral Sciences" (1977). Strayhorn (1987) stated that the "...overriding principle of power analysis is that as differences between groups become smaller, we need a greater sample size to have a good chance of detecting the difference at a statistically significant level" (p.279). In particular, power analysis exploits the relationship among the four variables involved in statistical inference: statistical power, population effect size (ES), the alpha level (α), and sample size (N). Given that the

assumptions of the statistical model hold, the value of any one of these variables may be determined as a function of the other three. Each of these variables is described below along with an evaluation of power surveys and their implications. Finally, the use of power analysis as a technique for increasing design sensitivity is examined with regard to EMF research.

The power of a statistical test can be calculated *a priori* or *post hoc* by estimating the ES, and specifying the sample size and alpha level. J. Cohen (1977) provides tables for calculating the power of many univariate statistical tests. Likewise, Hager and Moller (1986) and Stevens (1980) provide limited tables for calculating the power of multivariate tests of significance.

J. Cohen (1990) suggested that estimating ES is found by many researchers to be the most difficult aspect of power analysis. To specify ES, an estimate can be made based on past research. However, there are several reasons why it may not be desirable to do so. First, it has been argued (Fagley, 1985) that the calculation of ES should be based on convention rather than estimates based on the sample data or logical argument. Fagley provided the following reasons: (a) it is simpler, (b) it standardizes the procedure and allows the comparison of power across studies, and (c) it requires less statistical expertise. Second, the interpretation of ESs based on sample data is complicated because of the inherent error in any measure of behaviour. J. Cohen (1977) suggested that any irrelevant source of variance in one's measures (i.e., lack of experimental control) will serve to reduce the measured ES so that what would be a medium or even a large effect, if one could use "true"

measures, may be reduced to a small ES in practice. Additionally, Murray and Dosser (1987) demonstrated that sample ES is not independent of the sample size or the number of treatment variables and therefore tells us little about the true population ES.

As an alternative to estimating ES from sample data, ES can be based on estimates derived from the literature. For example, J. Cohen (1992) stated that "...a medium ES represents an effect likely to be visible to the naked eye of a careful observer." Small effects are "...noticeably smaller than medium but not so small as to be trivial" and large effects are "...the same distance above medium as small was below it" (p.156). The values of J. Cohen's ESs depend on the statistical test employed. For example, for the *F*-test the definitions of small, medium, and large effects are .10, .25, and .40 standard deviation units, respectively. For the Pearson correlation coefficient, the definitions for small, medium, and large effects are correlations of .10, .30, and .50, respectively.

The maximum risk of mistakenly rejecting the null hypothesis (i.e., committing a Type I error) is controlled by the alpha level. The Fisherian legacy is responsible for sanctifying the " .05 level of significance" (J. Cohen, 1990). More will be said about alpha when methods of increasing power are reviewed.

Sample size is often not a statistical issue, but dictated by the resources of time and money. However, power analysis can also be used *a priori* to calculate the required sample size needed to attain a specific level of power (see J. Cohen, 1977, for sample size tables). However, when using power analysis in this way, care must be taken to avoid

committing what Muller, LaVange, Ramey, and Ramey (1992) called a Type III error. A Type III error refers to the calculation of the wrong sample size because the analysis was based on the wrong statistical test.

J. Cohen (1962) was the first to publish a comprehensive survey of statistical power. He calculated the average power of small, medium, and large effects from 2,088 statistical tests in 70 journal articles published in the 1962 volume of the *Journal of Abnormal and Social Psychology*. Following J. Cohen's power survey there have been over two dozen similar surveys conducted. Together these power surveys account for 40,000 statistical tests published in over 1,500 journal articles spanning a wide range of disciplines (Rossi, 1990). Averaging across these power surveys, Rossi found that the mean statistical power for small, medium, and large effects was .26, .64, and .85, respectively. These values lead to one conclusion: power has been generally low for small and medium effects. However, before describing the implications of these results, the surveys themselves have several limitations that must be addressed.

Previous power surveys have three major limitations. First, the sample period has generally been limited to just one year of one journal (Rossi, 1990). Second, the specific definitions of small, medium, and large ESs are, by J. Cohen's (1977) own admission, arbitrary. Therefore, the power surveys will only be as representative as the ESs are of the actual effects in psychological research (Rossi, 1990). However, J. Cohen's estimates have been supported by several ES surveys (Rossi, 1990; but see Murray & Dosser, 1990, for survey limitations). Third, nearly all power surveys have covered broad research domains (Rossi, 1990) and

therefore they tell us little about specific areas of research. To overcome these limitations, power surveys should be conducted on specific research literatures spanning several years across many journals.

The average power levels reported by Rossi (1990) have several important implications depending on how large we suppose population ESs are in psychological research. If we suppose that ESs are generally small, and accept that on average, power is very low to detect small effects, the situation is especially problematic because the probability of both Type I and Type II errors increases dramatically (Rossi, 1990). Rossi suggested that in these circumstances "the probability of rejecting a true null hypothesis may be only slightly smaller than the probability of rejecting the null hypothesis when the alternative is true. That is, the ratio of Type I errors may be uncomfortably large, indicating that a substantial proportion of all significant results may be due to false rejections of valid null hypotheses" (p.652).

If we suppose that, on average, ESs are medium, the problem of increased Type I error rates is less serious than if ESs are small. However, another problem arises when power is marginal. Rossi's (1990) review shows that, on average, power for a medium effect is .64. In this situation an inconsistent pattern of results is likely because researchers, on average, will only have a 64% chance of obtaining significance even if the effect is real. Naturally, with marginal power, replication attempts will often fail, leading to controversy over the existence of an effect. In fact, this appears to have happened in the magnetic field literature. That is, inconsistencies have been interpreted by some as evidence that electromagnetic fields have no real effects on

biological systems (e.g., Adair, 1991). With large ESs, power is generally adequate and so the effect of low power is not an issue. However, there is no evidence to suggest that average ESs are large in psychology (Rossi, 1990). In fact, all available ES surveys show that the average ES is near J. Cohen's (1977) definition of a medium effect (Rossi, 1990).

Further danger stemming from studies that use low powered significance tests can be found in the interpretation of nonsignificant effects. In such cases the result is ambiguous because it may mean that either (a) there is no effect, or (b) there is an effect but the study was just not sensitive enough to detect it (Fagley, 1985). This problem becomes more serious when the null hypothesis is used as the research hypothesis, and thus, is confirmed when the results are nonsignificant. Therefore, null results should only be interpreted when statistical power is high. However, this must be qualified with J. Cohen's (1977) suggestion that although high statistical power is necessary for interpretation of nonsignificant results it is not sufficient to ensure valid results. Consequently, nonsignificant results from a statistical test with high power are only potentially interpretable. As in any study, the factors concerning the conduct of the research also influence the validity of the results.

Magnetic fields are likely to produce small behavioural effects due to the subtlety of the issues involved and to problems of measurement. The idea that behavioural effects are likely to be small has some intuitive appeal since everyday exposure to magnetic fields has not lead to widespread reporting of behavioural changes. Indeed, the difficulty of detecting such effects through controlled research (e.g., Cook et al.,

1992; Podd et al., in press) seems to support this view. In fact, other authors (e.g., Maresh et al., 1988) have explicitly called upon researchers to design studies sensitive enough to detect small effects. At any rate, magnetic field research should be designed with small effects in mind since effect size may not tell us much about the practical significance of an effect (J. Cohen, 1977). The reason for this is, as noted, that any source of variance in a measure will serve to reduce what actually may be a medium or even a large effect to a small effect in practice (J. Cohen, 1977). Moreover, given the exploratory nature of this area of research, it is desirable to detect any real field-related effects, no matter how small. In other words, serious consideration must be given to the degree of statistical power available.

To determine the average level of power that past EMF researchers had available, a power survey was conducted (Whittington and Podd, 1995). The survey included only those published reports involving human performance and physiology. Following the method of Rossi (1990), all major statistical tests reported in each article were analyzed in terms of power. Averaging across each study, it was found that the mean power for small, medium, and large effects was .07, .22, and .44, respectively. Clearly, at least in the research surveyed, power was poor for each of J. Cohen's (1977) ESs. Researchers looking for small effects, on average, only had a 7% chance of detecting them. Put another way, the chance of replicating a study having a small effect size is just 7%. It is small wonder that most replication attempts in the EMF literature fail.

J. Cohen (1977) recommends a minimum statistical power of .80. That is, we should give ourselves at least an 80% chance of detecting an

effect, should one exist. To obtain sufficient power researchers need to consider: (a) the statistical test employed, (b) the sample size used, (c) the likely ES, and (d) the alpha level. It should be noted that different statistical tests may not have the same power when applied to the same data (Lipsey, 1990). In addition, the presence of error in measuring a dependent variable diminishes the power of the statistical tests employed. (For a theoretical analysis of this relationship see Williams & Zimmerman, 1989.) In sum, many factors influence statistical power and several approaches can be taken to increase the power of one's research.

Increasing sample size is the most obvious method for increasing power. However, the practical problems associated with obtaining large samples and the cost of doing so often limit the usefulness of this option (Rossi, 1990). Relaxing the alpha level is perhaps the easiest method of increasing power for it does not require any increase in time or money (Cascio & Zedeck, 1983). However, it does require a break from convention (Cascio & Zedeck, 1983) and may not be acceptable to many reviewers, editors, and researchers (Rossi, 1990). Nevertheless, faced with the prospect of low power it has been argued by several authors (e.g., Cascio & Zedeck, 1983; J. Cohen, 1977; Lipsey, 1990) that researchers should consider the relative seriousness of both Type I and Type II errors and set the alpha level at a point that reflects this consideration. Lipsey (1990) put it succinctly when he suggested that researchers should set "error risk levels... on rational grounds rather than according to a narrow and one-sided convention" (p.145). Moreover, Murray and Dosser (1990) argued that "...the choice of an alpha level is, properly, not a statistical issue" (p.71), but should be based on an informed decision made by the researcher.

Finally, increasing the magnitude of the effect is often the most practical method of increasing power (Rossi, 1990). This can be done by using a more sensitive research design, for example, a repeated measures design. Another way is by employing a more powerful statistical model. That is, multivariate and univariate procedures may differ in power depending on sample size and the validity of their statistical assumptions. In addition, error variance not associated with the independent variable may be removed statistically through a procedure such as analysis of covariance. Researchers should consider every available method of increasing ES so as to give themselves a realistic chance of detecting a true effect. The forgoing discussion shows that this is especially the case when the ES is known, or believed, to be small.

In summary, statistical power analysis can be used to check the adequacy of an investigation's experimental sensitivity. In particular, statistical power is the probability of correctly rejecting the null hypothesis. In hypothesis testing, the power for any given statistical test can be calculated by estimating the ES and specifying the sample size and alpha level. The evaluation of the ES can be based on past research or the sample data, but it is probably best to use J. Cohen's (1977) estimates of ES (which themselves have empirical support). Although EMF effects are likely to be small, past research involving humans has had extremely low power for detecting such effects. Power can be increased by manipulating the factors involved in statistical inference. In this respect, sample size is generally a practical issue, while the alpha level used should reflect the relative seriousness of Type I and Type II errors. In addition, the magnitude of the effect can by increased through statistical control of error variance. For example, using an analysis of covariance

to remove the effects of such factors as age. Finally, the most powerful statistical test should be employed, but this will often depend on the size of the sample and the validity of the test's assumptions.

Purpose and Rationale of the Present Study

The research reported here extended the work of Podd et al. (in press) by examining the effects of exposure to a weak intermittent ELF magnetic field on measures of human performance and cardiovascular response. Prior research has indicated that ELF field exposure may affect performance on relatively difficult tasks (e.g., Cook et al., 1992; Graham & H. D. Cohen, 1985; Graham et al., 1994), but does not seem to affect simple RT (e.g., Cook et al., 1992; Lyskov et al., 1993; Podd et al., in press). In the present study, a two-alternative, forced-choice visual duration discrimination task, with three levels of difficulty, was used as the measure of performance. The purpose of using this task was two-fold: (a) previous research had shown that performance on a similar signal detection type task was enhanced during real exposure compared to sham exposure (Graham & H. D. Cohen, 1985), and (b) it was important to find out whether magnetic field effects interact with task difficulty. The signal detection task used in the present study allowed distinctly different levels of difficulty to be set during pilot work. No previous EMF research on humans has attempted to maintain task constancy while varying task difficulty. The normal method for increasing task difficulty has been to change the task thereby confounding it with difficulty (e.g., Cook et al., 1992).

In addition to the performance measure, four cardiovascular measures were used because of their known sensitivity to environmental factors (see Cook et al., 1992). Also, past research at MRI has produced consistent field-related effects involving heart rate (e.g., Graham et al., 1994). Generally, these effects were greatest just after the field had been turned off. Therefore, in the present study, cardiovascular response was measured before and after both sham and real exposure. Previous research examining BP and EMFs has not shown field-related effects (Graham & H. D. Cohen, 1985). However, no research has specifically examined whether magnetic fields alone affect BP. Therefore, this question was incorporated into the present study.

Past research has produced a number of reliable effects, but has been plagued by inconsistent results and a failure to reproduce field-related effects. Thus, it was important to perform an experiment that provided the greatest chance of detecting a field-related effect if one actually existed. Podd et al. (in press) suggested that researchers in this area must give serious thought to minimising error variance and maximising statistical power. Therefore, a second aim of the present study was to have sufficient statistical power to detect a real effect by maximising experimental sensitivity. Statistical power analysis, both before and after the experiment, was used to examine the adequacy of the techniques used to maximise sensitivity. Therefore, the number of subjects needed to detect small effects was estimated based on a statistical power analysis (J. Cohen, 1977) conducted before the experiment began.

Cohen recommends a minimum statistical power of .80. Based on this level of power and an alpha level of .05, the experiment would have

required a total of 786 subjects to detect a "small effect" (Cohen, 1977), using a between-subjects analysis of variance. Clearly, practical constraints precluded this sample size. In the present study the largest sample size practically possible was judged to be about 100 subjects. With this sample size, power was estimated to be only .16. In other words, given a real field effect, there would be only a 16% chance of detecting it. Therefore, several methods of increasing statistical power were utilised.

First, a standardized experimental procedure and computer aided data collection were used to reduce experimental error and measurement error respectively. Secondly, a repeated measures design was used. Repeated measures designs are generally more powerful than between-subjects designs since they control for random between-groups differences (Plake & Wise, 1986). However, repeated measures designs have inherent disadvantages that must be addressed if they are to be used successfully, for example, carryover effects and practice effects. In the present study, these potentially confounding effects were controlled by counterbalancing session order under double-blind conditions and using each subject as his or her own control. Thirdly, the alpha level used to control the probability of a Type I error was relaxed. A traditional alpha level of .05 and beta of .20 (i.e., power of .80) implies that Type I errors are four times as serious as Type II errors. Given the exploratory nature of magnetic field research, it seems reasonable to suggest that Type II errors are in fact equally as serious as Type I errors. That is, given our poor understanding of the relationship between magnetic fields and human performance, it is just as much a problem to claim incorrectly that the null hypothesis is true as it is erroneously to conclude the

alternative hypothesis is true. In other words, it may be inappropriate to set the costs and values associated with making a Type I error at $p < .05$. Therefore, with this in mind, and the fact that at least 80% power was desirable, the alpha level was relaxed for testing field-related effects. (For the logic behind this argument see *Power and Design Sensitivity,* p. 61.)

The fourth method of maximising design sensitivity involved the use of intermittent exposure. Cook et al. (1992) suggested that some of their results pointed to the idea that intermittent exposure may produce stronger effects than continuous exposure. The reasoning behind the stronger effect of intermittent exposure is that the subject may be more sensitive to the transient signals created when the field is switched on/off compared to the continuously presented field. Subsequently, Lyskov et al. (1993) observed field-related effects on human physiology and learning during intermittent exposure but not during continuous.

Finally, the applied magnetic field was aligned with the geomagnetic field as specified by the parametric resonance model to maximise the chance of producing an effect (e.g., Liboff et al., 1987). The model was also used to determine the flux density of the applied field. However, since humans are typically exposed to magnetic fields generated by electrical equipment, the frequency of the applied AC field was set at 50 Hz.

METHOD

Subjects

One hundred and eighteen healthy volunteers (65 females and 53 males, age range 17 to 48 years, M = 22.80 years, SD = 5.67) who were Massey University undergraduates, postgraduates, or staff, served as subjects. Before the study each subject was screened to ensure that they met the following criteria: (a) they had not previously participated in magnetic field research; (b) they were not pregnant; (c) they had no chronic health or cardiovascular problems, and no history of brain of nervous system damage or disorder; (d) they had no illness resulting in bed confinement for more than three days in the past three months; (e) they were not currently undergoing psychotherapy and were not contemplating such treatment; (f) they were not taking any medication; (g) they had no dietary restrictions or unusual dietary habits; and (h) they had no metal prostheses, or implanted metal or electronic devices. The screening criteria were adapted from Cook et al. (1992). (See Appendix A for a copy of the screening questionnaire.) Seven subjects (5 females and 2 males) failed the screening questionnaire and were excluded from the study.

In addition to failing the screening questionnaire, a subject may have been excluded from the study if their BP fell outside the normal adult range. Normal adult BP has been defined by the World Health Organisation (WHO) as a systolic pressure equal to or below 140 mmHg, together with a diastolic (fifth Korotkoff phase) equal to or below 90

mmHg. No subjects were excluded from the study for having BP that fell outside this range. However, seven subjects (2 females and 5 males) were excluded because they did not appear at either the first or second session. Additionally, all the data for one female and one male subject were lost due to system failures, as were the performance data for two male subjects. Lastly, for one male subject no cardiovascular data were collected. This left valid performance data for 100 subjects (57 females and 43 males) and valid cardiovascular data for 101 subjects (57 females and 44 males).

At the first of two sessions each subject was required to read an information sheet and sign a consent form (See Appendix A for copies of the information sheet and consent form.) The information sheet gave a complete and accurate description of the goals, procedures, risks and benefits associated with the study, except where it would have compromised the double-blind procedure required by the experimental design. All procedures in this study were approved by the Massey University Human Ethics Committee and subjects were informed of their right to withdraw from the study at any time.

Experimental Design

A repeated measures design was used where all subjects participated in two 30 min experimental sessions on consecutive days. To control for time-of-day effects, each session was scheduled for roughly the same time each day. All bar two subjects had session times between 09:00 and 13:00 hrs. In addition, sessions were on consecutive days so as to

reduce the chance of external factors influencing the subjects' performance. However, this did introduce the potential for two further problems. First, there is the problem of the magnetic field if presented on the first day still affecting the subject on the second day (i.e., a carryover effect). Secondly, practice effects: that is, a subject's performance may change from one day to the next due to practice, regardless of a field-related effect. To control for these potential confounding effects the session order was counterbalanced under double-blind conditions and each subject served as his or her own control. Repeated measures designs have important advantages over between-subjects designs. First, they control for random between-groups differences. Second, they allow greater statistical power for detecting within-subjects effects. And third, they allow generalisations to be made to individuals rather than just groups (Plake & Wise, 1986).

Measures

Two performance measures, four cardiovascular measures, and a subjective measure were used as dependent variables. The performance task, conducted during both real and sham exposure, was a two-alternative, forced-choice visual duration discrimination task with 3 levels of difficulty. The three levels of difficulty were determined *a priori* from pilot work. The hardest level of difficulty was set to yield, on average, 60% correct decisions, the intermediate level 80%, and the easiest level 90%. The cardiovascular measures were collected before and after exposure. The subjective measure was conducted at the end of the experiment. Definitions for each measure are:

Reaction time (RT). RT is the time taken in ms for a subject to press one of the response keys after the onset of the second stimulus in the discrimination task.

Percentage correct (PC). PC is the percentage of correct decisions calculated separately for each level of task difficulty.

Systolic blood pressure. The maximum pressure in the arteries measured in millimeters of mercury. This is determined from the point the pulse begins to beat again after having been totally cut off by the inflation of the cuff.

Diastolic blood pressure. The minimum pressure in the arteries measured in millmeters of mercury. This is determined as the point that pulse pressure in the artery returns to normal after cuff deflation.

Pulse rate. Pulse is based on palpitation in the brachial artery and is recorded as the number of heart beats per minute.

Mean arterial pressure (MAP). MAP is defined as the "...value occurring at the point of maximum oscillations within the cuff, and can be geometrically presented as the value corresponding to a horizontal line through a pressure wave tracing such that the systolic area above the line is equal to the diastolic below it....MAP has been shown to be a good indicator of blood pressure variability associated with sympathetic activity" (Cumes-Rayner & Price, 1988, p.183).

Field status questionnaire (FSQ). After the subjects were debriefed, the FSQ (developed by Cook et al., 1992) was used to evaluate the effectiveness of the double-blind procedure (see Appendix A for a copy of the FSQ). During debriefing the subjects were told that they had only been exposed to the magnetic field during one of the two sessions, rather than during both. They were then asked to judge which session they thought the field was on and which session they thought the field was off.

Apparatus

A Helmholtz configured coil pair was used to generate a homogeneous, time-varying magnetic field around the subject's head. Each coil was wound from 120 turns of 0.001 m diameter copper wire with the vertical axis having a 0.39 m diameter, spaced 0.19 m (see Figure 1), and orientated north-south. The magnetic field had a sinusoidal waveform, its flux density being 100 μT (rms) and frequency 50 Hz. Exact computations of the magnetic field within the exposure volume were performed using a computer programme[1] which showed that the field was homogeneous to ± 10% of the nominal value (see Figure 2). Sham exposure was carried out with the same exposure system, but no current was flowing through the coils. The geomagnetic field (GMF) was 56 μT (approximately 56% of the applied field) at an inclination of 65.56 degrees North.

[1]Items not given a manufacture's name were made in the workshops of the Departments of Production Technology and Psychology, Massey University.

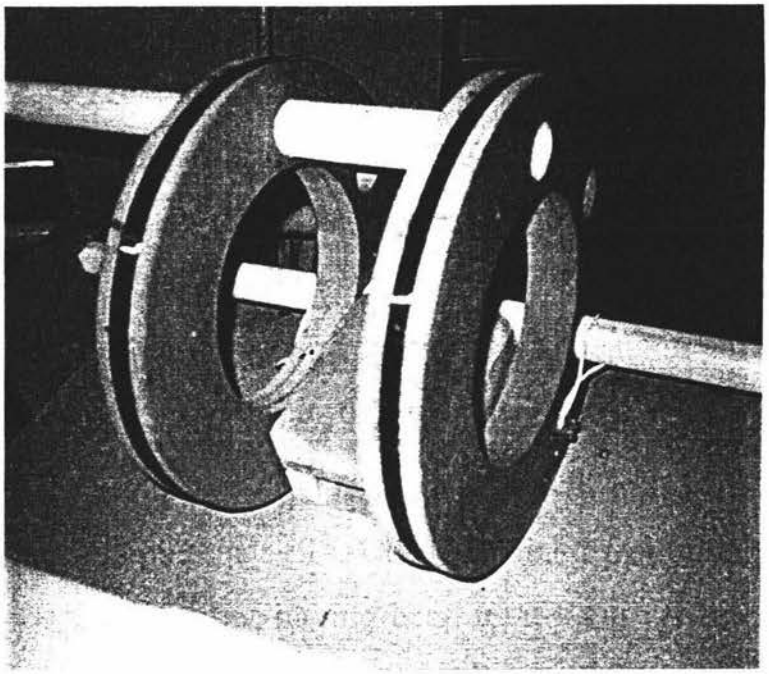

Figure 1. Photograph of Helmholtz-type coil pair with the coil interspace distance equal to the radius.

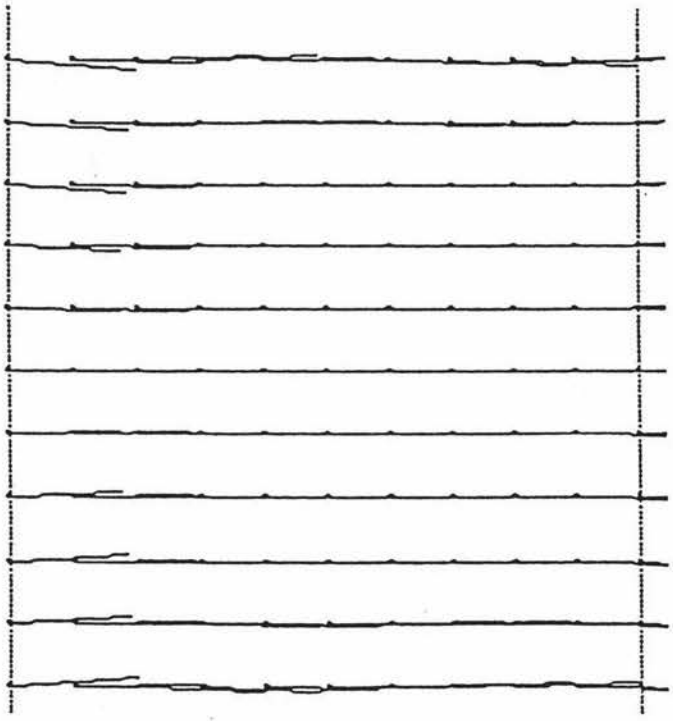

Figure 2. Lollipop plot showing coil interspace. Vertical lines represent coils, horizontal lines represent homogeneity (deviations from the horizontal plane indicate decreasing homogeneity).

To correctly position the magnetic field parallel to the geomagnetic field, subjects were faced towards magnetic north and inclined on a foam covered wooden platform at an angle of 24.44 degrees (see Figure 3). The coils were positioned to the front and back of the head. All materials used in the construction of the exposure apparatus were made of wood, plastic, or foam with no metal parts that might disrupt the field.

Regular measurements of the ambient AC magnetic field were made using a Bell 9200 gaussmeter and a Bell 4th generation Hall effect probe. The background field was consistently less than 30 μT in the area of the exposure apparatus.

The data-acquisition system consisted of a Hewlard Packard (HP) 9000 (series 310) computer in conjunction with an HP 6944 multiprogrammer that controlled the experiment and collected the performance data. The multiprogrammer was located in a room adjacent to, but separate from, the room that contained the HP computer and exposure apparatus. The computer switched the current to the coils on or off depending upon the condition being run. The actual order of conditions for any given subject was pseudorandomized with the restriction that no more than six consecutive subjects could receive the same order. A restriction of six was used to ensure that similar numbers of subjects received each order and conversely to ensure that the order remained unpredictable as required by the double-blind protocol. The HP computer also constantly monitored the current to ensure that the correct field strength was maintained. In the event the current ranged outside the set limits, the system was programmed to shut down automatically.

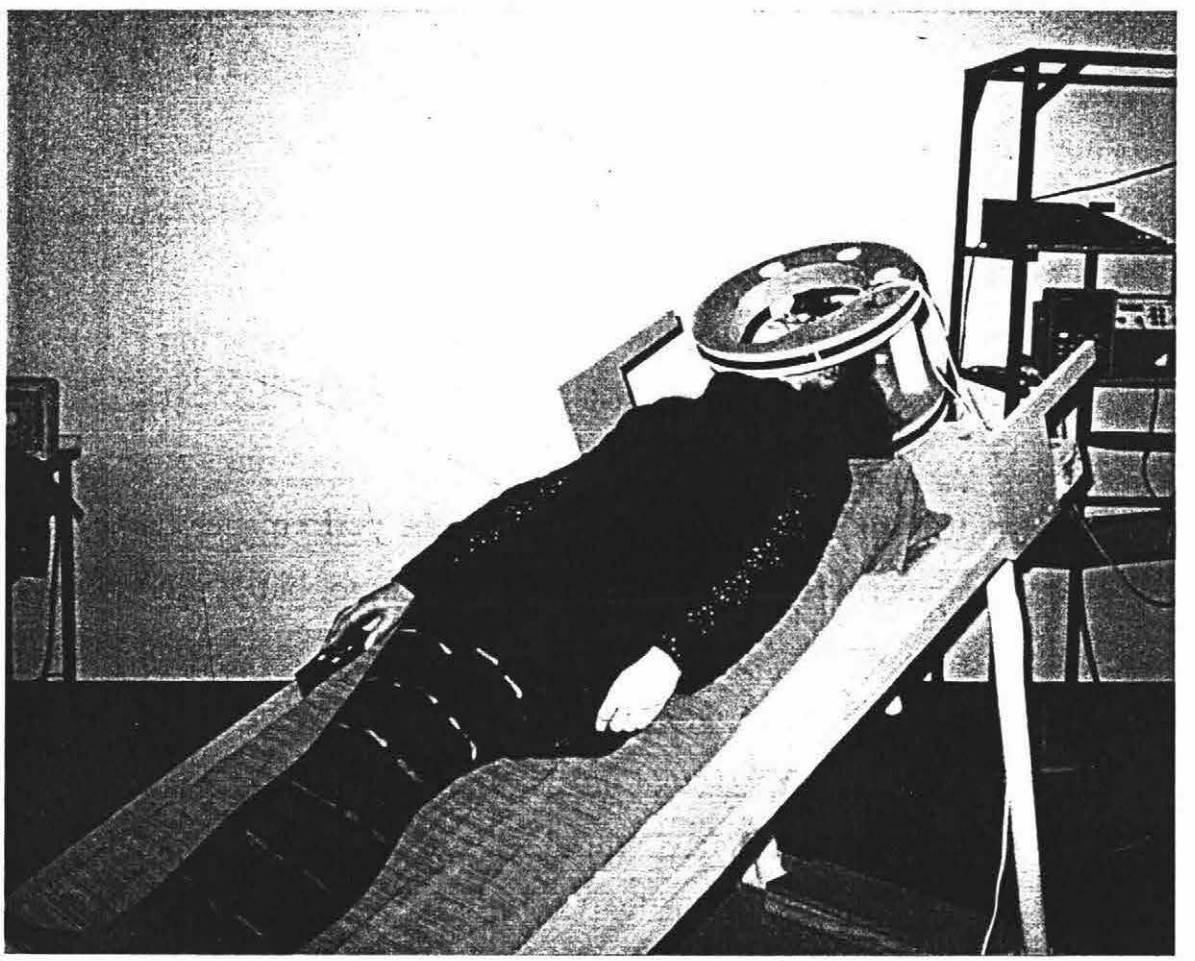

Figure 3. Exposure apparatus, with subject facing north and inclined on an angle of 24.44 degrees.

To produce the magnetic field, a 50 Hz sine wave was created by a function generator and sent through a zero-crossover switch. The HP computer was programmed to turn the switch on and off at zero-axis crossings following a 1 s on/ 1 s off cycle, thus creating an intermittent field. In addition, the sham (no field/control) condition was created by turning the zero-crossing switch off. After passing through the switch, the signal was sent to a 300 W power operational amplifier that produced a current of 0.18 A (rms), which was passed directly to the coils. All generating equipment was located inside a small sound attenuated booth. The sine wave output was monitored initially by means of a Tektronix 2221 oscilloscope and during subsequent checks by a Fluke 87 digital multimeter. The current of 0.18 A produced a theoretical field strength, B, midway between the coils, of 100 μT. The field strength in milliTesla is calculated as

$$B = ([0.9 \times N \times I] / A) / 1000 \qquad (2)$$

where N is the number of turns of wire around each coil, I is the number of amps, and A is the coil radius in meters. Verification of the theoretical field strength was made with the Hall effect probe placed in the center of the Helmholtz coil.

During test sessions, the coils were not observed to cause perceivable sound, vibration, or thermal radiation. Lyskov et al. (1993) found that subjects could not detect a magnetic field 10 times as strong as the field used in the present study.

A Critikon Dinamap 8100T Portable blood pressure monitor in conjunction with an IBM-compatible computer were used to record and store the cardiovascular data. The Dinamap 8100T uses oscillometric measurement to record systolic and diastolic BP and pulse rates. Reliability is high because re-measurement is automatic in the presence of movement or other artifacts that might affect measurement (Cumes-Rayner & Price, 1988). Fortnightly calibration of the Dinamap 8100T against a standard sphygmomanometer (Trimline, PyMaH Corp.) provided accurate pressure readings to within ± 2 mmHg. The complete exposure system is presented in Figure 4.

Trial Sequence

The temporal sequence of events for one trial is shown in Figure 5. The stimulus consisted of two consecutive flashes (500 ms apart) of a red LED. On every trial the computer emitted a 1000 Hz warning tone of 100 ms duration followed 400 ms later by either a standard 50 ms flash or one of three alternate flashes: a 65 ms flash (hard task), a 100 ms flash (intermediate task), or a 125 ms flash (easy task). A standard light flash was always paired with an alternate flash. The actual order of flashes in any given trial was pseudorandomized with the restriction that no more than four trials with the same order were presented consecutively. A nominal 1500 ms decision interval was given, at which point if the subject had not responded, the computer recorded the trial as invalid. The warning tone sounded again 2650 ms after the onset of the second flash signalling the beginning of the next trial. Each trial lasted an average of 3723 ms with a range of 3700 ms to 3775 ms depending on stimulus difficulty. The whole trial sequence was validated by

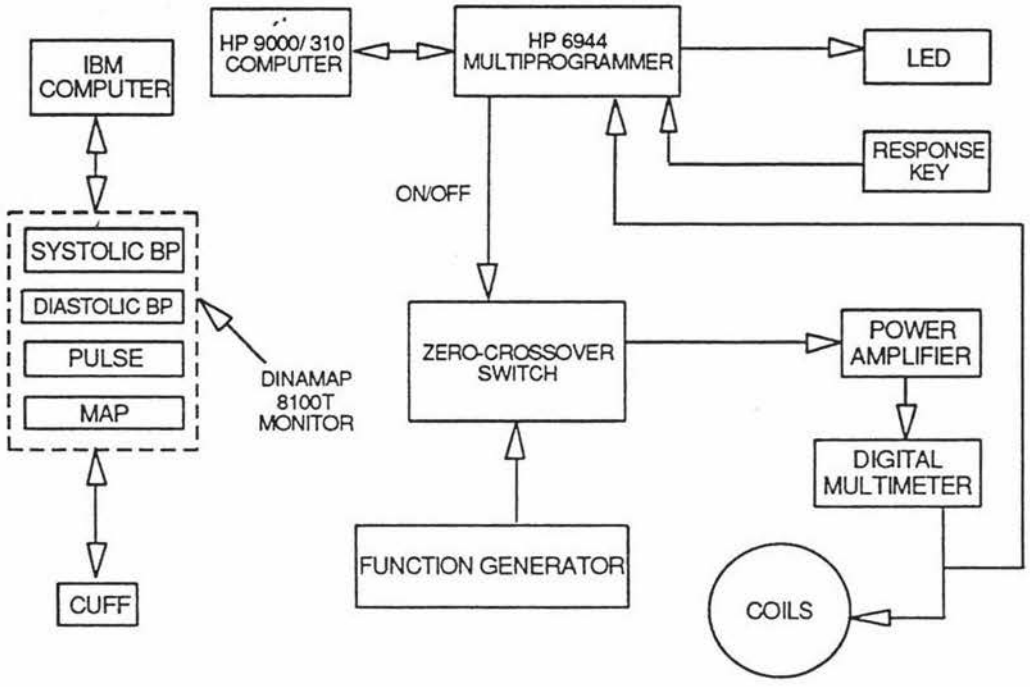

Figure 4. Flow diagram of the complete exposure system.

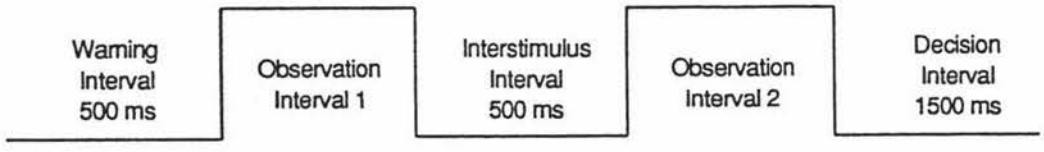

Figure 5. Temporal sequence of events for one trial.

means of a Tektronix 2221 oscilloscope. The LED was suspended from the ceiling approximately 2.50 m from the subject and in direct line-of-sight when the subject was correctly positioned on the exposure apparatus. An adjustable response pad with two keys was placed in the most comfortable position at the subject's side for use with the preferred hand.

Procedure

Subjects individually participated in two sessions each, approximately 30 min in duration, on consecutive days at the same time each day. At the beginning of the first session subjects were asked to read an information sheet, were shown the exposure system, and then asked for written informed consent. Subjects were then positioned on the experimental apparatus with their head held in place by a head rest and centred between the two coils. Standardized prerecorded instructions were played to subjects via a portable cassette player. (See Appendix B for a copy of the instructions.) The instructions asked each subject to fixate on a small LED and stated that a warning tone would sound, after which the LED would flash twice, and it was their task to decide which flash was longer in duration, the first or the second. Subjects were asked to respond by pushing one of two buttons located on the side of their dominant hand. Subjects were told to push button 1 if they believed the first flash was longer than the second flash, or button 2 if they believed the second flash was longer. Equal emphasis was placed on speed and accuracy. The instructions also led subjects to believe that the magnetic field would be on for both sessions and stressed that they had the right

to withdraw from the study at any stage. The code number of each subject was then entered into the HP computer.

All sessions began with two sets of 25 warmup trials. After each set of warmup trials the computer produced mean performance data. Verbal feedback was given to subjects when either accuracy was less than 50% (indicating they had not understood the instructions) or response times were greater than 1000 ms. A short break then followed during which the preexperimental cardiovascular measures were recorded. The subject remained on the exposure apparatus while a BP cuff was attached to the left arm covering the brachial artery. Each subjects' code number was then entered into the IBM computer after which automatic cuff inflation began. Each inflation and determination of BP took 20-45 sec following 1 min cycles, yielding four readings during the preexperimental period. Subjects were unable to see the blood pressure reading. The cuff was then removed and the 150 experimental trials were run without a break (approximately 9 min in duration). The experimental trials were immediately followed by four postexperimental BP readings, taken in the same way as the preexperimental readings. At the end of the second session subjects were fully debriefed concerning the design of the experiment and asked to complete the FSQ. Subjects were then thanked for participating and told when and where the group results would be displayed. Subjects were also given the opportunity to obtain their own results if they wished.

STATISTICAL ANALYSES PROCEDURE

The MANOVA Procedure

All major data analyses were executed using the multivariate analysis of variance (MANOVA) procedure in the Statistical Package for the Social Sciences (SPSS/PC+, SPSS Inc., 1986). Appendix C contains a copy of the SPSS/PC+ command programmes used to run the statistical analyses. The MANOVA procedure can be used as a method of conducting doubly multivariate tests of significance, where a researcher is interested in looking for overall (main, interaction) effects on some combination of dependent variables that are repeatedly measured. Repeated measures designs are essentially multivariate in nature since the observations obtained are correlated (Vasey & Thayer, 1987). In the case of a repeated measures design involving multiple dependent variables (DVs), SPSS/PC+ can provide multivariate tests of significance using all DVs, multivariate tests of significance on each DV alone, and univariate tests of significance (equivalent to a repeated measures ANOVA).
Traditionally, omnibus MANOVA has been interpreted by following the overall analysis with multiple univariate *F*-tests where each DV is analyzed separately. However, it has been argued that multivariate tests and univariate tests address different research questions (e.g., Bray & Maxwell, 1982; Huberty & Morris, 1989). Moreover, there is no direct relationship between the significance of the MANOVA test and the individual univariate tests (Bray & Maxwell, 1982). For this reason Huberty and Morris suggest that a "doubly" multivariate analysis (i.e.,

involving more than one DV) should be interpreted with a multivariate approach such as discriminant analysis.

Discriminant analysis is especially useful in assessing the relative importance of each DV since the intercorrelations among the DVs are taken into consideration (Bray & Maxwell, 1982). In contrast, the univariate *F* ratios are calculated without regard to the other variables. However, Huberty and Morris (1989) suggested that it may be appropriate to follow an overall MANOVA with multiple tests of significance when previous studies have examined the dependent variables separately. Thus, using multiple multivariate or univariate *F*-tests would allow comparisons to be made with past research.

Nevertheless, a number of other reasons may influence what approach should be taken when the experimental design includes a repeated measures factor. For example, the multivariate approach is preferred to the univariate approach when the assumption of homogeneity of variance over within-subjects independent variables is violated (Tabachnick & Fidell, 1989), or when the assumption of sphericity is violated substantially (Hertzog & Rovine, 1985). For sphericity to hold, all repeated measures must have equal variance and be correlated equally with each other. Hertzog and Rovine suggested using MANOVA when estimates of epsilon are below .75, since MANOVA is not limited by the sphericity assumption. Moreover, given severe violations of the sphericity assumption the multivariate approach is generally thought to be as powerful as the epsilon-corrected univariate approach (O'Brien & Kaiser, 1985), and provides more valid Type I error rates (Hertzog & Rovine, 1985). Additionally, the power of a doubly multivariate test is

influenced by the size and direction of the correlations between DVs and the relationship between ESs (Cole, Maxwell, Arvey, & Salas, 1994). In the present study all DVs are likely to be associated with small effects (the logic behind this reasoning is given in a later section), and so power will increase as the correlations between DVs move from 1.0 to -1.0 (Cole et al., 1994). Where high positive correlations are expected in conjunction with small effects, and the statistical assumptions are not severely violated, the power of an averaged univariate test is likely to be greater than its multivariate counterpart. Therefore, the approach used in the present study involved a combination of the methods just described depending on the situation. The details of the methods used are given within the context of the appropriate analyses.

SPSS/PC+ provides the user with several useful multivariate statistics to test significance of main effects and interactions, including Pillai's trace which is the criterion used in the present study. Pillai's trace, the most robust and often most powerful criterion for testing whether mean differences among groups on a combination of DVs are likely to have occurred by chance, has been recommended for general use (Hand & Taylor, 1987; Olson, 1976; but see Bird & Hadzi-Pavlovic, 1983, for exceptions).

The statistical assumptions of both the multivariate and univariate approaches were checked prior to the statistical analyses. The first assumption, that each subject's observations were independent of those of the other subjects, was assumed valid because of the experimental design used. That is, each subject was run through the procedure individually and asked not to discuss the experiment with other subjects.

SPSS/PC+ was used to validate the other assumptions of MANOVA. In particular, the assumption of homogeneity of variance-covariance matrices was considered to be violated (for the multivariate case) if Box's M test was highly significant (Tabachnick & Fidell, 1989, stated that this test is extremely sensitive.) Similarly, for the univariate case the assumption was considered to be violated when Cochrans C or the Bartlett-Box F were significant. In the present investigation, the homogeneity assumption was considered to be satisfied (all p values > .01). In addition, the assumptions of multicollinearity and singularity, necessary for MANOVA, were confirmed by the fact that all determinants of the pooled within-cell correlation matrices significantly differed from zero (all p values < .05). The assumption of multivariate normality was assumed to be valid as the sample size of 100 provided far more than the 20 df for error suggested to assure multivariate normality (Tabachnick & Fidell, 1989). Z scores were calculated for both the performance and cardiovascular data to check for univariate outliers. (Note that the RT data checked for outliers were the median RTs of each subject.) Several subjects had z scores of 3 or more. In particular, one subject had slow response times during both sham and real exposure. The possibility existed that this subject was performing slowly in an attempt to be more accurate (i.e., a speed-accuracy tradeoff). However, a check of the subject's accuracy did not reveal any such tradeoff (i.e., PC scores were within one standard deviation of the mean). Therefore, there were no grounds for removing this subject's data. Three subjects had accuracy z scores of more than 3 standard deviations from the mean. These subjects all had low PC scores (two subjects during real exposure, one subject during sham exposure). A check of RT did not reveal a speed-accuracy tradeoff, and so these

subjects' data were considered valid and left in the analysis. Multivariate outliers were assessed using Mahalanobis' distance. Mahalanobis' distance is based on the distance a case is from the average values of the independent variables, and can be used to determine how influential the case is (SPSS Inc., 1992). No outliers were found for the performance data, although for the cardiovascular data four cases appeared to be multivariate outliers. However, a careful check of these subjects' data revealed no basis for removing them.

The performance and cardiovascular data were subjected to separate MANOVAs since these measures were taken to represent separate variable systems (Huberty & Morris, 1989). That is, they were viewed as being conceptually independent of each other. Under these circumstances, it is usual to conduct separate MANOVAs.

Performance Data

The discrimination task yielded data for two DVs: reaction time (RT), and accuracy (recorded as the percentage of correct decisions, PC). To analyze the data from these DVs a number of steps were taken:

1. The raw data for each subject (a maximum of 150 trials per condition) were subdivided according to the three levels of difficulty.

2. The median RT, and PC for each level were then computed (see Appendix D for a copy of each subject's data). The median was used to

summarize the RT of each subject because the median is a measure of central tendency that accords less weight to outlying scores (Milner, 1986; Ratcliff, 1993; but see Bush, Hess, & Wolford, 1993, and J. Miller, 1988, for warnings about using the median).

3. The data for both DVs were subjected to a 2 x 2 x 2 x 3 (Order by Gender by Exposure by Difficulty) doubly multivariate analysis of variance with sequential adjustment for nonorthogonality. There were two between-subjects factors: order, with two levels (real exposure on day one, sham exposure on day two, or alternatively, sham exposure on day one, real exposure on day two), and gender (male or female). The inclusion of gender effectively made the design nonorthogonal since the number of males and females differed substantially. Order was included in the analysis to check that the counterbalancing procedure worked and to remove any variance due to practice. There were two within-subjects factors: exposure, consisting of two levels (real or sham), and difficulty, with three levels (hard, intermediate, or easy). Age was considered for use as a covariate since research (Salthouse, 1994) has shown that increased age is associated with slower RT and lower accuracy. However, age was finally rejected as a covariate since an initial analysis indicated that, at least in the present study, there were no consistent linear relationships, across exposure conditions, between the DVs and age (see Appendix E). The most likely reason for this was the fact that while the age range was 31 years, 88% of all subjects were under the age of 26 years.

4. Initially a doubly multivariate analysis was used because the two DVs were not independent and there was likely to be some intercorrelation

between the two. In fact, a preliminary analysis indicated that RT and PC were negatively correlated, r (100) = -.20, p = .03. Therefore, MANOVA was used to look for an overall magnetic field effect on performance. Averaged tests of significance were not used since small values of the Huynh-Feldt epsilon (i.e., < .75), indicated that the assumption of sphericity was violated substantially. In addition, the F_{max} test indicated that the assumption of homogeneity of variance over within-subjects independent variables was violated. That is, there was a significant main effect for difficulty, F_{max} (2, 192) = 81.76, p < .01, and a significant interaction between exposure and difficulty, F_{max} (1, 192) = 31.71, p < .01.

5. Discriminant analysis was used to assess the relative contribution of the DVs to any field-related effects. Standardized discriminant function coefficients were calculated for each DV with an alpha of .30 for entry. (See p. 61 for a discussion on relaxing alpha.) The magnitude of the coefficients provide information about the variables contributing most to group differences (SPSS Inc., 1992).

6. Whether or not significant doubly multivariate effects were found, separate multivariate (or univariate, where the numerator df was 1) tests were run on each DV alone. The reason for doing this was based on the logic of Huberty and Morris (1989) which was described above. Essentially, the use of this approach allows comparisons with past research which have examined the effects of ELF fields on each DV alone (e.g., Graham et al., 1994). In addition, where sphericity was not substantially violated (i.e., Huynh-Feldt epsilon > .75), averaged tests of significance, adjusted by the Huynh-Feldt epsilon correction, were also

reported where appropriate. The degrees of freedom reported were the uncorrected values. Following significant omnibus effects, tests of the simple main and interaction effects were used to interpret where the effect was occurring. All tests of simple effects were performed within MANOVA.

Cardiovascular Data

The cardiovascular data consisted of four dependent variables: systolic BP, diastolic BP, pulse rate, and mean arterial pressure (MAP). The statistical analysis of these data followed similar steps to that of the performance data:

1. For each dependent variable, data consisted of four preexperimental readings and four postexperimental readings for each subject. To establish an accurate measure, only the mean of the last two readings was used for both pre- and post-periods (see Appendix D for a copy of each subject's data).

2. The mean data were subjected to a 2 x 2 x 2 x 2 (Order by Sex by Exposure by Period) doubly multivariate analysis of variance with the sequential adjustment for nonorthogonality. Order, again with two levels (real exposure on day one, sham exposure on day two, or alternatively, sham exposure on day one, real exposure on day two), and gender (male or female) were between-subjects factors, and exposure (real or sham) and period (pre- or post-) were within-subjects factors. Note that the clearest indication of a field-related effect would be a significant

exposure by period interaction (real and sham exposure equivalent before the exposure period, but different after the exposure period). As with the performance measures, there were intercorrelations among the cardiovascular measures. All measures were positively correlated. Hence, the need for an overall MANOVA. In particular, for systolic and diastolic BP, $r = .443$, $p < .001$, for diastolic and pulse, $r = .451$, $p < .001$, for systolic and pulse, $r = .120$, $p = .230$, for systolic and MAP, $r = .78$, $p < .001$, for diastolic and MAP, $r = .78$, $p < .001$, and for pulse and MAP, $r = .44$, $p < .001$, ($n = 101$ for all correlations).

3. The multivariate analysis was then followed by univariate F-tests on each DV (again following Huberty and Morris, 1989) to look for separate field-related effects and allow comparisons with past research. Any significant effects were then interpreted using tests of simple interaction effects to detect where the effect was occurring. Again, as with performance, the multivariate interaction involving gender was examined to assess whether the field differentially affected males and females, and age was again considered for use as a covariate since research has shown that it is positively correlated with BP (Scragg, Baker, Metcalf, & Dryson, 1993). Nevertheless, age was finally rejected as a covariate for the analysis of systolic BP, pulse, and MAP since an initial analysis indicated that there was no linear association with age (see Appendix E). However, the initial analysis did indicate that there was a reliable association between age and diastolic BP. Therefore, age was tried as a covariate when examining the effect of exposure on diastolic BP, but it did not make any difference to the results. So, the results reported here are those produced without age as a covariate.

Power and Design Sensitivity in the Present Study

Given the fact that ELF electromagnetic field research on humans and animals has produced inconsistent and rather elusive results, it seems reasonable to suggest that any effects are likely to be small. Therefore, it is necessary to ensure that experiments are maximally sensitive to any effects that might occur. For this reason it is imperative that when considering the likelihood of making a correct decision concerning hypothesis support, the costs and values of making both a Type I error and a Type II error be considered. Furthermore, traditional significance testing in this area of research is associated with extremely low statistical power (just 7%) to detect small effects (see *Design Sensitivity and Statistical Power,* p.25, for evidence). In the present study several methods (e.g., using as large a sample size as practically possible and using a repeated measures design) were first used to increase statistical power. Even so, the amount of power available was still not adequate to detect small effects. In such circumstances, it has been argued that alpha can be relaxed *a priori* after considering the relative seriousness of both Type I and Type II errors (e.g., Cascio & Zedeck, 1983; J. Cohen, 1977). Given the exploratory nature of magnetic field research, it can be argued that Type II errors are equally as serious as Type I errors. Any indication at all that the magnetic field might be having an effect should not be overlooked, or dismissed as "not statistically significant". In other words, in exploratory research, especially where ESs are likely to be small, it may be inappropriate to set the costs and values associated with making a Type I error at $p < .05$. Therefore, with the above arguements in mind coupled with the desire to have at least an 80% chance of detecting real field-related effects, alpha was set *a priori* at .30.

Once the alpha level has been established, the next problem is how to partition alpha within an experiment so as not to capitalise on chance (i.e., how to prevent the probability of a Type I error being inflated). R. G. Miller (1966) states that there is no convention when it comes to this matter and it is up to the researcher to decide which approach to take.

What ever approach is taken, the first decision to be made when attempting to control Type I error is what constitutes a family of statistical statements. R. G. Miller (1966) suggested that there are two extremes. On the one hand, it may be argued that a single family should consist of every statement one might make in one's lifetime. On the other hand, each separate statistical statement may be considered a family without regard to the fact that a group of statements may be related. R. G. Miller suggested that for factorial designs, one (less conservative) approach is to take the row effect statements as one family, columns effects as another, and interactions another. It is this approach that is used in the present study. As described above, the performance and cardiovascular data represent separate variable systems and so each was considered to come from a separate family. Each variable system was further divided into separate families. For performance, the difficulty effects were considered as one family, the exposure effects as another, and interactions another. It seemed sensible to separate the two main effects into separate families because the affect of difficulty was established before the experiment, during pilot work. Because the effect of difficulty was set *a priori*, a more conservative alpha level was used for the main effect of task difficulty (i.e., $\alpha = .05$). For the cardiovascular data a similar approach was taken, period effects being

considered as one family, exposure effects as another, and interactions another. It seemed reasonable to do this because only an interaction could be taken as evidence of a field-related effect.

The second decision to be made was how to control Type I error when multiple, related DVs are used. Since both the performance and cardiovascular data consisted of multiple DVs, the Bonferonni adjustment was used. This procedure controls for inflated Type I error rates due to testing multiple DVs by dividing alpha by the number of DVs. Therefore, for field-related effects familywise error = .30 (i.e., the probability of a Type I error within a family of statistical tests was set at .30) was achieved for the performance data by setting alpha at .15, and for the cardiovascular data by setting alpha at .075. For non field-related effects involving difficulty, familywise error = .05 was achieved by setting alpha at .025. Because tests of simple main or interaction effects were only used to interpret significant omnibus analyses, Fisher's least significant difference (LSD) test was used to make the required multiple comparisons while maintaining familywise error. Kirk (1968) provides a clear description of the LSD test, suggesting that once the overall F ratio is significant, the test can be used to make all pairwise comparisons among means. The least significant difference between two means according to the LSD test is given by $t_{\alpha/2,\nu}\,(2MS_{error}/n)^{1/2}$, where $t_{\alpha/2,\nu}$ is the upper percentage point from the student's t distribution for ν degrees of freedom (Kirk, 1968). The degrees of freedom, ν, for this test is the ν associated with the denominator of the F ratio. If a difference between sample means exceeds the LSD, the difference is declared significant.

In the present analysis, for all significant effects the exact *p* values are reported followed by the observed ES (J. Cohen's *f*, calculated from partial eta^2 [eta squared], see J. Cohen, 1977). For multivariate effects, partial eta^2 was taken to be equivalent to Pillai's trace (Hager & Moller, 1986). For univariate effects, partial eta^2 was based on the following expression: partial eta^2 = [*F* x (df effect)] / [*F* x (df effect) + df error]. Partial eta^2 slightly overestimates the magnitude of the effect in the population but has the advantage of being consistent and applicable to all *F*-tests (SPSS Inc., 1992). Cohen's ES for an *F*-test was then determined from partial eta^2 using the relation, $f = [\eta^2 / (1 - \text{eta}^2)]^{1/2}$ (Cohen, 1977).

Finally, the power of those statistical tests used to examine field-related effects was calculated *post hoc*. A knowledge of the power of such tests allows greater accuracy in interpreting both significant and nonsignificant results. Power values for selected multivariate and univariate tests using J. Cohen's (1977) small, medium, and large ESs, at alpha levels of .05, .10, and .30 were calculated where possible. In addition, the power of those tests that showed significant field-related effects were calculated using the observed ESs and the actual alpha level employed.

RESULTS

Analysis of the FSQ[2]

Ninety seven subjects provided valid data on the FSQ. One could expect by chance alone that 50% of the subjects would make correct judgements about whether the field was on or off. The results showed that 55% of the subjects actually made correct judgements. A Chi-square test showed that the difference between the observed frequencies and the expected frequencies was not significant, X^2 (3, N = 97) = .50, p =.92.

Analyses of Performance Measures

Reaction Time and Accuracy

Doubly multivariate tests of significance. The counterbalancing procedure was effective with no evidence of a main effect for order, F (2, 95) < 1. As expected, with an alpha level of .05, the main effect for the levels of task difficulty was statistically significant, F (4, 93) = 334.15, p < .001, ES = 3.64. However, with an alpha level of .30, the MANOVA provided no evidence of a multivariate main effect for exposure, F (2, 95) < 1. Nevertheless, with an alpha level of .30, the MANOVA indicated a significant interaction between exposure and difficulty, F (4, 93) = 1.45, p = .23, ES = .25.

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[2]The SPSS/PC+ output for all major tests of significance can be found in Appendix F.

Discriminant analysis. Standardized discriminant function coefficients were only calculated for the exposure by difficulty interaction since this was the only reliable field-related effect. The results showed that RT had the largest coefficient (.99) when compared to PC (-.04). These coefficients indicate the relative contribution of each DV to the interaction effect. Clearly, RT was the most important variable involved in the interaction.

Reaction Time

Multivariate tests of significance. Averaging across exposure conditions mean RTs[3] for the hard, intermediate, and easy levels of the task were 723.97 ms (132.61), 643.38 ms (114.79), and 610.99 ms (108.31), respectively. With an alpha level of .025, the MANOVA indicated a significant main effect for difficulty, F (2, 95) = 100.26, $p < .001$, ES = 1.46. Averaging across the levels of task difficulty, mean RTs for real and sham exposure were 656.81 ms (121.82) and 662.08 ms (118.38), respectively. With an alpha level of .15 there was no indication of a significant main effect of exposure ($F < 1$). Most importantly, and as can be seen in Figure 6, the effect of exposure on RT appeared to depend on the level of task difficulty. With an alpha level of .15, both the multivariate F-test and averaged F-test indicated that this interaction was significant, F (2, 95) = 2.95, $p = .06$, ES = .25, and F (2, 192) = 3.65, $p = .03$, ES = .20, respectively. Table 4 provides the means and standard deviations for RT for sham and real exposure by task difficulty. To interpret these significant results, tests of the simple main and interaction effects were undertaken within the MANOVA procedure.

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[3]Here and in all future presentations of mean values, the standard deviations will be given in parentheses following the means.

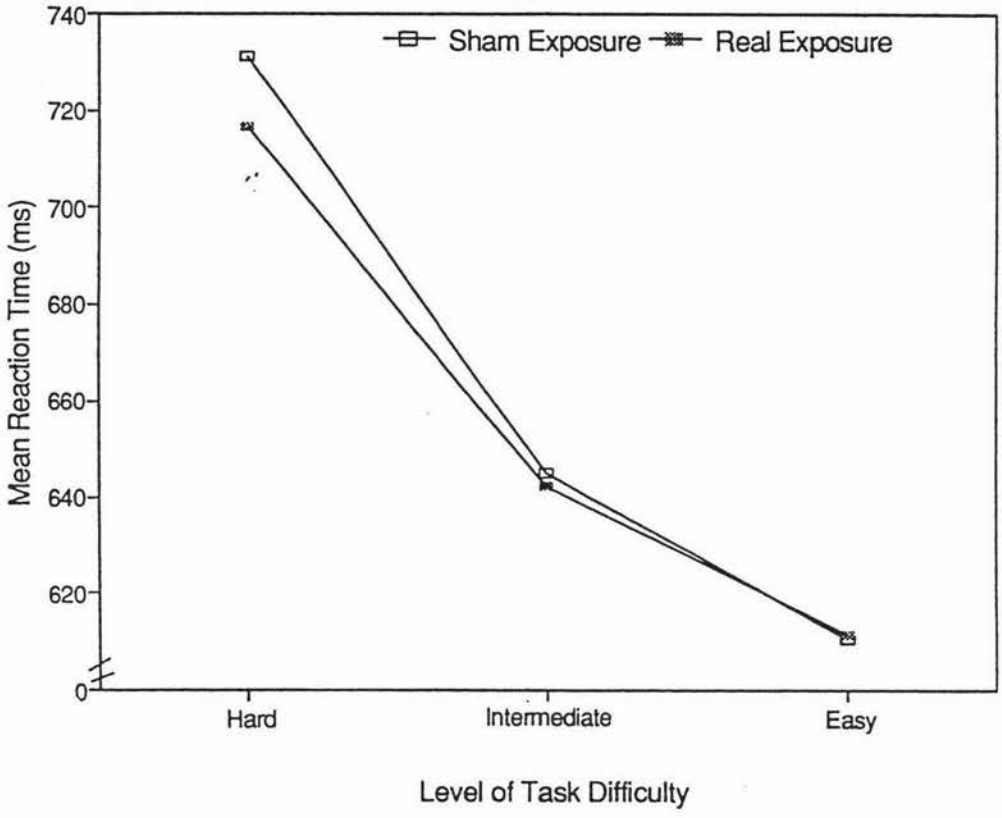

Figure 6. Mean reaction time as a function of exposure and task difficulty. The difference between sham and real exposure was only significant for the hard level of difficulty (p = .04).

Tests of the simple main effects. For the tests that follow, alpha was set at .025. The results indicated that all pairwise comparisons between the levels of difficulty were highly significant (all *ps* < .001). Because multiple comparisons were made, these results were confirmed using the LSD test which controls for inflated familywise error. The LSD test indicated that the least significant difference between the hard and intermediate levels of the task was 21.15 ms, and between the hard and easy levels it was 25.87 ms, and between the intermediate and easy levels, 11.47 ms. Since the observed differences of 80.59 ms, 112.98

Table 4

Mean reaction time and accuracy for all subjects during real and sham exposure for each level of task difficulty. SDs are shown in parentheses.

	Task Difficulty		
Exposure Condition	Hard	Intermediate	Easy
	Reaction Time[a]		
Real	716.80_{d} (140.85)	642.00 (127.18)	611.64 (115.53)
Sham	731.14_{c} (139.31)	644.77 (118.37)	610.35 (117.25)
	Accuracy[b]		
Real	62.11 (8.35)	83.49 (10.45)	89.09 (10.13)
Sham	61.90 (7.31)	83.62 (10.66)	89.55 (9.09)

Note. Means with different subscripts differ significantly at $p = .04$.
[a]The values represent reaction time in milliseconds. [b]The values represent percentages of correct discriminations.

ms, and 32.39 ms for the hard and intermediate, hard and easy, and intermediate and easy comparisons, respectively, were well above these values it appeared that all pairwise differences were reliable.

Tests of the simple interaction effects ($\alpha = .15$). On average, subjects showed significantly faster RTs for the hard level of the task when exposed to the 100 μT magnetic field ($M = 716.80$ ms, $SD = 140.85$) compared to sham exposure ($M = 731.14$ ms, $SD = 139.31$). The F-test

indicated that this difference was significant, F (1, 98) = 4.15, p = .04, ES = .20. The decrease in RT did not appear to be due to a speed-accuracy tradeoff. There was no significant field-related effects for the intermediate or easy levels of the task, all F values being less than unity. According to the LSD test, the least significant difference between real and sham exposure was 11.66 ms. Since the observed difference for the hard level of the task was 14.34 ms, the difference was assumed to be reliable. However, the observed differences of 2.77 ms and 1.29 ms for the intermediate and easy levels, respectively, could not be considered reliable.

Accuracy

Multivariate tests of significance. Averaging across exposure conditions mean PC for the hard, intermediate, and easy levels of the task were 62.01% (6.45), 83.55% (9.66), and 89.32% (8.79), respectively. With an alpha level of .025, the MANOVA indicated a significant main effect for difficulty, F (2, 95) = 680.20, $p < .001$, ES = 3.64. However, there was no evidence that accuracy was affected by the presence of the magnetic field. Averaging across the levels of task difficulty, mean PCs for real and sham exposure were 78.23% (8.38), and 78.36% (7.43), respectively. With an alpha level of .15, there was no evidence of a significant main effect of exposure ($F < 1$). For the interaction between exposure and difficulty, with an alpha level of .15, neither the multivariate nor the averaged F-tests were significant, Fs < 1. Table 4 shows the mean PC values and their standard deviations for sham and real exposure by task difficulty. To further interpret the main effect of difficulty, a test of the simple main effects was carried out within MANOVA.

Test of the simple main effects (α = .025). The results indicated that all pairwise comparisons between the levels of difficulty were highly significant (all *p*s < .001). The LSD test showed that the least significant difference between the hard and intermediate levels of the task was 2.57, between the hard and easy levels it was 2.49, and between the intermediate and easy levels, 1.71. Since the observed differences of 21.54, 27.31, and 5.77 for the hard and intermediate, hard and easy, and intermediate and easy levels, respectively, were well above these values it is safe to conclude that all pairwise differences were statistically reliable.

Reaction Time and Accuracy by Gender

Doubly multivariate tests of significance involving gender (α = .30). Since this research was exploratory, and no study known to date has looked at whether males and females are affected differentially by the magnetic field, interactions involving gender were examined. The MANOVA indicated that there were no main effects for gender, or any field-related interactions. That is, the interaction between gender and exposure, and the interaction between gender, exposure and difficulty were not significant (all *F*s < 1).

Accuracy Reanalysed

Fifty subjects had faster RT for the hard task in the presence of the magnetic field. These subjects were responsible for the significant difference between exposure conditions on the hard task. Since it was

possible that the magnetic field affected only some individuals, the accuracy data of those subjects who showed the RT effect were reanalysed. The data were subjected to a 2 x 2 x 3 (Order by Exposure by Difficulty) MANOVA. The results of the MANOVA ($\alpha = .15$) showed the interaction between exposure and difficulty was significant, $F(2, 47) = 2.62$, $p \doteq .08$ ES = .33. However, as can be seen in Table 5 there is little difference in accuracy between sham and real exposure for any level of difficulty. Tests of the simple interaction effects within MANOVA confirmed this observation with no significant field-related effects (all ps > .15).

Table 5

Mean accuracy for those subjects who showed the RT effect for each level of exposure and task difficulty. SDs are shown in parentheses.

	Task Difficulty					
Exposure Condition	Hard		Intermediate		Easy	
	Accuracy[a]					
Real[b]	62.24	(7.98)	83.95	(11.70)	89.23	(11.36)
Sham[b]	61.57	(7.00)	82.19	(11.84)	89.14	(10.38)

[a]The values represent percentages of correct discriminations. [b]N = 50.

Analyses of Cardiovascular Measures

Systolic BP, Diastolic BP, Pulse, and Mean Arterial Pressure

Doubly multivariate tests of significance (α = .30). Overall, the counterbalancing procedure was effective with no evidence of a significant main effect for order, F (4, 94) < 1. The MANOVA provided evidence of significant main effects for both period (pre/post), F (4, 94) = 8.72, p < .001, ES = .61, and exposure (sham/real), F (4, 94) = 1.26, p = .29, ES = .23. However, there was no evidence of a field-related effect, since the interaction between period and exposure was not significant, F (4, 94) < 1. To examine the effect of field exposure on each cardiovascular measure separately, individual significance tests were performed. The means and standard deviations for each measure are presented in Table 6.

Univariate tests of significance (α = .075). For systolic BP the main effect for order and the main effect for exposure were not statistically significant, Fs (1, 97) < 1. There was a significant main effect for period, F (1, 97) = 8.19, p = .01, ES = .29. However, the critical period by exposure interaction was not significant, F (1, 97) < 1.

For diastolic BP there was no significant main effect for order, F (1, 97) < 1, or for exposure, F (1, 97) = 1.70, p =.20, ES = .13. There was a significant main effect for period, F (1, 97) = 3.67, p = .06, ES = .19. Nevertheless, the interaction between period and exposure was not significant, F (1, 97) < 1.

Table 6

Mean systolic BP, diastolic BP, Pulse, and MAP by exposure and period. SDs are shown in parentheses.

Condition	Period	
	Preexperimental	Postexperimental
	Systolic BP	
Real[a]	119.25 (9.63)	118.29 (10.10)
Sham[a]	119.24 (8.84)	118.28 (8.80)
	Diastolic BP	
Real[a]	60.67 (7.93)	60.03 (7.24)
Sham[a]	60.15 (7.98)	59.42 (7.75)
	Pulse Rate	
Real[a]	76.65 (12.22)	74.64 (10.46)
Sham[a]	78.04 (12.82)	76.00 (11.17)
	Mean arterial pressure	
Real[a]	84.60 (8.10)	83.87 (7.50)
Sham[a]	84.20 (7.31)	83.27 (7.11)

[a]N = 101.

For pulse rate there was no significant main effect for order, F (1, 97) = 1.31, p = .26, ES = .11, or for exposure, F (1, 97) = 1.79, p =.18, ES = .14. There was a significant main effect for period, F (1, 97) = 30.37, p < .001, ES = .56. However, there was no significant period by exposure interaction, F (1, 97) < 1.

Similarly, for mean arterial pressure there was no significant main effect for order, F (1, 97) < 1, or exposure, F (1, 97) = 1.17, p =.28, ES = .11. Again, there was a significant main effect for period, F (1, 97) = 4.70, p = .03, ES = .22, but there was no interaction between period and exposure, F (1, 97) < 1.

Tests of significance with gender as a factor (α = .30). The MANOVA indicated a significant doubly multivariate main effect for gender, F (4, 94) = 6.71, p < .001, ES = .53. Compared to female subjects, male subjects had, on average, higher systolic BP (122.00 vs. 116.37), higher MAP (85.60 vs. 83.51), and lower pulse (73.96 vs. 78.10), with individual F-tests indicating these differences to be significant (all ps < .10). In contrast, there was no significant difference in diastolic BP (59.46 vs. 60.52). The clearest indication of a field-related effect involving gender would have been a significant three-way interaction between gender, period, and exposure. The overall MANOVA indicated no such relationship, F (4, 94) < 1.

Statistical Power

Power to Detect Field-Related Effects Involving Performance

The power of selected multivariate tests was calculated based on the methods of Hager and Moller (1986). Hager and Moller's tables can be used to calculate power for limited values of alpha. In addition, the reason that some of the power values in Table 7 are given as <50% is because Hager and Moller's tables do not allow for the calculation of power values less than .50. The power of repeated measures univariate tests was obtained directly from the computer programme of Borenstein and Cohen (1988). The computer programme can be used to calculate exact power for any value of alpha.

Doubly multivariate exposure by difficulty interaction. As can be seen in Table 7, the power to detect small and medium effects at two levels of alpha was less than satisfactory, but the power to detect large effects was high. Whereas Table 7 refers to the power values calculated for Cohen's (1977) ESs, in the present study, the interaction produced an *observed* ES of .25. Thus, with $\alpha = .05$, power was 53%. Relaxing alpha to .15, increased power to 78%.

Multivariate exposure by difficulty interaction involving either RT or PC. The power to detect small effects was less than 50% (Table 7). The power to detect medium effects was only satisfactory when $\alpha = .15$. In the current investigation, the interaction for RT produced an observed ES of .25. Thus, with $\alpha = .15$, power was satisfactory at 80%. The

Table 7

Power of selected multivariate tests of significance.

		Alpha Level	
Effect Size	(*f*)	.05	.15
Doubly Multivariate Exposure by Difficulty Interaction[a]			
Small	(.10)	<50	<50
Medium	(.25)	<50	60
Large	(.40)	89	96
Exposure by Difficulty Interaction for RT or PC[b]			
Small	(.10)	<50	<50
Medium	(.25)	<50	80
Large	(.40)	97	>99

Note. The values in the body of the table are power times 100, i.e., the percentage of tests carried out under the specified conditions which will result in rejection of the null hypothesis.[a]With u = 8 and N = 100 (see Hager & Moller, 1986, p.662, for method). [b]With u = 2 and N = 100.

interaction involving PC produced an F value of less than one; therefore, the observed ES and the associated statistical power could not be calculated.

Univariate exposure by difficulty interaction involving either RT or PC. Table 8 shows that, with 2 and 192 df, power was not satisfactory to detect small effects even when alpha was relaxed to .30. However, power was adequate to detect medium and large effects at all alpha levels. In the present study, the interaction between exposure and difficulty produced an observed ES of.20 for RT. Thus, with $\alpha = .05$, power was 71% and with $\alpha = .15$, it increased to 86%.

Simple main and interaction effects. As Table 8 shows, with 1 and 96 df, power to detect small effects was poor even with an alpha of .30. Power to detect medium effects was satisfactory only when alpha was relaxed to .10. For the test of the simple effect involving RT for the hard level of the task, with 1 and 96 df, power to detect the observed ES of .20, when $\alpha = .05$, is 51%. Relaxing alpha to .15 increased power to 71%.

Reanalysis of accuracy. In the reanalysis of the accuracy data, with 2 and 90 df, power to detect small effects was extremely poor for all levels of alpha shown in Table 8. Power to detect medium effects was adequate only when alpha was set at .30.

Univariate exposure by period interaction for all cardiovascular measures. With 1 and 97 df, power was inadequate to detect small effects, but satisfactory to detect medium and large effects (Table 8).

Table 8

Power of selected univariate tests of significance.

	Alpha Level		
Effect Size[a]	.05	.10	.30
Exposure by Difficulty Interaction for RT or PC[b]			
Small	22	34	60
Medium	88	93	98
Large	99	99	99
Simple Interaction Effects[c]			
Small	17	28	54
Medium	72	82	94
Large	98	99	99
Exposure by Difficulty Interaction for the Reanalysis of accuracy[d]			
Small	12	22	48
Medium	56	69	87
Large	94	97	99
Exposure by Period Interaction for all cardiovascular measures[e]			
Small	18	29	55
Medium	78	87	96
Large	98	99	99

Note. The values in the body of the table are power times 100, i.e., the percentage of tests carried out under the specified conditions which will result in rejection of the null hypothesis.

[a]Small (f = .10), medium (f = .25), large (f = .40). [b]With 2 and 192 df, n for calculating power was 65 (see J. Cohen, 1977, p.365, for method). [c]With 1 and 96 df, n = 49. [d]With 2 and 90 df, n was 31. [e]With 1 and 97 df, n = 50.

DISCUSSION

The results of the present study support the assertion that ELF magnetic fields can affect human performance. Compared to sham exposure, subjects' RT was some 14 ms faster, on average, for a difficult task during exposure to a 100 μT intermittent magnetic field sinusoidally modulated at 50 Hz. In contrast, field-related effects were not seen for two easier levels of difficulty, for accuracy at any level of difficulty, or for any cardiovascular measure. In the following discussion these results are interpreted with respect to several issues including field-related effects and design sensitivity.

Magnetic Field Effects

The current study was designed to minimise the likelihood of any changes in the dependent variables being the result of extraneous factors. Nonetheless, there are at least three possible explanations for the RT changes in addition to field-related effects. First, subjects may have been able to detect the magnetic field. If this was the case, it is possible that subjects may have consciously (or unconsciously) responded differently during real exposure compared to sham exposure. However, the results of the FSQ provide no evidence that subjects could detect the presence of the field at better than chance levels. Second, subjects may have been making a speed-accuracy tradeoff. That is, it is possible that some subjects responded more quickly at the expense of making more errors. The nature of the performance task makes it difficult to be

certain that a tradeoff was not occurring. Still, a careful examination of the performance data did not reveal any evidence for a speed-accuracy tradeoff. Moreover, it is hard to see why a speed-accuracy tradeoff should occur only under field conditions. Third, there might have been carry-over or practice effects which would have been confounded with a field induced effect, seriously compromising the validity of the results. However, there was no main effect for order, providing evidence that the counterbalancing procedure removed any carry-over or practice effects that might have been present.

Extremely low frequency EMFs may affect human performance in very subtle ways requiring sensitive measures to detect real effects. Prior research has indicated that ELF field exposure may affect performance on complex tasks (e.g., Cook et al., 1992; Graham & H. D. Cohen, 1985; Graham et al., 1994), but does not affect simple RT (e.g., Cook et al., 1992; Lyskov et al., 1993; Podd et al., in press). Therefore, the present study used a performance task that produced different levels of difficulty, but one where the actual task (visual duration discrimination) was held constant. No previous EMF research has systematically investigated task difficulty free of the potentially confounding affects of task changes. The results reported here show that for both RT and PC there was a highly reliable difference between each level of difficulty. As would be expected, RT increased and PC decreased as the task changed from easy to hard. In terms of a field-induced effect, the results also show that the hardest level of difficulty was the only level affected by exposure. However, the current investigation confounds task with RT speed. That is, it is unclear whether the field-induced changes in RT are dependent on the type of task used, or on the speed of the RT (about 700 ms on

average for the hard task). It is possible that there is an RT window where field-induced effects may occur but which is independent of the nature of the task. Future research needs to replicate and extend the current results to clarify the speed-task issue (see *Future Research,* p. 91). Nevertheless, it is interesting that the magnetic field should enhance a performance measure like RT but only when the task is difficult and RT slowest.

The fact that field exposure enhanced performance in the current study supports several effects reported by Graham and H. D. Cohen (1985) and Cook et al. (1992). In particular, Graham and H. D. Cohen observed field-induced improvements in performance on a signal detection task, a selective attention task, and a time perception task. Similarly, Cook et al. observed enhanced performance on a choice RT task and on an interval production task. Note that, in both studies, task difficulty was varied by using different tasks. Cook et al. (1992) state that other researchers have interpreted performance enhancement as indicative of field-induced excitation. Interestingly, Lyskov et al. (1993) reported increased frontal lobe beta activity during exposure, which they interpreted as representing increased psychomotor activation. Cook et al. noted that some studies appear to support a field-induced excitation theory. For example, they cite studies using rats where synaptic activity, avoidance activity levels, and recovery from fatigue was increased after electric field exposure. Similarly, Thomas et al. (1986) noted an increase in the response rate of rats exposed to a combined AC/DC magnetic field. Likewise, Smith and Justesen (1977, cited in Thomas et al., 1986) found activity levels increased in mice exposed to magnetic fields. In contrast, previous research has also shown field-induced

decrements in performance. Interestingly, decrements have occurred more frequently *after* the exposure period ends. For example, Graham and H. D. Cohen found that compared to sham exposure, performance on a signal detection task was worse immediately after real exposure, but better during real exposure. In addition, similar results have been reported recently by Graham et al. (1994). Their results show that on an auditory signal detection task and on a DRL task, performance was not affected during exposure, but immediately after exposure decrements in performance were observed. Studies producing decrements in performance are not necessarily at odds with the increased excitation view since activation at the synaptic level may produce inhibiting effects at the behavioural level. Other investigators have suggested that there may be a link between exposure and physiological and behavioural arousal (Cook et al., 1992). Since performance is possibly linked with arousal, field-induced changes in arousal may be seen as performance effects. Similarly, it was suggested by Cook et al. that "...exposure is a 'Zeitgeber' and induces a shift of normal circadian variations, physical recovery processes, or rhythms of hormonal regulation. Thus, appropriate responsivitiy [*sic*] still occurs under exposure conditions, but is slowed or delayed" (p. 281). Nevertheless, until a mechanism is proposed whereby the interaction between biological systems and fields is elucidated, it is hard to explain in any convincing way how EMFs may affect humans at the behavioural or physiological level.

Although the mechanisms underlying field-related performance effects are unknown, it is widely considered that the most likely sites of interaction are the brain and nervous system (Cook et al., 1992). Cellular level research shows that EMFs have the potential to affect

biological functioning. The parametric resonance model (see *Mechanisms of Interaction,* p.10) has been postulated as a possible mechanism underlying these effects and is useful in explaining the absence of a linear dose-response relationship. However, the gap in knowledge between biological effects and behavioural effects is too wide to suggest how effects at the cellular level may be seen as changes in performance. Moreover, the lack of research at the behavioural level allows little insight into field-related effects. Additionally, there is the problem of comparing experiments that have used a wide and varied range of EMF parameters (e.g., frequency, flux density, interaction with the geomagnetic field, exposure duration, continuous versus intermittent exposure, magnetic and/or electric fields). All of these problems add to the difficulty of producing a viable interaction mechanism. Furthermore, Graham et al. (1994) suggest that their results indicate that more than one mechanism may be at work.

Since running the present experiment, the parametric resonance model has been extended and revised (Blanchard and Blackman, 1994). Blanchard and Blackman call the revised model the ion parametric resonance (IPR) model. Based on the IPR model it was possible to predict that the conditions used in the present study would most likely effect the following biologically relevant ions (with the valence in parentheses): Iron (3), Manganese (3), Chromium (3), Vanadium (3), and Molybdenum (6). Nevertheless, it is beyond the scope of the present research to explore what role these ions may have in biological functioning. Most prior research has concentrated on the effect of magnetic fields on calcium ions, but as Blanchard and Blackman note, a system's response may reflect the combined influence of several different

ions. In fact, Blackman et al. (1994) suggest that the more ions potentially affected, the greater the possibility of a field-related effect.

Approximately half the subjects were responsible for the observed effect on RT in the present study. Cook et al. (1992) alluded to the possibility that some subjects may be more susceptible to field effects than others. Additionally, Podd et al. (in press) noted that at least one subject in each of their two experiments, which produced overall null effects, may have been affected by field exposure. In each case it was not possible to tell whether this was spurious or not since Podd et al. did not reexamine those subjects. In the present case, it is simply not possible to say whether those subjects showing a change in RT in the exposure condition are generally susceptible to magnetic field effects whereas the unaffected subjects are not. There are many alternative explanations. For example, the field effect may be small such that only a proportion of any group of subjects will be affected at any one time. Alternatively, it is possible that some subjects detected the field and responded differently in each condition as a consequence, although there is no evidence that humans can detect magnetic fields of the frequency and flux density used in the current investigation.

Despite the apparent RT effect, there was no indication that PC was affected by exposure. In constrast, past research has produced field effects involving PC (Cook et al., 1992; Graham & H. D. Cohen, 1985). One can only speculate as to why RT was affected while PC was not. Perhaps PC is only sensitive to field affects when accuracy is very high. In the present investigation, PC averaged between 60 and 90% depending on task difficulty. In contrast, the results of past studies

suggest that field effects were detected when PC was closer to 100% (e.g., Graham & H. D. Cohen, 1985).

Contrary to previous research (e.g., Cook et al., 1992; Korpinean et al., 1993), the present investigation found that exposure did not affect heart rate. Typically, heart rate has been found to decrease in the presence of EMFs (Cook et al., 1992; Graham & H. D. Cohen, 1985; Graham et al., 1994; Maresh et al., 1988), although it should be noted that this effect has rarely been replicated outside of MRI. At present, the mechanism responsible for this effect is not understood. Cook et al. suggested that such an effect may be indicative of field-induced changes in other parts of the cardiovascular system. However, in the study reported here, heart rate as measured by pulse in the brachial artery was not influenced by magnetic field exposure. Nonetheless, consistent with previous findings (e.g., Graham & H. D. Cohen, 1985; Sander et al., 1982, cited in Gamberale, 1990), BP was not affected by exposure. Still, the results of the present study may be accounted for in terms of deficiences in technique and statistical power, and should not be taken as strong evidence of a null effect. (See later section in *Study Limitations,* p. 88, for a more detailed discussion of these issues.)

Gender was included in the multivariate analysis since it is possible that magnetic fields differentially affect males and females and little data on gender effects exist in this research area. The clearest indication of such an effect, for performance, would have been a two-way interaction between gender and exposure, or a three-way interaction between gender, exposure, and difficulty. However, these interactions were not statistically significant, and so do not provide evidence that males and

females were affected in different ways. As for the cardiovascular measures, there was no evidence that males and females were affected differentially by the field. However, as the results show, there was a significant main effect for gender. This shows that disregarding any field-related effects, males and females are different in terms of several cardiovascular measures. Consistent with previous findings (Linden, 1991), males had higher systolic blood pressure, lower pulse rate, and higher MAP, on average, compared to female subjects.

The results of the current study may have implications for human behaviour in the real world, but this is a complicated issue. First, the conditions of exposure produced in the laboratory are unlikely to be exactly the same as those to which humans are exposed daily. Second, the current knowledge of the dose-response relationship is very limited. The fact that some research (e.g., Blackman et al., 1994) points to intensity and frequency windows only complicates the issue. The present study has demonstrated that magnetic fields can influence human performance, but at this point in time it is difficult to suggest, with any certainty, just what the real-world implications may be.

Design Sensitivity

The statistical power of past EMF research involving humans has been extremely low (Whittington & Podd, 1995). Given that small effects are likely in this area of research, several factors were incorporated into the design of the present investigation in an attempt to maximise experimental sensitivity and thereby increase statistical power. Initially,

several performance and cardiovascular measures were used because they had been shown in past research to be sensitive to EMF affects. Similarly, intermittent exposure and parametric resonance theory were used to set the exposure conditions because past research suggests that such exposure conditions may produce stronger effects (Liboff et al., 1987; Lyskov et al., 1993). In addition, a number of other techniques were used directly to increase power, including: increasing the sample size, relaxing alpha, and increasing the observed ES by reducing error variance.

Prior EMF experiments involving humans have used relatively small sample sizes (e.g., Cook et al., 1992; Lyskov et al., 1993), which may account for the low statistical power in this area of research. Therefore, in the present study, the first step to directly increasing power was to increase sample size. To demonstrate what effect increasing the sample size had on the present study, the RT data were reanalysed with varying numbers of subjects (while still counterbalancing for order). When 24 subjects were randomly selected from the total sample of 100 subjects, tests of the simple effects showed no significant differences between real and sham exposure within any level of difficulty (all $ps > .15$). When the number of subjects in the reanalysis was increased to 50, still no effects were significant. With 75 subjects the difference between exposure conditions was significant ($p = .04$) for the hard level of difficulty. Clearly, if a much larger than normal sample size had not been employed, a different conclusion would have been reached.

In similar fashion, relaxing the alpha level was used directly to increased power. Alpha adjustment is a statistically convenient way of increasing

power. If in the present investigation a familywise alpha level of .05 had been used, no *F*-tests would have reached significance. Additionally, the statistical power to detect small and most medium effects would have been largely inadequate. As a consequence, real field effects may have gone undetected. Thus, it is suggested here that researchers need to break away from the conventional $p < .05$ alpha level and consider the relative seriousness of both Type I and Type II errors. Where studies are exploratory, Type II errors are just as costly as Type I errors, perhaps even more so. At the present stage of development into research on the effects of ELF fields on human performance and physiology, where there is a real lack of both theory and data, any result which is even only slightly promising needs to be followed up.

Study Limitations

While the present study went a long way to providing a highly sensitive experimental design, there were still problems associated with sensitivity. For instance, although much attention was directed towards statistical power, the power to detect small effects was still well below 80%. This makes the interpretation of the present study's null results difficult because such results are ambiguous when power is low (Cohen, 1977).

Besides low statistical power, other limitations of the current investigation may account for the failure to detect cardiovascular effects, especially those involving heart rate. First, pulse rate was measured by palpitation providing an indirect measure of heart rate. This method gives less accuracy and resolution than electrophysiological measurement

techniques (Cook et al., 1992). Therefore, it is possible that the measurement of pulse was simply not sensitive enough to show field-related effects. Second, research at MRI and the work of Korpinean et al. (1993) used combined electric and magnetic fields, so it is possible that magnetic fields alone do not produce cardiovascular effects. Third, Graham et al. (1994) noted that their heart rate effects were only observed at a specific field strength, not at higher or lower strengths. The present investigation used a higher strength magnetic field than that used by Graham et al. It may be that cardiovascular effects only occur at certain field strength windows, and the field strength used in the current research was outside one of these windows. Finally, the length of exposure used in the present experiment was relatively short compared to other studies (e.g., Cook et al., 1992). Some researchers are of the opinion that longer exposure would increase the chance of detecting an effect (Medici, 1982).

The issue of whether field-related effects are positive or negative may depend on when performance is measured. However, the present study cannot be used to help clarify this issue since performance was only measured during exposure. Conversely, the cardiovascular measures were only recorded before and after exposure.

The current investigation was conducted as an extension of Podd et al.'s (in press) study. Therefore, the same basic experimental protocol that Podd et al. used was followed here. That is, under double-blind conditions, each subject was individually exposed and sham exposed on consecutive days at the same time each day. In addition, the applied magnetic field was aligned with the geomagnetic field. However, to

increase experimental sensitivity many factors were changed. First, the task used to measure performance was changed from simple RT to a cognitively more complex signal detection task. Second, exposure time was increased from five minutes to nine minutes. This was done simply to increase the reliability of measurement. Third, intermittent exposure was used rather than continuous exposure. (Recall that prior research has indicated that intermittent exposure may produce larger effects.) Fourth, the field frequency was changed from the 0.1, 0.2, and 43 Hz frequencies used by Podd et al. to 50 Hz in order to use a frequency that humans were commonly exposed to (i.e., the power frequency in New Zealand).

So while the changes to the present methodology certainly increased experimental sensitivity their presence limited the validity of making comparisons with Podd et al. (in press). Moreover, the validity of comparing the results reported here with any other EMF research is questionable. As explained earlier, this is a real problem in the whole area of EMF research. It might be argued that results should be able to withstand the changes that occur in replication attempts within the same laboratory and across laboratories. However, it has yet to be demonstrated that EMF effects are phenomena robust enough to persist across even very small procedural and methodological changes. Many more data are required on the effect sizes involved in EMF exposure before we can make detailed comparisons across studies. Until these data are available, it seems prudent to assume a small effect size for field effects. The thesis argued here is that there is a need for greater experimental sensitivity and a great deal more statistical power if small,

but nonetheless real field-related effects are to be detected and replicated.

Future Research

Ideally, the results reported in the present study need reproducing by an independent laboratory. At the very least the laboratory where the current investigation was done needs to run the experiment again with a different sample of subjects. In addition, since the results show that only half of the subjects were affected by the magnetic field, these subjects should be asked to participate in further testing.

The current research provides a much larger group of potentially susceptible individuals for retesting. The problem with retesting is that the double-blind protocol was revealed to the subjects at the conclusion of the experiment, thus introducing the potential for bias when retesting those subjects. Nevertheless, with careful control of all field-related cues, valuable information may be gained from reexamining those subjects.

While it was interesting to find that the magnetic field effect apparently depends on task difficulty, it was not possible to delineate the effect as speed or task dependent. Future research may clarify this issue by using different tasks that yield two different levels of about the same RT . For example, a study could be designed that used a signal detection task and a selective attention task that each produced about the same fast RT and about the same slow RT. The results of a study such as this may separate out an actual RT effect from a task effect.

The study reported here used many techniques to increase statistical power, but still had unsatisfactory power to detect small effects. Future research needs to find further ways of increasing design sensitivity to ensure sufficient statistical power. Perhaps the most obvious method is to increase sample size. However, the cost of doing so may be too great. One alternative to increasing sample size is to increase the magnitude of the effect. In the present study, the use of standardized procedures, intermittent exposure, and the parametric resonance model was designed to do this. In addition, between-subjects variance not associated with field exposure was removed by using a repeated measures design. However, Graham et al. (1994) recently alluded to the fact that further error variance, not associated with field exposure, can be removed by using alertness as a covariate in the analyses. Future investigators should consider whether alertness (and maybe other factors) could be used as covariates to increase statistically the magnitude of the effect.

The results of the present study did not show field-related cardiovascular effects. However, this result is open to interpretation because of low levels of statistical power, limited measurement techniques, and short exposure duration. Future research should be designed to overcome these problems. For example, power could be increased as described above, and a more accurate measurement of cardiovascular response used, in conjunction with longer exposure times. These changes may allow for a replication of the cardiovascular changes found in other laboratories.

The issue of whether field exposure produces an improvement or decrement in performance is complicated. It should be noted that some

results contradict the idea that performance may improve during exposure, but decline after exposure. Therefore, further research measuring performance before, during, and after exposure and sham exposure is needed to clarify this issue.

General Conclusion

In the current investigation a weak ELF magnetic field was seen to affect human performance on a difficult task when a relatively sensitive experimental design was used. This result adds to a growing body of evidence showing that weak magnetic fields may affect human performance, albeit in subtle ways. The research reported here highlights the need for all researchers, but especially those dealing with small effects, to maximise experimental sensitivity by paying close attention to the issue of statistical power. It has been demonstrated that the current study would have failed to yield significant field effects when only 50 subjects' data were analyzed (a sample size that is still large in comparison to prior research). A combination of relatively high subject numbers, relaxed alpha level, and a detailed consideration of design sensitivity issues will be required in all future studies on the effects of weak magnetic fields on human performance or physiology. As things currently stand in EMF research, investigators have given themselves only a 7% chance, on average, of detecting a small effect given that one exists. Thus, two major conclusions relating to statistical power can be drawn from the current research programme. First of all, many, if not all, previous studies have had little chance of detecting the likely small effect sizes associated with weak, ELF fields; similarly, most replication

attempts have been doomed to failure. Second, the uncertainty created by low statistical power is something that can be largely eliminated. Only when this happens can we be sure that the results obtained from EMF research, and their replication attempts, are meaningful.

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Appendix A

This appendix contains:

The screening questionnaire
The information sheet
The consent form
The field status questionnaire

EFFECTS OF MAGNETIC FIELDS ON ON HUMAN PERFORMANCE AND PHYSIOLOGICAL RESPONSE

Subject screening questionnaire

Please answer the following questions by writing "Yes" or "No" next to each. Do not hesitate to ask if something is not clear.

1. Have you previously participated in magnetic field research? _____
2. Are you pregnant? _____
3. Have you any chronic health problem? _____
4. Have you any cardiovascular problems? _____
5. Have you a history of brain or nervous system damage or disorder, such as epilepsy? _____
6. Have you had an illness which has confined you to bed for more than 3 days in the past 3 months? _____
7. Are you currently undergoing psychotherapy, or are you contemplating such treatment? _____
8. Are you taking any medication? _____
9. Do you have any dietary restrictions or unusual dietary habits? _____
10. Do you wear any form of metal prosthesis, or do you have implanted any metal or electronic devices such as a cardiac pacemaker? _____

EFFECTS OF MAGNETIC FIELDS ON ON HUMAN PERFORMANCE AND PHYSIOLOGICAL RESPONSE

Information for Participants

The principal researchers for this study are Craig Whittington (Department of Psychology), Dr John Podd (Department of Psychology) and Dr Geoff Barnes (Department of Physics/Biophysics). Craig Whittington can be contacted through the Department of Psychology or at his home number, [redacted]. Dr Podd can be contacted at work by phoning 350-4135. His home phone number is [redacted]. Dr Barnes' work number is 350-4047, and his home number is [redacted]

We are conducting a series of investigations that will help us find out if weak magnetic fields (such as those associated with electric blankets, jugs, and toasters) affect human performance. In the present study, we are going to assess the effect of such a weak magnetic field on **visual discrimination** and **reaction time**, and on your **heart rate** and **blood pressure**.

You will be asked to watch an LED flash twice and respond by indicating which flash was longer. We will ask you to do this 200 times a day (including 50 practice and warm-up trials) for two consecutive days at exactly the same time each day. You will be positioned between two large copperwire coils which will have an electric current passed through them. This current generates the magnetic field.

The **experimental** time involved each day is about 20 minutes, including practice trials and blood pressure readings. Thus, in all, you could expect each of the daily sessions to be complete in 30 minutes. The extra time, over and above the experimental time, is to introduce you to the study and for you to be able to ask any questions.

You will no doubt be aware of the current interest in the possibility that weak magnetic fields may affect human behaviour, albeit in very small ways. In return for your participation in our study, we will be very willing to tell you as much as we can about magnetic fields and why they interest us so much.

The field strengths we are concerned with are of the same order of magnitude as those produced by electrical appliances in your home, such as an electric toaster. The field strength we are using is well within the limits set by the Department of Health National Radiation Laboratory, and those set by the International Radiation Protection Association. Therefore, by current standards, the magnetic fields we are using are not harmful.

If you agree to take part in our study, you have the right to:

* refuse to answer any particular question we might ask

* withdraw from the study at **ANY** time

* ask questions as they occur to you at any time during your participation

* provide information on the understanding that it is completely confidential to the researchers. All information is collected anonymously, and it will not be possible to identify you in any reports prepared from the study

* be given access to your own personal data, and a copy of it if you want it

* be given access to a summary of the findings from the study when it is concluded

Can low intensity magnetic fields affect our behaviour, even in subtle ways? And if so, **how** do these field affect us? These are controversial yet fascinating questions for us. We hope you will be willing to help us find some answers by agreeing to be a research subject in our study.

Craig Whittington (Department of Psychology)

Dr John Podd (Department of Psychology Extn 4135)

Dr Geoff Barnes (Department of Physics/Biophysics, Extn 4047)

EFFECTS OF MAGNETIC FIELDS ON ON HUMAN PERFORMANCE AND PHYSIOLOGICAL RESPONSE

Consent Form

I have read the Information Sheet for this study and have had the details explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study at any time, or to decline to answer any particular questions in the study. I agree to provide information to the researchers on the understanding that it is completely confidential.

I wish to participate in this study under the conditions set out in the Information Sheet.

Signed:_____

Name:_____

Address:_____

Age:_____

Date:_____

FIELD STATUS QUESTIONNAIRE (FSQ)

1. In your judgment was the field on or off:
(Please circle your decision)

Day 1 **on / off**

Day 2 **on / off**

2. How confident are you in this judgment:
(Please circle your decision)

Day 1 **1** **2** **3** **4** **5**
Not confident Very confident

Day 2 **1** **2** **3** **4** **5**
Not confident Very confident

3. What are you basing this judgment on?
(Please write your answer in the space provided)

Day 1

Day 2

Appendix B

Prerecorded instructions to subjects

Subject Instructions for Session One

Hi, what follows are standardised instructions. Each daily session will begin with 50 practice trials of a visual discrimination task after which your blood pressure will be monitored for 5 minutes. You will then complete 150 experimental trials in the presence of a low intensity magnetic field. This will be followed immediately by a further blood pressure reading.

Please place your first finger on button 1 and your second finger on button 2. Now concentrate on the small red light on the ceiling above you. Shortly a warning tone will sound after which the light will flash twice. Your task is to decide which flash was **longer** in duration. If you believe the first flash was longer press button 1. If you believe the second flash was longer press button 2. Guess when uncertain. Please respond as quickly and accurately as you can. Remember you have to decide which flash is **longer** in duration. Shortly after your response the warning tone will sound again, indicating the next trial.

The two coils near your head are used to generate the magnetic field. You have been assigned to a group in which the field will always be on during the discrimination task. There is no need for you to touch the coils but should you do so accidentally, they wont harm you because the current passing through the coils is very weak.

Remember you have the right to withdraw from the study at any stage.

Subject Instructions for Session Two

What follows are standardised instructions for session two. The procedure is the same as yesterday. There will be a maximum of 50 practice trials after which your blood pressure will be recorded. Then you will complete the 150 experimental trials followed by a second blood pressure reading. Remember your task is to decide which flash is longer in duration and also remember that the magnetic field will be switched on for all trials.

Appendix C

SPSS/PC+ command programmes used to run the statistical analyses

Omnibus MANOVA for Performance Measures

MANOVA PCD1S PCD2S PCD3S PCD1R PCD2R PCD3R RT_HS RT_HR RT_IS RT_IR RT_ES RT_ER by order (1,2) sex (1,2) /WSFACTORS EXPOSURE (2) DIFFICULTY (3) /WSDESIGN exposure BY duration, exposure, duration /MEASURE PC RT /METHOD SEQUENTIAL /RENAME CONPC DIFSRPC D1V3PC D13V2PC INTPC INT2PC CONRT DIFSRRT D1V3RT D13V2RT INTRT INT2RT /PRINT SIGNIF (AVERF) TRANSFORM ERROR (CORRELATIONS COVARIANCES SSCP) HOMOGENEITY (ALL) /DESIGN.

Omnibus MANOVA for performance with discriminant analysis

MANOVA PCD1S PCD2S PCD3S PCD1R PCD2R PCD3R RT_HS RT_HR RT_IS RT_IR RT_ES RT_ER by order (1,2) sex (1,2) /WSFACTORS EXPOSURE (2) DIFFICULTY (3) /WSDESIGN exposure BY duration exposure duration /MEASURE PC RT /DISCRIM STANDARD ESTIMATES CORRELATIONS ALPHA (.3) /METHOD SEQUENTIAL /RENAME CONPC D1V3PC D13V2PC DIFSRPC INTPC INT2PC CONRT D1V3RT D13V2RT DIFSRRT INTRT INT2RT /PRINT SIGNIF (AVERF) TRANSFORM /DESIGN.

Omnibus MANOVA for Reaction Time

MANOVA RT_HS RT_HR RT_IS RT_IR RT_ES RT_ER by order (1,2) sex (1,2) /WSFACTORS EXPOSURE (2) DIFFICULTY (3) /WSDESIGN exposure BY duration, exposure, duration /METHOD SEQUENTIAL /RENAME CONRT DIFSRRT D1V3RT D13V2RT INTRT INT2RT /PRINT SIGNIF (UNIV AVERF) TRANSFORM /DESIGN.

Test of Simple Interaction Effect for RT

MANOVA RT_HS RT_HR RT_IS RT_IR RT_ES RT_ER by order (1,2) sex (1,2) /WSFACTORS EXPOSURE (2) DIFFICULTY (3) /WSDESIGN duration, exposure WITHIN duration (1), exposure WITHIN duration (2), exposure WITHIN duration (3) /RENAME CONRT INT1 INT2 HARD INTER EASY /PRINT SIGNIF (UNIV MULTIV) TRANSFORM /DESIGN.

Test of Simple Main Effect for RT

MANOVA RT_HS RT_HR RT_IS RT_IR RT_ES RT_ER by order (1,2) sex (1,2) /TRANSFORM SPECIAL (1, 1, 1, 1, 1, 1, .5,-.5, 0, .5,-.5, 0, .5, 0,-.5, .5, 0,-.5, 0, .5,-.5, 0, .5,-.5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0) /RENAME con d1v2 d1v3 d2v3 d d /PRINT SIGNIF (UNIV SINGLEDF) TRANSFORM /DESIGN.

Omnibus MANOVA for Accuracy

MANOVA PCD1S PCD2S PCD3S PCD1R PCD2R PCD3R by order (1,2) sex (1,2) /WSFACTORS EXPOSURE (2) DIFFICULTY (3) /WSDESIGN exposure BY duration, exposure, duration /METHOD SEQUENTIAL /RENAME CONPC DIFSRPC D1V3PC D13V2PC INTPC INT2PC /PRINT SIGNIF (UNIV AVERF) TRANSFORM /DESIGN.

Tests of the Simple Main Effects for PC

MANOVA PCD1S PCD2S PCD3S PCD1R PCD2R PCD3R by order (1,2) sex (1,2) /TRANSFORM SPECIAL (1, 1, 1, 1, 1, 1, .5,-.5, 0, .5,-.5, 0, .5, 0,-.5, .5, 0,-.5, 0, .5,-.5, 0, .5,-.5, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0) /RENAME con d1v2 d1v3 d2v3 d d /PRINT SIGNIF (UNIV SINGLEDF) TRANSFORM /DESIGN.

MANOVA for those Subjects who showed RT Effect

SELECT IF (RTD1RL EQ 1).
MANOVA PCD1S PCD2S PCD3S PCD1R PCD2R PCD3R by order (1,2) sex (1,2) /WSFACTORS EXPOSURE (2) DIFFICULTY (3) /METHOD SEQUENTIAL /PRINT SIGNIF (UNIV AVERF) TRANSFORM /DESIGN.

Omnibus MANOVA for Cardiovascular Measures

MANOVA SYS_BCM SYS_BEM SYS_ACM SYS_AEM DIA_BCM DIA_BEM DIA_ACM DIA_AEM PUL_BCM PUL_BEM PUL_ACM PUL_AEM MAP_BCM MAP_BEM MAP_ACM MAP_AEM by order (1,2) sex (1,2) /WSFACTORS PERIOD (2) EXPOSURE (2) /MEASURE SYS DIA PUL MAP /RENAME CONSYS PERSYS EXPSYS INTSYS CONDIA PERDIA EXPDIA INTDIA CONPUL PERPUL EXPPUL INTPUL CONMAP PERMAP EXPMAP INTMAP /METHOD SEQUENTIAL /PRINT ERROR (CORRELATIONS COVARIANCES SSCP) TRANSFORM PARAMETERS (ESTIMATES CORRELATIONS) SIGNIF (UNIV AVERF) /DESIGN.

Appendix D

This appendix contains:

Data that were used in the
multivariate analysis of variance (MANOVA).

Table D1 contains the subject characteristics and performance data for each subject. The RT data are medians from the 150 trials each subject performed. Tables D2 and D3 contain the cardiovascular data for each subject. The cardiovascular data are means calculated from the last two readings taken before and after sham or real exposure. The data presented here, and the raw data from which these were generated, can obtained by sending a high density diskette to the author.

Table D1

Subject characteristics and performance data for each subject.

(*Note.* SUB [subject code number]; G [gender]; A [age]; HS [hard task during sham exposure]; HR [hard task during real exposure]; IS [intermediate task during sham exposure]; IR [intermediate task during real exposure]; ES [easy task during sham exposure]; ER [easy task during real exposure].)

[a]The values represent the percentage of correct discriminations. [b]The values are median RTs calculated from the raw data. [c]The values represent subjects gender with 1 = females, and 2 = males. [d]Age in years.

			PC[a]						RT[b]					
SUB	G[c]	A[d]	HS	HR	IS	IR	ES	ER	HS	HR	IS	IR	ES	ER
100	1	20	58.0	46.3	72.9	77.1	80.0	89.6	629.0	431.5	633.5	417.5	616.5	418.0
101	2	19	71.7	74.0	100.0	92.0	95.8	97.9	678.0	719.0	517.0	583.5	470.0	518.0
103	1	26	63.0	71.7	89.6	91.3	84.8	87.8	656.5	683.5	634.0	646.5	593.5	578.0
105	2	19	56.6	35.3	58.3	57.1	71.4	55.3	633.0	668.0	646.5	667.0	630.0	666.0
106	2	19	52.9	60.0	94.2	84.3	91.5	91.1	559.0	595.0	474.5	561.0	472.0	493.0
108	2	21	64.2	66.7	91.7	93.8	93.9	95.8	511.0	521.5	426.5	401.0	456.0	402.0
109	1	22	64.6	59.6	76.5	74.0	82.0	87.5	550.5	715.5	548.0	665.5	538.0	651.5
110	1	19	64.7	47.1	83.7	78.8	86.0	76.6	666.0	755.0	659.0	669.0	622.5	648.0
111	2	24	54.9	60.8	81.6	80.8	85.7	87.2	764.0	781.0	742.0	740.5	642.0	646.0
112	1	22	55.1	65.4	70.6	68.0	78.0	70.2	765.0	808.5	773.0	853.0	737.5	822.0
113	1	23	56.1	61.2	75.0	76.0	83.7	85.1	870.0	1022.0	846.0	948.0	761.0	889.0
114	1	19	41.2	60.8	77.1	88.5	81.6	95.7	871.0	792.0	850.5	725.0	795.0	700.0
115	2	21	63.3	75.0	94.1	96.0	96.0	95.8	685.0	674.0	579.0	556.5	512.0	543.5
116	1	20	78.8	74.5	85.7	76.9	89.6	91.5	746.0	679.0	748.0	671.5	739.5	656.0
118	2	19	57.7	69.4	85.7	90.2	91.7	100.0	791.5	733.0	682.0	689.0	647.0	628.0
119	2	21	60.4	63.5	83.3	80.0	93.9	85.4	665.0	605.5	597.5	653.0	602.0	635.0
120	1	25	70.0	60.8	90.4	86.5	97.9	93.6	743.5	682.0	618.0	653.5	535.0	580.0
121	1	21	62.7	53.1	75.5	84.3	84.0	86.0	581.0	555.0	598.0	536.0	560.0	503.5
122	2	20	62.3	63.5	79.2	84.0	98.0	95.8	649.0	728.5	585.0	662.0	566.0	601.5
123	2	21	68.6	52.9	96.2	80.8	93.5	93.6	787.0	841.0	742.0	738.5	675.0	684.0
124	1	19	60.8	66.7	85.7	88.2	98.0	83.0	633.0	637.0	565.0	577.0	532.0	624.0
126	1	29	64.7	79.6	92.3	86.3	100.0	100.0	659.0	570.0	555.5	517.0	554.0	496.5
127	2	20	64.7	66.0	89.6	91.7	98.0	98.0	593.0	508.0	470.0	446.0	464.5	455.0
128	2	23	60.8	61.5	84.6	88.0	89.4	83.3	718.0	777.5	607.5	646.5	602.0	618.0
129	1	20	61.1	60.8	89.6	93.9	100.0	98.0	521.5	481.0	448.0	410.0	408.5	359.5
130	1	19	68.6	69.2	86.5	68.0	87.2	81.3	606.0	622.0	562.0	632.0	537.0	600.0
131	1	20	61.2	59.6	96.1	78.0	94.0	87.5	810.0	862.5	600.0	707.5	556.5	626.5
133	1	27	64.7	69.4	68.9	92.2	76.6	92.0	1011.0	823.0	888.0	640.0	857.0	650.5
134	2	20	61.2	72.5	97.9	94.0	98.0	97.9	1133.0	1054.0	897.0	806.5	801.0	747.5
135	1	20	50.0	58.3	75.5	69.4	82.2	75.0	902.0	859.0	856.0	887.0	914.0	890.0
136	1	20	48.9	60.0	94.0	90.4	98.0	85.1	968.0	754.0	720.0	637.0	633.0	583.0
137	1	19	57.1	64.2	82.4	85.4	86.0	98.0	549.0	434.0	462.0	349.0	460.0	357.0
138	1	19	63.5	67.9	86.0	68.8	91.7	83.7	644.0	547.5	623.0	481.5	599.0	437.0
140	1	22	82.4	76.5	87.8	94.2	92.0	95.7	737.0	778.0	634.0	710.0	622.0	711.0
141	1	20	52.2	52.9	66.0	62.7	72.9	63.8	928.5	762.5	895.0	778.0	860.5	719.0
142	2	24	55.6	69.4	81.3	80.4	85.4	94.0	628.5	633.0	558.5	543.0	566.0	526.5
143	2	24	66.0	61.5	91.5	86.0	95.9	93.8	814.0	741.5	664.0	690.5	613.0	615.5
144	1	21	62.7	66.7	82.7	86.0	89.4	93.8	585.0	621.0	567.5	517.5	476.0	527.0
145	2	23	56.9	55.1	81.6	80.4	90.0	82.0	660.0	590.0	646.0	561.0	584.5	532.0
146	1	19	56.6	68.6	85.4	80.0	93.9	85.4	549.0	612.0	526.0	600.0	429.0	587.0
147	1	31	66.7	76.5	95.9	94.2	100.0	100.0	763.0	709.0	624.0	498.5	533.0	469.0
148	1	20	59.3	53.7	77.1	72.9	72.9	77.1	811.0	689.5	738.5	714.0	705.0	657.5
149	1	17	74.5	57.1	86.5	81.3	97.9	93.8	636.0	678.0	588.0	613.0	541.0	572.0
150	1	21	61.2	57.7	52.9	78.0	81.6	66.7	867.0	734.5	858.0	767.0	867.0	747.0
151	1	19	60.8	58.5	73.5	80.9	82.0	83.7	926.0	825.0	838.0	769.0	834.0	638.0
152	2	32	56.9	57.7	90.4	90.0	93.6	97.9	577.0	632.5	487.5	527.5	461.0	489.0
153	2	23	66.7	66.0	89.8	80.4	96.0	92.0	926.0	856.0	718.0	826.0	735.0	725.5
154	2	24	79.2	71.2	97.9	92.0	95.9	97.9	556.0	589.0	381.5	394.5	376.0	636.5
155	1	21	54.9	70.6	83.7	94.2	96.0	95.7	701.0	702.0	642.0	602.0	638.0	567.0
250	2	18	52.8	51.0	70.8	66.7	77.6	91.7	804.0	1029.0	733.5	922.4	680.0	765.0
157	1	20	56.6	57.7	77.1	76.0	93.9	85.4	590.0	515.5	562.5	511.0	540.0	547.5
158	1	19	60.8	66.7	67.3	88.5	92.0	95.7	608.0	585.0	624.0	533.0	519.5	512.0
159	1	44	46.9	46.2	72.5	74.0	78.0	77.1	671.0	707.0	624.0	653.5	632.0	729.5
160	1	20	68.6	62.3	77.6	87.5	92.0	93.9	856.0	633.0	770.0	603.0	721.5	589.0
162	1	20	56.0	61.7	94.2	85.1	100.0	97.8	844.5	979.0	630.5	782.0	638.0	736.0
163	1	20	62.7	75.5	89.8	90.2	98.0	100.0	612.0	634.0	581.0	576.0	541.5	557.5
167	2	21	52.9	48.1	53.1	56.3	50.0	62.5	622.0	621.0	619.0	628.5	596.5	600.5
169	1	18	66.7	63.5	98.1	90.0	100.0	91.7	631.0	637.5	562.0	518.0	527.0	497.0

Table D1 cont.

170	2	27	62.5	72.5	72.5	75.0	86.0	87.2	721.0	747.0	730.0	725.5	712.5	663.0
171	1	25	72.5	71.7	82.7	93.8	87.2	85.7	704.0	698.0	694.5	702.5	673.0	694.0
172	2	21	58.8	64.0	73.5	74.5	84.0	87.0	832.0	755.0	739.0	724.0	770.5	681.0
173	2	38	55.1	57.1	82.4	90.0	98.0	100.0	651.0	713.5	613.0	639.5	566.0	580.5
174	2	21	54.7	58.8	72.9	67.3	85.7	80.9	691.0	805.0	647.5	715.0	615.0	629.0
176	2	19	70.8	72.0	94.0	98.1	100.0	97.9	690.0	735.5	558.5	568.0	491.5	482.0
177	2	20	51.9	46.9	91.7	86.3	97.9	100.0	556.0	429.0	518.5	383.0	485.5	406.5
180	1	19	69.2	64.7	79.2	78.8	91.8	93.6	805.0	691.0	663.5	526.5	658.0	569.0
181	1	22	50.9	54.9	60.4	69.2	63.3	63.8	705.0	704.0	740.5	686.5	664.0	669.0
182	2	19	66.0	70.2	97.9	96.1	100.0	98.0	954.0	865.0	681.5	663.0	624.5	619.5
184	2	20	71.4	59.6	76.5	91.8	90.0	89.6	597.0	691.0	533.0	534.0	419.5	512.5
185	1	20	56.6	49.0	70.2	76.0	85.7	76.6	799.0	923.0	772.0	862.0	787.0	831.0
187	2	19	66.0	66.7	95.8	98.1	91.7	95.7	814.0	768.0	727.0	759.0	682.0	697.0
188	2	21	61.7	51.0	88.0	90.0	88.0	91.5	878.0	764.0	570.0	627.0	492.0	563.0
190	2	19	46.9	67.3	80.0	93.9	98.0	97.9	805.0	845.5	684.0	793.0	623.0	752.0
192	2	21	65.9	54.7	97.8	91.7	72.3	91.8	1009.5	1030.0	938.0	771.5	894.0	849.0
197	2	21	63.5	70.8	96.0	98.0	100.0	97.8	1041.0	1075.0	711.5	791.0	587.5	655.0
198	1	19	53.1	66.7	68.6	62.5	88.0	88.0	708.0	646.0	661.0	608.0	625.5	606.0
199	2	21	66.7	65.3	85.4	82.4	89.6	89.4	801.0	821.0	666.0	623.0	643.0	651.0
200	1	29	65.3	67.3	88.2	80.0	90.0	89.6	601.0	731.0	452.0	664.5	466.0	574.0
202	1	21	67.9	63.5	97.9	92.0	98.0	87.5	739.0	827.0	598.0	742.0	616.0	766.5
203	1	20	70.6	56.9	89.8	94.2	90.0	95.7	565.0	502.0	525.0	448.0	512.0	420.0
205	1	19	57.8	65.2	91.8	93.5	98.0	95.7	1180.0	1142.5	953.0	1048.5	855.0	991.0
206	2	20	66.7	62.3	95.9	93.8	100.0	93.9	751.0	697.0	613.0	637.0	582.0	666.0
207	1	20	70.6	48.1	92.3	88.0	91.5	93.8	626.0	647.5	559.0	582.5	535.0	605.5
208	2	20	58.8	59.6	83.7	88.0	96.0	100.0	960.0	885.0	812.0	723.0	652.5	619.5
209	1	21	73.6	70.6	91.7	78.0	91.8	79.2	707.5	763.0	504.5	657.0	473.0	612.5
210	2	23	57.1	65.3	94.0	98.0	97.9	96.0	928.0	706.0	646.5	591.0	579.0	482.0
211	1	19	61.2	69.4	92.2	85.4	100.0	91.5	730.0	857.0	585.0	704.0	512.5	638.0
212	1	21	56.9	50.9	77.6	66.7	78.0	87.5	717.0	775.0	711.0	807.0	679.5	731.0
213	1	18	54.7	61.5	85.4	80.0	79.6	85.4	464.0	478.5	400.0	426.5	368.0	400.5
214	1	21	64.7	70.6	96.2	100.0	97.9	97.9	696.0	639.0	581.0	548.5	541.0	546.0
215	1	23	71.4	55.1	85.1	80.4	84.1	97.9	817.0	910.0	641.0	669.0	666.5	620.5
216	1	32	64.2	51.0	72.9	77.6	81.6	70.8	659.0	696.0	635.5	757.0	645.0	700.5
218	2	41	60.8	61.2	79.6	74.0	72.0	85.7	629.0	617.0	603.0	599.0	581.0	594.0
220	1	31	67.9	71.4	95.8	94.1	95.8	98.0	830.0	655.0	706.0	589.0	693.5	553.5
221	1	21	66.7	64.2	91.7	97.9	95.8	93.9	743.5	689.0	688.5	617.0	643.0	631.0
222	1	43	72.0	65.4	90.4	82.0	97.9	91.7	712.5	657.5	659.0	627.5	612.0	588.0
223	2	48	58.8	45.1	73.5	42.9	84.0	47.9	803.0	669.0	726.0	651.0	702.0	662.0
224	2	23	62.7	55.8	88.5	86.0	95.7	91.7	548.0	624.0	466.0	545.5	456.0	526.0
255	2	18	65.4	53.7	62.0	77.1	83.3	91.7	755.0	582.5	683.0	544.5	690.0	487.0
256	2	17	54.9	68.1	82.7	85.7	91.5	91.7	739.0	808.0	652.5	706.0	634.0	678.0

Table D2

Subject characteristics and systolic and diastolic blood pressure (BP) data for each subject.

(*Note.* SUB [subject code number]; G [gender]; A [age]; BS [before sham exposure]; BR [before real exposure]; AS [after sham exposure]; AR [after real exposure].)
[a]The values are the means of the last two readings taken from each period. [b]The values represent subjects gender with 1 = female, 2 = male. [c]Age in years.

			Systolic BP[a]				Diastolic BP[a]			
SUB	G[b]	A[c]	BS	BR	AS	AR	BS	BR	AS	AR
100	1	20	101.50	101.50	106.50	102.50	54.50	54.50	55.50	57.00
101	2	19	104.50	104.50	109.50	105.00	66.50	58.00	58.50	58.00
103	1	26	116.00	112.50	113.50	112.50	59.50	58.00	54.50	59.50
104	1	23	113.00	120.00	119.00	112.00	67.50	63.50	61.00	61.50
105	2	19	139.00	138.50	135.00	146.50	67.00	70.00	65.50	68.00
106	2	19	128.00	125.50	124.00	123.50	45.00	48.50	49.00	51.00
107	2	21	121.00	121.00	110.50	113.00	56.50	55.00	61.50	60.00

Table D2 cont.

108	2	21	123.00	122.00	120.50	112.00	57.00	59.00	57.50	56.00
109	1	22	122.00	124.00	124.50	122.00	81.00	78.00	81.50	80.50
110	1	19	121.50	122.50	119.50	129.00	65.50	63.50	62.50	57.00
111	2	24	121.00	116.00	119.50	117.50	66.00	75.00	66.50	67.50
112	1	22	103.00	104.50	106.00	104.50	52.00	58.00	55.00	61.00
113	1	23	113.50	110.00	118.00	111.00	51.50	52.50	49.50	53.00
114	1	19	129.50	125.00	131.00	125.00	57.50	62.50	57.00	59.00
115	2	21	119.00	123.00	120.00	131.00	60.00	56.00	57.50	49.50
116	1	20	122.00	119.00	114.00	112.00	60.50	65.00	55.50	66.00
118	2	19	130.00	123.00	131.00	116.50	58.50	58.50	53.50	55.50
119	2	21	134.00	130.00	131.00	133.00	62.00	66.00	61.00	61.00
120	1	25	115.00	117.50	115.50	119.50	69.00	63.50	65.00	62.50
121	1	21	118.00	113.00	113.00	112.00	63.50	66.00	52.00	57.50
122	2	20	121.00	123.00	118.50	115.00	54.50	44.50	41.00	42.50
123	2	21	122.00	126.00	121.00	121.50	52.00	50.00	53.00	53.00
124	1	19	117.50	122.50	120.00	113.00	63.00	54.00	56.00	58.50
126	1	29	123.50	118.50	117.00	118.00	56.00	54.00	51.00	54.00
127	2	20	111.50	101.50	101.50	103.00	55.00	51.00	58.50	56.50
128	2	23	120.00	125.50	120.00	126.00	54.50	59.00	50.50	54.00
129	1	20	133.50	141.00	139.00	133.50	83.00	84.00	80.50	70.50
130	1	19	106.00	111.50	110.50	110.00	53.50	53.00	56.50	53.00
131	1	20	113.50	110.00	114.00	113.00	68.50	68.00	72.00	67.50
132	1	19	127.50	127.50	122.00	117.50	69.50	74.50	68.00	67.50
133	1	27	125.00	121.50	124.50	118.50	80.50	72.50	78.50	65.00
134	2	20	119.00	119.00	115.50	114.00	47.00	47.00	50.00	50.00
135	1	20	125.50	135.50	126.50	131.00	63.00	69.50	68.50	65.00
136	1	20	112.00	107.50	105.50	105.50	58.00	51.00	53.00	54.50
137	1	19	130.00	131.00	126.50	119.50	74.00	70.00	70.50	70.50
138	1	19	115.00	116.50	115.50	117.00	62.00	62.00	56.50	50.00
140	1	22	108.00	109.50	112.50	112.50	57.50	58.50	58.00	58.00
141	1	20	123.00	123.50	129.50	118.00	63.00	57.50	65.50	54.00
142	2	24	140.00	139.00	136.00	140.00	67.00	69.00	65.50	70.00
143	2	24	125.50	124.00	133.00	127.50	69.00	71.00	69.00	66.00
144	1	21	105.50	109.50	106.50	110.50	60.50	62.50	63.50	66.00
145	2	23	116.50	120.50	121.50	116.00	54.50	56.00	53.50	49.50
146	1	19	116.50	109.50	110.00	113.50	54.00	58.50	47.50	60.50
147	1	31	128.50	134.00	125.00	133.50	60.50	56.00	59.00	63.50
148	1	20	127.50	121.50	123.50	120.00	62.50	55.50	57.50	50.00
149	1	17	111.00	118.50	114.50	113.00	63.00	68.50	65.50	64.50
150	1	21	129.00	139.00	128.00	142.00	64.00	69.00	63.00	72.00
151	1	19	110.00	98.50	101.50	99.00	59.50	50.00	52.50	51.00
152	2	32	129.50	110.00	132.00	101.50	65.00	59.50	65.50	52.50
153	2	23	108.00	112.00	105.50	108.00	61.50	65.50	61.00	63.00
154	2	24	107.50	117.00	116.00	113.50	51.50	68.50	55.50	66.50
155	1	21	109.50	113.00	105.00	108.50	58.50	54.00	52.00	50.00
157	1	20	123.00	135.00	117.00	136.00	79.00	77.00	67.00	71.50
158	1	19	113.50	112.50	111.00	113.50	63.50	72.00	66.00	69.00
159	1	44	123.00	120.00	133.00	116.00	78.00	75.50	77.50	69.50
160	1	20	124.00	124.00	122.50	130.50	68.00	69.00	64.00	68.50
162	1	20	118.00	105.00	122.50	109.00	56.50	57.00	59.00	56.50
163	1	20	111.00	120.50	117.50	117.50	46.00	58.50	42.50	50.00
167	2	21	122.00	121.00	121.50	129.50	64.50	64.00	65.50	66.50
169	1	18	107.00	118.50	109.00	118.50	49.00	57.50	54.50	59.50
170	2	27	126.00	130.00	119.50	125.00	56.00	63.00	56.00	61.00
171	1	25	102.50	115.50	105.00	98.50	43.00	56.50	49.50	52.50
172	2	21	126.00	133.00	132.00	124.00	52.00	55.50	52.50	55.50
173	2	38	120.00	123.50	124.50	120.50	64.00	72.00	63.00	72.50
174	2	21	130.00	130.50	126.00	126.00	54.50	53.00	52.50	50.00
176	2	19	130.00	131.00	125.50	126.00	65.00	65.50	71.00	64.00
177	2	20	119.50	136.50	122.50	135.00	58.50	67.50	65.50	58.00
180	1	19	115.50	113.50	112.50	114.50	64.00	56.50	63.50	58.50
181	1	22	108.00	109.00	108.00	106.50	59.00	60.50	53.50	60.00
182	2	19	129.50	133.50	117.50	123.00	57.00	57.00	62.50	62.50
184	2	20	130.50	117.00	123.50	120.00	63.00	58.50	56.00	53.50
185	1	20	128.50	122.00	126.50	130.00	62.50	65.50	68.50	73.00
187	2	19	111.00	113.50	110.50	119.50	61.00	56.50	51.50	58.50
188	2	21	117.50	118.50	126.50	120.50	49.50	52.50	56.50	58.00
190	2	19	121.50	120.00	112.50	120.00	54.00	58.00	52.50	56.00
192	2	21	130.50	131.50	136.00	134.50	59.00	61.00	62.00	58.50
197	2	21	136.00	132.50	131.50	132.00	57.50	58.50	59.50	62.50
198	1	19	109.00	103.00	103.50	104.50	53.00	50.50	53.50	55.50
199	2	21	131.50	129.50	130.00	128.00	67.00	68.00	65.50	70.50
200	1	29	132.50	127.00	122.00	143.50	70.50	68.50	75.50	72.00
202	1	21	115.00	115.00	107.50	107.00	63.00	59.00	59.50	63.00
203	1	20	125.00	127.00	119.00	125.00	53.00	58.50	58.50	60.50
205	1	19	112.00	103.00	112.00	117.00	48.00	47.00	51.50	55.00
206	2	20	128.50	122.00	125.00	116.00	61.00	53.50	54.50	57.00
207	1	20	115.00	114.00	112.50	115.00	58.50	61.00	53.50	64.50
208	2	20	106.00	106.00	107.00	108.00	55.50	55.50	58.50	60.50
209	1	21	117.00	111.50	113.00	110.50	56.50	55.50	51.00	52.00
210	2	23	114.50	114.50	110.50	109.50	57.50	61.50	61.50	62.00

Table D2 cont.

211	1	19	115.00	110.00	120.50	113.00	51.00	51.00	54.50	53.50
212	1	21	106.50	117.00	104.50	113.00	55.50	50.50	59.00	50.50
213	1	18	113.00	102.50	113.50	102.00	45.00	52.50	49.50	51.50
214	1	21	113.50	112.00	115.00	112.50	50.50	53.00	53.00	52.50
215	1	23	112.50	120.00	116.00	118.00	62.00	71.50	66.00	68.00
220	1	31	109.00	103.50	103.00	104.50	59.00	56.50	60.50	58.00
221	1	21	116.00	113.00	118.00	118.00	62.00	57.00	50.50	52.00
222	1	43	107.00	110.50	108.00	106.50	64.50	58.50	59.00	60.00
223	2	48	111.00	120.00	112.00	123.00	68.50	71.00	69.50	74.50
224	2	23	122.00	121.00	122.00	123.50	69.50	66.50	63.50	65.00
255	2	18	123.00	117.50	115.00	121.00	45.50	45.50	56.50	55.00
256	2	17	128.00	119.00	118.50	123.50	58.00	66.50	59.00	62.50
250	2	18	124.00	128.50	125.00	126.00	71.00	66.50	68.50	72.50

Table D3

Pulse and mean arterial pressure data for each subject.

(*Note.* SUB [subject code number]; BS [before sham exposure]; BR [before real exposure]; AS [after sham exposure]; AR [after real exposure].)

[a]The values are the means of the last two readings taken from each period. [b]Pulse was recorded as the number of beats per minute.

	Pulse rate[ab]				Mean arterial pressure[a]			
SUB	BS	BR	AS	AR	BS	BR	AS	AR
100	65.50	66.50	63.00	68.50	70.50	71.50	79.50	75.50
101	98.00	86.50	90.00	85.50	81.50	81.50	86.50	82.00
103	57.00	60.50	59.50	63.00	81.00	81.50	78.50	81.50
104	89.50	75.00	85.00	74.50	90.00	85.50	88.50	81.50
105	86.50	84.50	85.00	81.00	100.50	100.00	95.50	104.00
106	57.50	57.50	57.00	56.00	81.50	74.50	73.00	73.00
107	80.00	78.00	79.50	71.00	78.00	82.00	78.00	82.00
108	78.50	87.50	81.50	87.00	77.00	87.00	86.50	78.50
109	69.00	68.00	73.00	73.00	90.50	86.00	93.50	94.50
110	71.00	72.50	71.00	71.00	82.50	87.50	80.50	86.50
111	84.50	71.50	86.50	71.00	82.50	85.00	88.50	86.00
112	91.00	58.00	81.00	67.00	75.00	73.50	71.00	82.00
113	53.00	53.50	49.50	54.00	76.00	72.50	75.50	73.00
114	81.00	82.00	81.50	76.00	91.50	90.00	88.50	91.00
115	91.00	78.50	87.00	78.50	80.00	77.00	85.50	85.00
116	83.00	83.00	78.00	82.00	80.00	84.00	75.00	81.00
118	90.50	89.00	83.00	81.00	83.50	89.00	88.50	78.00
119	61.50	82.50	56.50	81.00	91.00	91.00	85.00	90.00
120	85.50	80.00	77.00	74.00	88.00	78.50	80.50	80.50
121	68.00	82.50	63.00	71.50	87.00	86.00	82.00	81.00
122	76.50	61.00	73.50	59.00	82.50	77.00	68.50	76.50
123	66.00	59.50	66.50	61.00	84.00	84.00	87.00	82.50
124	72.00	72.50	67.50	70.00	83.50	84.00	78.00	78.50
126	64.00	76.00	60.00	75.00	86.00	81.00	79.50	80.50
127	78.00	84.00	74.50	78.00	77.50	76.00	75.50	81.00
128	70.00	69.50	72.00	68.50	78.50	87.50	78.50	85.00
129	85.50	83.50	79.00	85.50	98.50	102.00	100.50	102.50
130	74.50	71.00	78.00	67.00	79.50	73.00	72.00	71.00
131	81.50	73.00	87.50	75.00	82.50	80.00	84.00	83.50
132	93.50	97.50	86.00	86.50	97.50	97.50	88.00	91.50
133	111.50	97.00	105.00	92.50	101.50	94.50	97.50	88.00
134	53.00	68.50	57.00	61.50	79.00	73.00	81.50	76.00
135	87.50	89.00	81.50	85.00	95.00	97.00	92.50	96.00
136	81.00	69.00	86.00	76.00	74.00	77.00	75.00	74.50
137	97.50	86.00	88.00	82.00	95.00	103.50	96.00	89.00
138	90.50	83.00	73.00	74.00	84.00	77.50	76.50	74.00
140	75.50	87.50	70.50	82.50	77.50	82.50	78.00	82.00
141	75.50	72.50	71.50	64.50	92.00	89.00	83.50	87.50
142	92.00	92.00	89.00	88.50	93.50	96.00	97.50	101.50
143	86.50	81.50	84.50	81.00	91.00	93.00	95.00	89.00

Table D3 cont.

144	82.00	80.50	81.00	77.50	79.00	78.50	83.50	88.00
145	89.00	42.50	78.50	43.00	86.50	80.00	72.00	78.50
146	71.00	75.00	69.00	78.00	82.00	78.50	71.50	82.50
147	74.00	70.00	73.00	72.00	82.50	80.00	87.00	87.50
148	91.00	88.00	81.00	77.50	89.50	79.00	93.50	82.00
149	91.50	91.00	87.00	84.50	81.00	92.00	87.50	90.50
150	71.00	75.00	65.50	76.00	79.00	92.50	81.00	91.00
151	96.50	78.50	92.50	80.00	79.00	71.50	70.50	68.50
152	63.50	96.50	66.50	92.50	90.50	79.00	86.00	70.50
153	79.50	79.50	77.50	77.50	82.00	86.00	79.50	85.50
154	77.00	73.00	83.00	73.00	73.50	91.00	78.50	91.00
155	82.00	79.00	81.50	75.00	82.50	78.00	78.00	74.00
157	99.50	121.00	98.00	114.00	96.50	104.50	86.00	97.50
158	88.00	93.00	84.50	87.50	86.50	89.50	84.50	86.50
159	81.50	83.50	77.50	81.00	100.50	97.50	95.50	89.00
160	99.50	95.00	91.50	95.50	89.50	89.00	80.00	88.50
162	80.00	87.00	84.50	86.50	75.50	78.50	80.00	78.50
163	66.00	87.00	67.00	75.50	76.50	83.00	75.50	79.00
167	100.50	70.50	87.00	72.00	88.50	91.00	91.00	87.50
169	72.00	87.00	76.50	85.50	77.00	87.50	78.50	79.50
170	84.50	79.50	72.00	80.00	84.50	87.50	85.50	79.00
171	65.50	78.00	67.00	71.00	69.00	74.00	75.50	72.50
172	75.50	70.00	86.00	72.50	87.50	91.00	80.50	89.50
173	65.50	50.00	64.00	52.50	82.00	86.50	83.50	85.50
174	77.00	66.50	73.00	63.50	88.00	84.50	88.00	84.00
176	81.50	86.00	87.00	85.00	100.00	89.00	98.50	87.50
177	80.00	88.00	77.00	88.50	89.00	102.00	92.00	86.00
180	88.00	67.50	84.00	73.00	85.50	78.50	85.50	80.00
181	90.00	81.00	81.00	75.50	81.00	81.00	81.50	79.00
182	85.50	84.50	88.00	79.50	87.00	84.00	86.50	89.50
184	79.50	68.50	84.50	67.50	88.50	86.50	85.00	82.00
185	80.00	68.50	78.50	68.00	97.50	91.00	92.00	99.00
187	69.50	74.50	73.50	69.00	85.00	75.50	77.50	80.50
188	60.50	64.50	62.50	67.00	71.50	76.50	79.50	79.00
190	59.50	73.00	59.50	73.00	88.00	90.00	79.00	91.00
192	50.00	54.50	46.50	52.50	84.50	92.50	90.00	91.50
197	74.00	54.50	74.00	59.50	86.50	94.00	89.50	93.50
198	61.50	61.00	54.50	58.50	71.00	68.50	67.50	70.00
199	87.00	92.00	86.50	83.00	97.00	99.00	95.50	93.50
200	103.00	102.00	84.50	90.00	94.50	97.00	91.00	102.50
202	86.00	80.00	78.50	74.50	81.00	85.00	81.00	76.50
203	59.00	60.50	60.00	63.50	79.00	81.50	84.50	82.50
205	79.00	87.00	78.00	86.50	77.50	85.50	77.50	86.50
206	65.50	76.00	69.00	70.50	81.50	87.50	87.50	82.00
207	66.50	83.00	76.00	77.00	76.50	74.50	81.50	84.00
208	60.00	64.00	60.00	69.50	79.50	76.00	80.50	80.50
209	82.50	74.50	74.50	66.00	82.00	78.00	78.00	75.50
210	62.00	62.50	65.50	61.00	80.50	84.50	79.50	83.00
211	87.50	79.50	85.00	82.00	76.50	80.00	78.50	79.50
212	109.50	81.00	102.50	82.00	80.00	79.00	82.00	79.00
213	65.50	68.00	64.00	64.00	75.00	76.50	83.50	75.50
214	70.00	64.50	69.00	74.00	75.00	77.00	77.00	82.50
215	65.00	83.00	62.50	75.00	82.50	93.50	85.50	88.00
220	78.00	66.00	76.00	72.00	79.00	76.50	76.50	77.00
221	86.00	85.00	92.00	73.50	82.00	75.50	80.00	72.00
222	74.00	76.00	71.50	72.00	84.00	76.50	77.00	76.00
223	88.50	83.50	88.00	82.50	88.50	93.00	89.50	89.00
224	58.50	68.00	62.00	65.50	88.00	86.50	91.50	85.50
255	71.00	68.00	71.50	68.00	77.50	75.50	85.00	87.00
256	75.50	79.50	78.50	82.00	89.50	88.00	84.00	89.50
250	67.00	65.50	67.50	65.50	94.00	91.00	83.00	93.00

Appendix E

The SPSS/PC+ Regression analysis output used to test the validity of using age as a covariate in the overall analyses. Note that a significant test would indicate that age may be a useful covariate.

Table E1

Summary of regression analysis for reaction time with age as a covariate.

Regression analysis for WITHIN CELLS error term
Dependent variable .. RT FOR HARD LEVEL OF TASK DURING SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-1.36	-.06	2.50	-.55	.59

Regression analysis for WITHIN CELLS error term
Dependent variable .. RT FOR HARD LEVEL OF TASK DURING REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-2.00	-.08	2.50	-.80	.43

Regression analysis for WITHIN CELLS error term
Dependent variable .. RT FOR INTERMEDIATE LEVEL DURING SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.25	-.01	2.11	-.11	.91

Regression analysis for WITHIN CELLS error term
Dependent variable .. RT FOR INTERMEDIATE LEVEL DURING REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.54	-.02	2.28	-.24	.81

Regression analysis for WITHIN CELLS error term
Dependent variable .. RT FOR EASY LEVEL DURING SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.49	.02	2.09	.23	.82

Regression analysis for WITHIN CELLS error term
Dependent variable .. RT FOR EASY LEVEL DURING REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.49	.02	2.07	.24	.82

Table E2

Summary of regression analysis for percentage correct with age as a covariate.

Regression analysis for WITHIN CELLS error term
Dependent variable .. PC FOR HARD LEVEL OF TASK DURING SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.0005	.0004	.13	.004	.99

Regression analysis for WITHIN CELLS error term
Dependent variable .. PC FOR HARD LEVEL OF TASK DURING REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.11	-.08	.15	-.80	.44

Regression analysis for WITHIN CELLS error term
Dependent variable .. PC FOR INTERMEDIATE LEVEL DURING SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.07	-.04	.19	-.37	.71

Regression analysis for WITHIN CELLS error term
Dependent variable .. PC FOR INTERMEDIATE LEVEL DURING REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.36	-.19	.18	-1.94	.06

Regression analysis for WITHIN CELLS error term
Dependent variable .. PC FOR EASY LEVEL DURING SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.14	-.09	.16	-.86	.39

Regression analysis for WITHIN CELLS error term
Dependent variable .. PC FOR EASY LEVEL DURING REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.36	-.20	.18	-2.04	.04

Note. Although some tests were significant, age was not considered to be a good covariate since significant results were not consistent across exposure conditions.

Table E3

Summary of regression analysis for cardiovascular measures with age as a covariate.

Regression analysis for WITHIN CELLS error term
Dependent variable .. MEAN SYSTOLIC BP BEFORE SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.09	-.06	.16	-.59	.556

Regression analysis for WITHIN CELLS error term
Dependent variable .. MEAN SYSTOLIC BP BEFORE REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.02	-.01	.18	-.12	.91

Regression analysis for WITHIN CELLS error term
Dependent variable .. MEAN SYSTOLIC BP AFTER SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.07	.04	.16	.43	.67

Regression analysis for WITHIN CELLS error term
Dependent variable .. MEAN SYSTOLIC BP AFTER REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.06	-.03	.19	-.31	.76

Regression analysis for WITHIN CELLS error term
Dependent variable .. DIASTOLIC BP BEFORE SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.40	.27	.15	2.74	.01

Regression analysis for WITHIN CELLS error term
Dependent variable .. DIASTOLIC BP BEFORE REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.36	.24	.15	2.43	.02

Regression analysis for WITHIN CELLS error term
Dependent variable .. DIASTOLIC BP AFTER SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.38	.26	.14	2.62	.01

Regression analysis for WITHIN CELLS error term
Dependent variable .. DIASTOLIC BP AFTER REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.35	.25	.14	2.60	.01

Table E3 cont.

Regression analysis for WITHIN CELLS error term
Dependent variable .. PULSE RATE BEFORE SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.01	.004	.24	.04	.97

Regression analysis for WITHIN CELLS error term
Dependent variable .. PULSE RATE BEFORE REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.03	-.02	.23	-.15	.88

Regression analysis for WITHIN CELLS error term
Dependent variable .. PULSE RATE AFTER SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	-.06	-.03	.21	-.27	.79

Regression analysis for WITHIN CELLS error term
Dependent variable .. PULSE RATE AFTER REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.006	.003	.20	.03	.98

Regression analysis for WITHIN CELLS error term
Dependent variable .. MAP BEFORE SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.20	.14	.14	1.43	.16

Regression analysis for WITHIN CELLS error term
Dependent variable .. MAP BEFORE REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.11	.07	.15	.74	.46

Regression analysis for WITHIN CELLS error term
Dependent variable .. MAP AFTER SHAM EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.17	.13	.13	1.25	.22

Regression analysis for WITHIN CELLS error term
Dependent variable .. MAP AFTER REAL EXP.

COVARIATE	B	Beta	Std. Err.	t-Value	Sig. of t
AGE	.01	.009	.14	.09	.93

Appendix F

MANOVA and ANOVA tables taken from the SPSS/PC+ output. Note that in most cases the results have been rounded to two decimal places.

Table F1

Summary of doubly multivariate analysis of variance results for reaction time and accuracy, including discriminant analysis.

Test of Between-Subjects Effect.

EFFECT .. ORDER
Multivariate Tests of Significance (S = 1, M = 0, N = 46 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.004	.20	2.00	95.00	.82

Test of 'DIFFICULTY' Within-Subject Effect.

EFFECT .. DIFFICULTY
Multivariate Tests of Significance (S = 1, M = 1 , N = 45 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.93	334.15	4.00	93.00	<.001

Tests of 'EXPOSURE' Within-Subject Effect.

EFFECT .. EXPOSURE
Multivariate Tests of Significance (S = 1, M = 0, N = 46 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.008	.38	2.00	95.00	.68

Tests involving 'EXPOSURE BY DIFFICULTY' Within-Subject Effect.

EFFECT .. EXPOSURE BY DIFFICULTY
Multivariate Tests of Significance (S = 1, M = 1 , N = 45 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.06	1.45	4.00	93.00	.23

EFFECT .. 'EXPOSURE BY DIFFICULTY' Within-Subject effect

Standardized discriminant function coefficients

	Function No.
Variable	1
PC	-.039
RT	.992

Table F2

Summary of the multivariate analysis of variance and the univariate analysis of variance results for reaction time.

Tests of Between-Subjects Effects.

Tests of Significance for CONRT using SEQUENTIAL Sums of Squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	7486315.03	96	77982.45		
CONSTANT	260923130.70	1	260923131	3345.92	<.001
ORDER	21590.70	1	21590.70	.28	.60

Test involving 'DIFFICULTY' Within-Subject Effect.

EFFECT .. DIFFICULTY
Multivariate Tests of Significance (S = 1, M = 0, N = 46 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.68	100.26	2.00	95.00	<.001

Tests involving 'EXPOSURE' Within-Subject Effect.

Tests of Significance using SEQUENTIAL Sums of Squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	575023.55	96	5989.83		
EXPOSURE	4166.46	1	4166.46	.70	.41

Tests involving 'EXPOSURE BY DIFFICULTY' Within-Subject Effect.

EFFECT .. EXPOSURE BY DIFFICULTY
Multivariate Tests of Significance (S = 1, M = 0, N = 46 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.06	2.95	2.00	95.00	.06

AVERAGED Tests of Significance using SEQUENTIAL Sums of Squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	173439.91	192	903.33		
EXPOSURE BY DIFFICULTY	6587.50	2	3293.75	3.65	.03

Table F3

Summary of the simple main effects and simple interaction effects for reaction time.

Tests involving 'DIFFICULTY' Within-Subject Effect.

EFFECT .. SIMPLE MAIN EFFECTS

Univariate F-tests with (1,96) D. F.

Variable	Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
HARD vs INTER.	672065.54	405956.45	672065.54	4228.71	158.93	<.001
HARD vs EASY	1313615.97	607136.04	1313615.97	6324.33	207.71	<.001
INTER.vs EASY	106494.43	119488.75	106494.43	1244.67	85.56	<.001

Test involving 'EXPOSURE FOR THE HARD LEVEL' Within-Subject Effect.

EFFECT .. SIMPLE INTERACTION EFFECTS

Tests of Significance for EXPOSURE using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	305841.28	98	3120.83		
HARD LEVEL OF DIFF	12959.99	1	12959.99	4.15	.04

Test involving 'EXPOSURE FOR THE INTERMEDIATE LEVEL'

Tests of Significance for EXPOSURE using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	260680.92	98	2660.01		
INTERMEDIATE LEVEL	1108.27	1	1108.27	.42	.52

Test involving 'EXPOSURE FOR THE EASY LEVEL' Within-Subject Effect.

Tests of Significance for EXPOSURE using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	223187.91	98	2277.43		
EASY LEVEL OF DIFF	31.70	1	31.70	.01	.91

Table F4

Summary of the multivariate and univariate analyses of variance results for accuracy.

Test of Between-Subjects Effects.

Tests of Significance for CONPC using SEQUENTIAL Sums of Squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	31669.07	96	329.89		
ORDER	3.26	1	3.26	.01	.92

Tests involving 'DIFFICULTY' Within-Subject Effect.

EFFECT .. DIFFICULTY
Multivariate Tests of Significance (S = 1, M = 0, N = 46 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.93	680.20	2.00	95.00	<.001

Tests involving 'EXPOSURE' Within-Subject Effect.

Tests of Significance using SEQUENTIAL Sums of Squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	4218.94	96	43.95		
EXPOSURE	2.43	1	2.43	.06	.82

Tests involving 'EXPOSURE BY DIFFICULTY' Within-Subject Effect.

EFFECT .. EXPOSURE BY DIFFICULTY
Multivariate Tests of Significance (S = 1, M = 0, N = 46 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.004	.20	2.00	95.00	.83

AVERAGED Tests of Significance using SEQUENTIAL Sums of Squares

Source of Variation	SS	DF	MS	F	Sig. of F
WITHIN CELLS	5443.29	192	28.35		
EXPOSURE BY DIFFICULTY	11.40	2	5.70	.20	.82

Table F5

Summary of the simple main effects for accuracy.

Tests involving 'DIFFICULTY' Within-Subject Effect

EFFECT .. SIMPLE MAIN EFFECTS
Univariate F-tests with (1,96) D. F.

Variable	Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
HARD vs INTER.	46164.34	5977.15	46164.34	62.26	741.45	<.001
HARD vs EASY	74156.47	5218.15	74156.47	54.36	1364.28	<.001
INTER.vs EASY	3301.42	2640.60	3301.42	27.51	120.02	<.001

Table F6

Summary of the doubly multivariate analysis of variance results for reaction time and accuracy by gender.

EFFECT .. GENDER
Multivariate Tests of Significance (S = 1, M = 0, N = 46 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.004	.20	2.00	95.00	.82

EFFECT .. GENDER BY EXPOSURE
Multivariate Tests of Significance (S = 1, M = 0, N = 46 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.02	.97	2.00	95.00	.38

EFFECT .. GENDER BY EXPOSURE BY DIFFICULTY
Multivariate Tests of Significance (S = 1, M = 1 , N = 45 1/2)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.02	.41	4.00	93.00	.80

Table F7

Summary of the multivariate analysis of variance results for accuracy reanalysed.

Test of Between-Subjects Effect.

Tests of Significance using SEQUENTIAL Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1403505.41	48	407.78		
ORDER	7.09	1	7.09	.02	.90

Test involving 'DIFFICULTY' Within-Subject Effect.

EFFECT .. DIFFICULTY
Multivariate Tests of Significance (S = 1, M = 0, N = 21)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.90	214.29	2.00	47.00	<.001

Test involving 'EXPOSURE' Within-Subject Effect.

Tests of Significance using SEQUENTIAL Sums of Squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	2612.81	48	54.43		
EXPOSURE	4.17	1	4.17	.08	.78

Tests involving 'DIFFICULTY BY EXPOSURE' Within-Subject Effect.

EFFECT .. DIFFICULTY BY EXPOSURE
Multivariate Tests of Significance (S = 1, M = 0, N = 21)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.10	2.62	2.00	47.00	.08

Tests involving 'EXPOSURE WITHIN DIFFICULTY' Within-Subject Effect.

Tests of Significance for T4 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1507.95	48	31.42		
HARD LEVEL OF DIFF.	20.82	1	20.82	.66	.420

Tests of Significance for T5 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	2094.97	48	43.65		
INTER. LEVEL OF DIFF.	31.66	1	31.66	.73	.399

Tests of Significance for T6 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN CELLS	1552.41	48	32.34		
EASY LEVEL OF DIFF.	44.29	1	44.29	1.37	.248

Table F8

Summary of the multivariate and univariate analyses of variance results for the cardiovascular measures.

Test of Between-Subjects Effect

EFFECT .. ORDER
Multivariate Tests of Significance (S = 1, M = 1 , N = 46)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.02	.48	4.00	94.00	.75

Tests of Within-Subjects Effects.

Multivariate Tests of Significance (S = 1, M = 1 , N = 46)

Effect	Pillais	Approx. F	Hypoth. DF	Error DF	Sig. of F
PERIOD	.27	8.72	4.00	94.00	<.001
EXPOSURE	.05	1.26	4.00	94.00	.29
PERIOD x EXP.	.001	.03	4.00	94.00	.99

EFFECT .. ORDER
Univariate F-tests with (1,97) D. F.

Variable	Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
SYSTOLIC	1.45	25920.73	1.45	267.22	.01	.94
DIASTOLIC	53.41	19463.82	53.41	200.66	.27	.61
PULSE	531.11	39368.93	531.11	405.87	1.31	.26
MAP	103.93	17179.15	103.93	177.10	.59	.45

EFFECT .. PERIOD
Univariate F-tests with (1,97) D. F.

Variable	Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
SYSTOLIC	93.16	1103.58	93.16	11.38	8.19	.01
DIASTOLIC	47.14	1245.26	47.14	12.84	3.67	.06
PULSE	416.09	1328.91	416.09	13.70	30.37	<.001
MAP	69.03	1425.13	69.03	14.69	4.70	.03

EFFECT .. EXPOSURE
Univariate F-tests with (1,97) D. F.

Variable	Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
SYSTOLIC	.02	3149.32	.02	32.47	.0007	.98
DIASTOLIC	32.17	1838.45	32.17	18.95	1.70	.20
PULSE	189.92	10297.57	189.92	106.16	1.79	.18
MAP	25.25	2086.70	25.25	21.51	1.17	.28

EFFECT .. PERIOD BY EXPOSURE
Univariate F-tests with (1,97) D. F.

Variable	Hypoth. SS	Error SS	Hypoth. MS	Error MS	F	Sig. of F
SYSTOLIC	.001	1328.92	.001	13.70	.001	1.00
DIASTOLIC	.25	738.76	.25	7.62	.03	.86
PULSE	.04	939.20	.04	9.68	.004	.95
MAP	.99	1152.43	.99	11.88	.08	.77

Table F9

Summary of the multivariate analysis of variance results for the cardiovascular measures by gender.

EFFECT .. GENDER
Multivariate Tests of Significance (S = 1, M = 1 , N = 46)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.22	6.71	4.00	94.00	<.001

EFFECT .. GENDER BY PERIOD BY EXPOSURE
Multivariate Tests of Significance (S = 1, M = 1 , N = 46)

Test Name	Value	Approx. F	Hypoth. DF	Error DF	Sig. of F
Pillais	.03	.77	4.00	94.00	.55

Table F10

Summary of the chi-square test used to test the assumption that the subjects could not discriminate between sham and real fields.

- - - - Chi-square Test

Category[a]	Cases Observed	Expected	Residual
1	35	33.33	1.67
2	18	19.67	-1.67
3	18	16.33	1.67
4	26	27.67	-1.67
Total	97		

Chi-Square	D.F.	Significance
.497	3	.920

[a]1 = Field on, subject correct; 2 = Field on, subject incorrect; 3 = Field off, subject correct; 4 = Field off, subject incorrect.