IS HUMAN COGNITIVE PERFORMANCE MODULATED BY A POWER-LINE FREQUENCY MAGNETIC FIELD?

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Abstract

Previous studies have not found consistent effects of extremely low frequency (<300 Hz) magnetic fields (MF) on human cognitive processing. Although low-level exposures are experienced by the general population, there is little research using MF intensities comparable to the highest levels of occupational exposure. To examine this highest level of exposure we evaluated possible effects of a 60 Hz, 3000 μT MF on human cognitive performance. The experimental session consisted of a double-blind computer driven protocol (90 participants) with cognitive function assessed by repeated measures psychometric testing (statistical analysis: 3x2 mixed model ANOVA). As expected, there was a practice effect (improvement between blocks 1 and 2 on most tests). This was not consistent across all exposure groups as indicated by a significant interaction effect found on one of the working memory indexes: digit span forward (F=3.75, p<0.05). There was not, however, sufficient evidence to conclude this was a MF-induced effect on test performance. The absence of cognitive effects at this exposure level should be taken into account during the process of developing exposure guidelines. Future studies should increase exposure intensity until a reliable threshold for cognitive effects is found and the mechanism responsible is identified.

Introduction

Scientific literature suggests there are effects on human biology and functioning from exposure to extremely low frequency (ELF, < 300 Hz) magnetic fields (MF) (C. M. Cook, Thomas, & Prato, 2002; C. M. Cook, Saucier, Thomas, & Prato, 2006; Crasson, 2003), but to date, no widely accepted mechanism has been identified. Though inconsistent, research focused on a variety of organ systems has reported effects of MF interaction. Exposure to ELF MF is reported to modulate the cardiovascular system through altering heart rate and heart rate variability (Sait, Wood, & Sadafi, 1999). Musculoskeletal systems also respond to MF exposure through the healing of bone fractures (Deibert, Mcleod, Smith, & Liboff, 1994; Hanafy, Elhafez, Aly, & Elazhary, 2008). In the central nervous system, nerve stimulation and altered retinal function (e.g. magnetophosphenes) can occur with MF exposure (Attwell, 2003; Sienkiewicz, Saunders, & Kowalczuk, 1991; Taki, Suzuki, & Wake, 2003). Findings suggest that cognitive mechanisms are sensitive to MF exposure. While relevant to the public, this data is of particular interest to workers exposed to higher intensity ELF MF.

Typically, measuring human cognitive function involves psychometric testing. Specific tests are designed to evaluate certain cognitive functions, mainly those processed in the frontal lobes of the cortex, (e.g. working memory, perceptual reasoning, mental processing, memory, or visuo-motor coordination). The cognitive performance is usually evaluated in terms of accuracy (correctness of response) and timing (speed of completion). Though results are often heterogeneous, it appears that an ELF MF exposure would modulate the accuracy but rarely the timing (Preece, Wesnes, & Iwi, 1998). Moreover, tasks with higher levels of difficulty seem more sensitive to MF exposure than simple tasks. For example, this was seen in a study by Cook et al. (1992) where MF-induced effects occurred in a choice reaction time task (fewer errors were made during exposure in a task requiring a decision between three buttons). This same effect did not occur during a simple reaction time task (pressing a single button when the stimulus was present). Work conducted by Whittington et al. (1996) found reaction time significantly decreased during the most difficult level of a visual duration discrimination task, though due to low statistical power a compensation of $\alpha = 0.15$ was used. Another study by the same group saw improvement in accuracy on the most difficult level of the visual duration discrimination task with the presence of the MF (Kazantzis, Podd, & Whittington, 1998). Again, the alpha level was relaxed ($\alpha = 0.30$) to improve statistical power. Both studies utilized a 50 Hz, 100 µT MF with an exposure duration less than ten minutes. Most recently, a paper by the same group found memory recognition improved after exposure but no change on the visual duration discrimination task (Podd, Abbott, Kazantzis, & Rowland, 2002). This demonstrates the issue with replication inconsistency within ELF MF research.

There are many potential reasons for the difficulty in reproducing results between and within laboratories. A review article published by Crasson et al. (2003) mentions differences in MF parameters between studies (e.g. exposure duration, field strength, frequency, interaction with the geomagnetic field, intermittent vs. continuous exposure, order and time of day of exposure, orientation, polarity, waveform, and whole-body vs. cephalic exposure). Further: inter-individual and inter-group disparity; methodology variability, functional state of nervous system, measurement parameters, and task difficulty. Barth et al. (2009) performed a meta-analysis on nine studies to address inconsistent findings of work in this field. They found significance with the visual duration discrimination task at the hardest level (exposed individuals showing better performance) and at the intermediate level (exposed individuals showing worse performance) the authors suggest treating these results with caution due to so few studies per measurement parameter. Studies in this field have utilized a wide range of exposure levels and have not shown a consistent direction of effect (improvement or degradation of performance). As a result, there is no strong evidence to establish a dose response. Cook et al. (1992) found field exposed participants made fewer errors on a choice reaction time task while Preece et al. (1998) found MF exposure led to an increase in errors.

One consistency in human studies with a 50 Hz exposure level greater than 500 µT is a potential reduction in cognitive performance on tests examining attention, perception, and working and secondary memory. Preece et al (1998) found that numerical working memory sensitivity index, delayed word recognition sensitivity, and the choice reaction time accuracy all declined with exposure to a 50 Hz, 600 µT MF though speed of completion was unaffected. Trimmel & Schweiger (1998) found a performance reduction on visual attention, precision of visual processing, the speed and precision of perception, and verbal memory in humans at an even greater exposure intensity (50 Hz, 1000 µT).

The objective is to determine if exposure to a 60 Hz, 3000 µT MF induces changes in cognitive performance (both accuracy and time). The exposure level of this experiment is set to 3000 µT because this is the lower threshold at which a consistently reported biological effect is found (magnetophosphenes reported starting at 3000 µT; Silney, 1986) and previous studies finding MF induced cognitive effects were using high intensity field. Ideally, a threshold will be evident where consistent cognitive effects from power-line frequency MF exposure are found. It is expected that a large sample size with a wide-range of cognitive tests would narrow down the cognitive functions affected. It is hypothesized that exposure to a 60 Hz, 3000 µT MF will lower accuracy in test performance but will not affect the participant reaction time.

Method

Exposure Apparatus

Two octagonal Helmholtz-like coils generated the sinusoidal 60 Hz, 3000 µT MF centered at the level of the participant's head. The coils are 1.6 m wide and 1.2 m apart positioned parallel to each other. Each coil was made from 158 turns of 10-gauge copper wire and was encased within plastic. The field strength was checked before each participant to ensure it was at the appropriate level. The participant sat on a comfortable elevated chair located between the coils (Figure 1). A wooden table on a sliding track was positioned in front of the participant to carry out the testing. The experimenter sat across from the participant on the other side of the table.

Figure 1 – The MF exposure apparatus.

Participants

Poster advertisements were used to recruit participants from the hospital and university community. Ninety volunteers (57 female, 33 male) participated in the study. The mean age was 23.4 years (range 18 – 49 years). The University of Western Ontario Health Science Research Ethics Board approved the study (# 13460) and all participants gave informed consent. Participants were self-reported healthy adults between the ages of 18 and 55 inclusive. Participants could partake in the study only if they did not have a limitation of movement, ever experienced an epileptic seizure; suffered from chronic illness (e.g., diabetes, a psychiatric condition, or severe cardiovascular problems including susceptibility to arrhythmias or neurological diseases); used illicit drugs regularly; had a history of head or eye injury involving metal fragments; had ever worked in a metal shop or been a soldier; had some type of implanted electrical device (such as a cardiac or cerebral pacemaker); wore a hearing aid system; had metal braces on their teeth; had any permanent piercing, were potentially pregnant; or had an intrauterine device. Moreover, participants were asked to avoid smoking or consuming caffeine or alcohol in the 12 hours preceding participation in the study.

Procedure

The baseline session (Se1) lasted approximately 2.5 hours and during this time the participant completed the Oldfield Handedness Questionnaire (Oldfield, 1971), Beck Anxiety Inventory (BAI) (Beck & Steer, 1993), Beck Depression Inventory-II (BDI-II) (Beck, Steer, & Brown, 1996), and Wechsler Adult Intelligence Scale-III (WAIS-III) (Wechsler, 1997). The tests were designed to evaluate the participants' handedness, anxiety, depression, and intelligence respectively. All tests were administered by a trained experimenter who was working under the supervision of a clinical psychologist. If any response to these questionnaires suggested a pathologic state, the psychologist would contact the appropriate clinical service without delay. In order for the participant to become comfortable with all tests in the experimental session the Trail Making Tests A and B (TMTA and TMTB), Stroop, mental rotation (MR), and Fitts' Motor Task (FMT) were also introduced in the baseline session. There was never a MF exposure generated during this session. The experimental session (Se2) followed the baseline session (at least one day apart) and lasted 2.5 hours. The counterbalanced double-blind computer driven protocol (LabView 8.5, NI Inc., USA) consisted of two testing blocks each preceded by a 30-minute rest block. The participant underwent one of three possible exposures (Figure 2): Group 1 (G1, sham/sham), Group 2 (G2, real/sham), or Group 3 (G3, sham/real). During a testing block the participant completed the following subtests in order: Digit Symbol Coding (DSC), Block Design (BD), Arithmetic (AR), Digit Span Forwards (DSF), Digit Span Backwards (DSB), TMTA, TMTB, Stroop, MR, and FMT. At the conclusion of each test block the participant completed the field status questionnaire to determine awareness of the MF exposure (M. R. Cook et al., 1992).

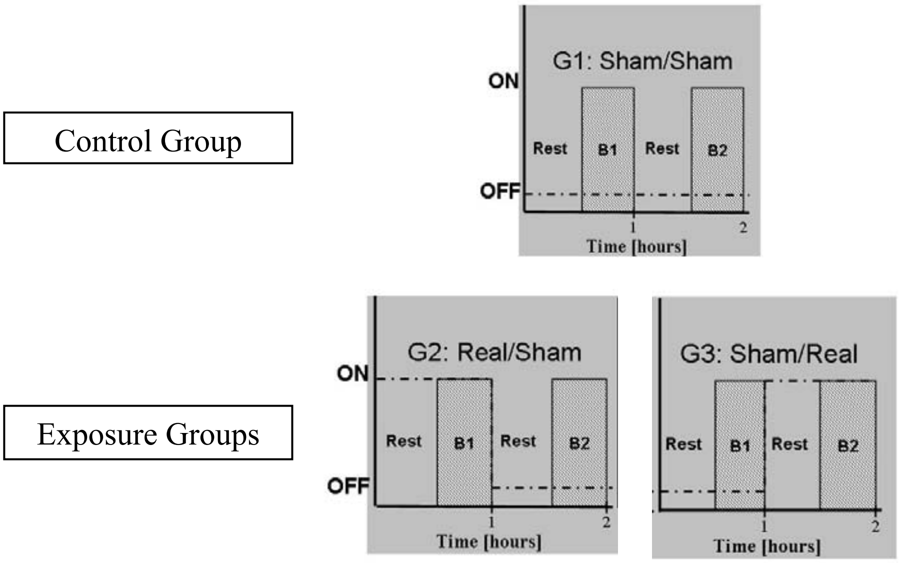

Figure 2 – The control and exposure groups with MF conditions.

Results

In the baseline session there were no significant differences found between the three groups (Figure 3) for scores on the BAI ($F = 0.178$, $p > 0.80$), BDI-II ($F = 0.515$, $p > 0.50$), and WAIS-III ($F = 0.679$, $p > 0.50$).

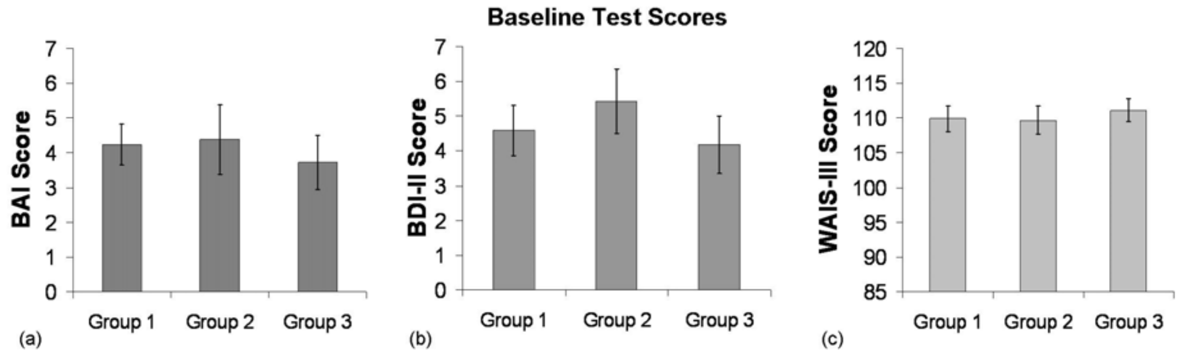

Figure 3 - The baseline (Se1) test scores for the BAI, BDI, and WAIS tests. There were no significant differences between groups. The error bars represent the standard error of the mean.

The participant performance in the experimental session (Se2) did not show any significant group effects (Table 1). However, there was a significant block effect for several performance indexes (Table 1). The scores on the DSC, BD, AR, and DSB were increased in B2. In addition, the percentage of correct responses on the Stroop and the mean displacement from T2 on the FMT was increased in B2 as compared to B1. There was also a block effect for the mean time of the TMTA, TMTB, Stroop, MR, and Fitts' task which decreased in B2 compared to B1. The DSF score, Stroop percentage of correct responses, MR percentage of correct responses, and the mean displacement from T1 on the FMT did not differ between B1 and B2.

Measure	F	p value	η_p^2
Digit Symbol Coding	22.27	p < 0.05*	0.20
Block Design	34.63	p < 0.05*	0.29
Arithmetic	3.96	p < 0.05*	0.04
Digit Span Forward	2.87	p > 0.05	0.03
Digit Span Backward	6.69	p < 0.05*	0.07
Trail Making Test A	21.17	p < 0.05*	0.20
Trail Making Test B	6.26	p < 0.05*	0.07
Stroop			
Percent Accuracy	8.71	p < 0.05*	0.09
Time	43.55	p < 0.05*	0.34
Mental Rotation			
Percent Accuracy	1.15	p > 0.05	0.01
Time	35.20	p < 0.05*	0.29
Fitts' Task			
Target 1 Displacement	0.43	p > 0.05	0.01
Target 2 Displacement	11.41	p < 0.05*	0.12
Movement Time	38.09	p < 0.05*	0.32

Table 1 - The results of testing Se2 data for block effects. Significance is indicated by an (*).

None of the tests showed any group effects. There was only one significant interaction effect and that was for the DSF ($F = 4.10$, $p < 0.05$, Figure 4). All other interactions were not significant (Table 2).

Measure	F	p value	η_p^2
Digit Symbol Coding	0.55	p > 0.05	0.01
Block Design	0.52	p > 0.05	0.01
Arithmetic	1.39	p > 0.05	0.03
Digit Span Forward	3.75	p < 0.05*	0.08
Digit Span Backward	1.68	p > 0.05	0.04
Trail Making Test A	0.04	p > 0.05	0.01
Trail Making Test B	0.40	p > 0.05	0.01
Stroop			
Percent Accuracy	0.37	p > 0.05	0.01
Response Time	0.33	p > 0.05	0.01
Mental Rotation			
Percent Accuracy	0.86	p > 0.05	0.02
Response Time	0.18	p > 0.05	0.01
Fitts' Motor Task			
Target 1 Displacement	1.46	p > 0.05	0.03
Target 2 Displacement	0.41	p > 0.05	0.01
Movement Time	1.40	p > 0.05	0.03

Table 2 - The results of testing Se2 data for interaction effects. Significance is indicated by an (*).

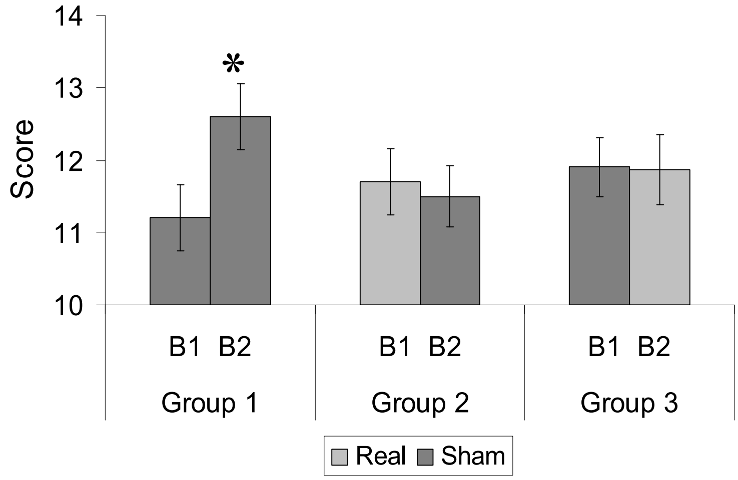

Figure 4 - The results of the digit span forward task for each test block of the three groups. The error bars represent the standard error of the mean.

Finally, the responses of the field status questionnaire were analyzed and participants were not able to judge the presence of the MF at better than chance levels (54.7% correct; chi-square = 1.49, df 1, ns, Yates correction applied).

Summary

In order to evaluate the impact of human exposure to a 60 Hz, 3000 µT MF on specific cognitive functions a double-blind counterbalanced procedure was used. The study included a large sample of human volunteers distributed into three experimental groups that where shown to be homogeneous with regards to their levels of anxiety, depression and intelligence. The results of BAI scores showed that all groups were at a minimum level of anxiety (score 0-7). The mean score on the BDI-II of each group was in the minimum depression interval (score 0-13). In terms of intelligence, all groups scored higher than average within the range of 100 to 115. This is expected since the majority of participants were university students.

It is important to note that the results of the field status questionnaire revealed that participants were unable to detect the presence of the MF, which is very satisfying considering the high level of MF exposure (to our knowledge, and according to our review of the literature, it corresponds to the highest power-line frequency MF exposure level used in human cognitive studies published in a peer-reviewed journal).

Many of the tests showed a significant block effect which suggests that there is a practice effect between B1 and B2. The improved performance found on processing speed, visual-motor coordination, cognitive-set shifting, and visual scanning have also been reported in other studies (Dikmen, Heaton, Grant, & Temkin, 1999; Fastenau, Hankins, & McGinnis, 2001; Solana et al., 2010). There was an improvement in two of the three memory performance tasks (AR and DSB). This is similar to previous research (Dikmen et al., 1999; Farahat, Rohlman, Storzbach, Ammerman, & Anger, 2003; Steele, Ball, & Runk, 1997; Wilson, Watson, Baddeley, Emslie, & Evans, 2000). Furthermore, consistent with the findings of previous research, processing speed improved from B1 to B2 but there was no change in accuracy for concentration task performance (Beglinger et al., 2005; Dikmen et al., 1999). On the perceptual reasoning tasks, the processing speed increased between blocks and this is in agreement with the findings of other studies (Dikmen et al., 1999; Vandenberg & Kuse, 1978; Wexler, Kosslyn, & Berthoz, 1998). In the FMT there was a decrease in the time necessary to move from one target to another, coupled with an increase in the displacement from Target 2 (furthest from the dominant hand of the participant). While the faster time is an improvement, the decrease in tapping precision indicates a decline in performance. The reduction in precision could be explained by a rise in the participant's speed and confidence. Participants in the original work of Fitts improved their speed (by 3%) between initial trials but did not make more errors (note that the measurement of precision was not as accurate as in this study). The decrease in precision for our study could be caused by increased speed since participants improved their time by 6%. The presence of the practice effect implies that these tests are sensitive enough to detect changes in performance.

The lack of a group effect for any of the tests suggests that the mean performance of all three groups was similar for all tests (on average over the two testing blocks). The overall absence of interaction effects suggest that a 3000 µT MF at 60 Hz does not modulate the cognitive performance in healthy subjects. There is, however, an interesting significant interaction on one of the memory tasks (DSF). Since this effect is not observed on the other numeric memory task (DSB), there is a chance that this corresponds to a statistical artefact (i.e. a type I error). This is a possibility since only one of the fourteen indexes examined showed an effect and DSB did not show a significant effect even though there are processes that overlap with DSF. However, the statistical procedure used here accounts for multiple comparisons, and one cannot exclude the possibility that the interaction corresponds to a real MF-induced effect. This would mean that the improvement of memory performance between the first and the second block within the control group (indicative of a practice effect) is not observed in participants exposed to the MF (regardless of MF presence during the first or second block). A practice effect occurring with repeated DSF testing is well known and has been previously reported (Otto, Hudnell, House, Molhave, & Counts, 1992; Subramanya & Telles, 2009; Taub, 1973). Past work examining repeated administrations of neuropsychological tests have found that the magnitude of a practice effect deteriorates as the length of the test-retest interval increases (Benedict & Zgaljardic, 1998). The short test-retest interval used in our study makes the likelihood of a practice effect being observed even more probable. An fMRI study examining the changes in brain activation during memory tests found increased activation in regions of the prefrontal cortex in both the training group and the control group with testing repetition (Jolles, Grol, Van Buchem, Rombouts, & Crone, 2010). We could speculate that the MF may be interfering with neurons in these regions and cancel the effect associated with the repetition of the task. In this regard, the exposure to a 60 Hz MF at 3000 μT seems to be able to deteriorate the performance in a memory task completed by a healthy subject. The MF exposure does not modulate any of the other parameters investigated here, but subtle changes from MF exposure may not be observable through traditional clinical means of detecting cognitive responses. Using more sensitive tools to study brain function like EEG and fMRI would be beneficial to better understanding the influence of MF on the human brain.

There are no significant MF-induced effects on human cognitive performance with one hour of exposure to a 60 Hz, 3000 μT field detected with our psychometric tests. Though it could be a statistical artefact, the possibility of an effect of the MF exposure resulting in a modulation of the normal practice effect in a memory task cannot be excluded. This would be indicative of a deterioration of the cognitive performance in a memory task as a consequence of MF exposure, which would be consistent with previous results from the literature. Research should be conducted with higher exposure levels and more objective measurements tools (like EEG or fMRI) to examine if there are any changes occurring within the brain due to MF exposure.

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