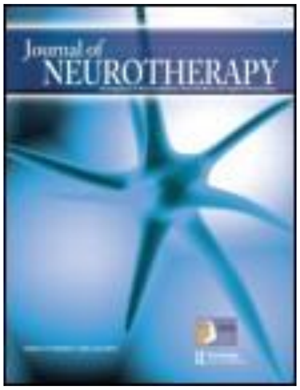

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Brain Inconspicuous Effect by Local Sinusoidal Extremely Low Frequency Magnetic Exposure Based on Wavelet Packet Analysis: Innovation in Online Passive Neurofeedback Therapy by the Neuro-LSELF System

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BRAIN INCONSPICUOUS EFFECT BY LOCAL SINUSOIDAL EXTREMELY LOW FREQUENCY MAGNETIC EXPOSURE BASED ON WAVELET PACKET ANALYSIS: INNOVATION IN ONLINE PASSIVE NEUROFEEDBACK THERAPY BY THE NEURO-LSELF SYSTEM

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Neurofeedback (NF) is a training approach that aims to reinforce brain activity by using the information of human electroencephalogram (EEG) rhythms as a feedback. In addition, some studies have reported Extremely Low Frequency (0–300 Hz, intensity $< 500\,\mu$T) Magnetic Field (ELF MF) effects upon the EEG and its rhythms. The purpose of this study is to determine if an approach that combines the effects of Local Sinusoidal Extremely Low Frequency Magnetic Fields (LSELF MF) with NF yields higher performance on desired NF goals. The NF protocol used in this study consisted of enhancement of the beta rhythm and inhibition of theta and high beta rhythms in exposed and sham groups for the purpose of improving attention. Twenty-four healthy subjects of at least average intelligence attended 10 sessions of NF training. Sixteen of them were exposed to 45 Hz sinusoidal ELF (360 μT) at F3 to lead to the desired LSELF MF effects on Cz. Wavelet packet analysis was used for the detection of changes in EEG rhythms. Results suggest that, compared to sham exposure, LSELF magnetic waves can significantly affect and modulate brainwaves according to this new neurofeedback approach. In comparison to sham exposure, improved ability to attend (as measured by a decrease in the theta-to-beta ratio) was observed when LSELF MF was combined with NF ($p < .05$). The hypothesis that LSELF MF can affect the theta-to-beta ratio was confirmed. These effects occurred after approximately 10 min of each NF procedure. This study aimed to pilot a new NF system known as the *Neuro-ELF system*, a method that may allow for more effective control of brainwave activity. However, we suggest that the effects of LSELF-NF require further research.

INTRODUCTION

Neurofeedback (NF) is a form of biofeedback training that is related to the electrical activity of the brain and that aims at reinforcing EEG rhythms in a desired direction to meet clinical objectives. NF consists of two main modalities: active (traditional NF) and passive. In active NF, some external factors can affect the training procedure, for example, volition and client characteristics such as intelligence (IQ). Traditional NF has encountered many difficulties

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such as the need for multiple treatment sessions and the absence of a proper index to determine the role of client characteristics in the treatment procedure. Some developments in active NF training have occurred such as the Low Energy Neurofeedback System (LENS). However, in the case of passive NF, volition does not play a role in treatment unlike in active NF. In other words, LENS (Ochs, 2006a, 2006b) is like passive NF and so does not require any conscious effort on the part of the subject. Ochs (2006a, 2006b) sent low energy electromagnetic waves (e.g., radio, light) as feedback to the subjects and measured the returned waves. This method of NF training is based on the delivery of electromagnetic waves carrying the feedback signal down the electrode wire. The stimulus in this method is based on the dominant EEG frequency. In contrast, in active NF, subjects learn to control physiological brain activity to acquire thought patterns and learn to manage them consciously. Both of these methods have some advantages and disadvantages. If the disadvantages are removed, NF can be applicable in efficiently treating many diseases such as depression, attention deficit hyperactivity disorder, addiction, and so on. The major goal of this study is to pilot implementation of a novel NF approach and to verify it as a viable option it for neurotherapy purposes.

Many studies confirm the effectiveness of NF training in improving concentration, consciousness, attention, and many brain diseases and disabilities (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009; Egner & Gruzelier, 2001, 2003, 2004; Vernon, 2005; Vernon et al., 2003; Vernon, Frick, & Gruzelier, 2004). The large number of required treatment sessions, especially with a medium effectiveness of about 70% to 90%, demonstrates that this method does not yet have optimal efficiency and capability. Absence of a proper index in utilizing NF is one of these deficiencies because EEG rhythm extraction in current systems is based only on filtering or the Fast Fourier Transform (FFT) method (Evans, 2007; Gunkelman & Johnstone, 2005; Hammond, 2007; L. Thompson & Thompson, 1998; M. Thompson & Thompson, 2003; Vernon et al., 2004). Absence of proper EEG rhythms estimation because of their nonlinear nature, artifact rejection foible and treatment time dependency are the deficiencies of these systems that result in reduced effectiveness.

In recent decades, there has been rapid proliferation of brain stimulation instruments that influence various aspects of brain activity. Magnetic brain stimulation is an example of one of these new techniques. These methods and techniques are used in a variety of applications such as neurotherapy, neuropsychiatric treatments, and brain performance improvement. Magnetic, electromagnetic, and electrical stimulators are included in this kind of stimulation, for example, transcranial magnetic stimulation (TMS; Farzan et al., 2008; George et al., 2002; Iramina, Maeno, Kowatari, & Ueno, 2002; Pascual-Leone, Walsh, & Rothwell, 2000; Post & Keck, 2001; Thut & Pascual-Leone, 2010; Walsh & Cowey, 2000; Weaver et al., 2012), repetitive TMS (Grunhaus et al., 2000; Jahanshahi et al., 1997; Pascual-Leone et al., 1993; Wassermann & Lisanby, 2001), transcranial direct current stimulation (Gladwin, den Uyl, Fregni, & Wiers, 2012; Paulus, 2011; Utz, Dimova, Oppenländer, & Kerkhoff, 2010), and electroconvulsive therapy (Grunhaus et al., 2000).

In many of these methods, the mechanisms of action are not clear from physiological and neurological perspectives. There are many studies on the physiological and neurological effects of very low magnetic fields even at the ρT range (Bardasano, Álvarez-Ude, Gutiérrez, & Goya, 2005; Bardasano & Ramirez, 1997; Bell, Marino, Chesson, & Struve, 1991; Cvetkovic & Cosic, 2006, 2009; Gerardi et al., 2008; Lednev, 1991; Nitsche et al., 2003; Shafiei, Firoozabadi, Tabatabaie, & Ghabaee, 2012b; Shafiei Darabi, Firoozabadi, Tabatabaie, & Ghabaee, 2010). In recent years, there has been an increase in the number of studies that provide evidence on the positive effects of TMS and repetitive TMS on several cognitive domains (Grosbras & Paus, 2002; Grunhaus et al., 2000; Iramina et al., 2002; Pascual-Leone et al., 1993;

Pascual-Leone et al., 2000; Walsh & Cowey, 2000; Wassermann & Lisanby, 2001). The wide range of the demonstrated effects of magnetic brain stimulation indicates that this method holds promise as an effective method to affect brain activity.

Another such method called extremely low frequency magnetic field (ELF MF) is used to affect brain activity. Research on weak magnetic ELF (with a frequency range that varies between 0 Hz and 300 Hz) and its effects on human cognitive functions, such as attention, perception and cognitive processing, has yielded incomplete and contradictory evidence. (Capone et al., 2009; C. Cook, Saucier, Thomas, & Prato, 2006, 2009; C. Cook, Thomas, & Prato, 2002, 2004). There is some research on the effects of very weak alternating magnetic fields when the frequency of the applied field matches the angular frequency and resonance phenomena investigations (Bell, Marino, & Chesson, 1994a, 1994b; Lednev, 1991). Table 1 summarized some of the ELF MF cellular interactions and mechanisms. As described, the researchers believe that, at some frequencies, ELF MF causes the reinforcement of brain signals in the same frequency as the exposure field. These studies investigated the effects of very weak alternating magnetic fields upon living organisms and related variations in the ion concentrations within the cells when the frequency of the applied field matches the angular frequency. This phenomenon is called a *cyclotron* or *Larmor* frequency mechanism by which biological systems become sensitive to small static and resonating magnetic fields and the existence of a resonating effect on ions. These studies are applicable for both TMS and ELF effects. De Ninno et al. (2008) described that the Larmor frequency of most of the ions involved lies between 10 and 50 Hz. The interaction of spin-correlated radical pairs with magnetic fields confirms that the magnetic effect accounts for the Larmor frequency coupling. This study indicates that the Larmor frequencies of the Fe^{2+} and Cu^{2+} ions are 17 Hz and 15 Hz, respectively. The Larmor precession provides a mechanism by which biological systems become sensitive to small static and resonating magnetic fields (Edmonds, 1993). Salamino et al. (2006) reported that weak magnetic fields strongly decrease enzyme catalytic activity, which affects the modified availability of Ca^{2+} due to the magnetic field.

Although there is no consensus on the mechanism of ELF effects, there is some evidence that ELF exposure has crucial effects on human beings and brain activity (Capone et al., 2009; C. Cook et al., 2002). Although no intensive and systematic effects have yet been determined, one of the purposes of this study is to estimate the MF frequencies that have considerable influence on cerebral signals, which can then be used to design protocols to treat some psychological disorders.

TABLE 1. Summary of ELF-MF Exposure Interaction on Ions, Cells, and Neurons

Study	Mechanism
Capone et al. (2009)	Enhancement in cortical excitatory neurotransmission
De Ninno et al. (2008)	Superoxide radical generation by a weak field having the Larmor frequency (f_L) of Fe^{2+} while the SOD1 kinetics are sensibly reduced by exposure to a weak field having the frequency f_L of Cu^{2+} ion
Gerardi et al. (2008)	Affecting parameters like blood glucose and fatty acid metabolism
Manikonda et al. (2007)	50 Hz ELF-MF Modify in NMDA receptor function mediated by alteration of Ca^{2+} signaling in rat hippocampus
McFarlane, Dawe, Marks, & Campbell (2000)	Changes in neuritis outgrowth, but not in cell division induced by ELF
Piacentini, Ripoli, Mezzogori, Azzena, & Grassi (2008)	Increases the expression and function voltage-gated Ca^{2+} channels that Ca^{2+} influx through Ca(v)1 channels, which plays a key role in promoting the neuronal differentiation of neural stem/progenitor cells (NSCs)
Pirozzoli et al. (2003)	Modify gene-expression in neuron-like cells
Salamino et al. (2006)	Weak magnetic fields strongly decreases the calpain catalytic activity

Studies of the effects of MF on the electrical activity of the human brain and the conceptual effects of field exposure on cognition and perception are insufficient thus far. Often, inconsistencies in test results are observed during these studies, which are the consequence of MF exposure protocols, for example, (a) windowing phenomena: the difference in magnetic wave response to a different frequency range, (b) field intensity, (c) frequency of the magnetic field, (d) wave shape, (e) exposure period and duty cycle, (f) the method of data acquisition, (g) location of the EEG recording electrode and the location of the coil, and (h) magnetic field exposure geometry. Despite these inconsistencies, it has been proven that ELF MF has conclusive effects. Various investigations indicate that some frequencies of ELF MF exposure affect the nervous system, and many experiments and some signal processing methods have been used to study the influence of ELF MF on EEG. Bell et al. (1991) found that 35% of the subjects exposed to 93 μT MF displayed increased spectral power in the recorded EEG. Fuller, Dobson, Wieser, and Moser (1995) found an increase in epileptiform activity in epileptic patients undergoing presurgical evaluation after exposure. Also Dobson, St. Pierre, Schultheiss-Grassi, Wieser, and Kuster (2000) found increased epileptiform activity after exposure to DC MF. Later, they found that a weak DC MF elicited changes in EEG activity in half of the epileptic patients that were exposed. Bell et al. (1994b) found decreased EEG activity in the occipital region, but not in the central or parietal regions after exposure to 10 Hz MF. It was concluded that a weak MF applied continuously to human subjects for 10 min resulted in a reduction in brain electrical activity in the frequency of the MF during the 1-min interval following the termination of the field. Their next study reported the effects of 1.5 and 10 Hz EMFs, 20–40 μT_{rms}, and the results indicated altered brain EEG activity (Bell et al., 1994a). The results showed that a 10 Hz–40μT_{rms} MF was more effective than a 1.5 Hz–20 μT_{rms} MF in eliciting increases in EEG activity at the frequency of exposure. It was reported that the application of electromagnetic fields beyond the range of 0–60 Hz and an intensity of 20–100 μT altered EEG activity in animals and human subjects during 2-s exposure epochs. Schienle, Stark, Kulzer, Klöpper, and Vaitl (1996) found that a pulsed 10KHz MF with a frequency of 6.6 Hz and 20 Hz reduced EEG spectral power within the frequency band of 10 Hz to 10.75 Hz. Marino and Becker (1977) found increases in spectral power at ($\geq$10.0 Hz) in the central, parietal, and occipital regions at two frequencies of 10 Hz and 1.5 Hz, both of 80 μT_{rms} intensity. Heusser, Tellschaft, and Thoss (1997) found increases in EEG spectral power in the beta and theta bands after 3 Hz MF exposure.

Various studies have investigated the effects of pulsed and sinusoidal MF on brain activity by analyzing the spectral power of the main frequency bands of EEG (Bardasano & Ramirez, 1997; Bell, Marino, & Chesson, 1992, 1994a, 1994b; Bell et al., 1991; C. Cook et al., 2006; C. M. Cook, Thomas, Keenliside, & Prato, 2005; C. M. Cook et al., 2004; Cvetkovic & Cosic, 2006, 2009; De Ninno et al., 2008; Lyskov, Juutilainen, Jousmaki, Hänninen, et al., 1993; Lyskov, Juutilainen, Jousmaki, Partanen, et al., 1993; Marino & Becker, 1977). These studies have used a wide variety of experimental designs and exposure conditions. Some researchers have focused on MF effects on electrical activity of the brain, and in some cases, the cognitive and perceptual effects of MF exposure were explored. C. M. Cook et al. (2004) found that exposure to ELF magnetic fields altered human EEG activity, specifically within the alpha frequency band. The findings indicated that alpha (8–13 Hz) activity was significantly higher over the occipital electrodes and marginally higher over the parietal electrodes post-exposure. Cvetkovic et al. (Cvetkovic & Cosic, 2006, 2009; Cvetkovic, Cosic, & Djuwari, 2004) found that sinusoidal ELF exposure from circular Helmholtz pairs of coils in the frequencies of 50, 16.66, 13, 10, 8.33 and 4 Hz, which were measured by linearly polarised magnetic flux density of $20 \pm 0.57\ \mu T_{rma}$, alter the EEG rhythms of humans after a period of 12 minutes. Also, an ELF MF field carried out inside Helmholtz coils generates a homogenous and continuous field. In these studies, in order to generate MF, one or several parts of the Helmholtz coil are used where the whole head is exposed to a monotonous magnetic field. C. Cook et al. (2002) reviewed a reported effect at different intensities of field and different EEG frequencies, and then he compared the resulting data and reported the results. In fact, in that research, the aim was to examine the effects of the surrounding MF on a body, especially on the brain and some diseases such as epilepsy. Some other experiments explored ELF MF effects upon cognitive or sensory processing, reaction time and memory recall (C. M. Cook et al., 2005; C. M. Cook et al., 2004; Cvetkovic & Cosic, 2006, 2009). M. R. Cook, Graham, Cohen, and Gerkovich (1992) found that the magnitude of the p300 component (a mid-latency positive peak that appears 300 milliseconds after a stimulus onset) of the ERP increased after 6 hours of electric and MF exposure. A slight increase in reaction time also occurred. Different findings have been reported after ELF-MF exposure with a positive impact on recognition memory (Vázquez-García et al., 2004) and spatial learning (Liu, Wang, He, & Ye, 2008), suggesting a crucial role for exposure in central and frontal regions. Lyskov and colleagues (Lyskov, Juutilainen, Jousmaki, Hänninen, et al., 1993; Lyskov, Juutilainen, Jousmaki, Partanen, et al., 1993) found significant increases in beta (14–25 Hz) activity after 15 min of 45 Hz ELF MF head exposure.

In total, magnetic brain stimulation by ELF has been implemented in two ways. In the first method that was discussed previously, the whole brain is exposed, and in the second approach, the exposure is local. In the whole-brain exposure method using ELF, the head is stimulated with Helmholtz coils, and in the second approach, the brain is stimulated with small coils that are placed on different regions locally. Shafiei et al. (2012b) exposed human brains to local sinusoidal ELF and investigated a relative power spectrum at 3, 5, 10, 17, and 45 Hz frequencies at T4, T3, F3, Cz, and F4 sites, respectively; these points were exposed to magnetic fields with similar frequencies and 100 μT intensity. The results indicated that the power value of the EEG did not necessarily alter significantly at the frequency of stimulation. However, significant changes were observed in different EEG bands caused by local exposure to ELF MF in different brain areas. The changes in the EEG bands were not necessarily limited to the exposure point.

An important conclusion from this research indicates that applying the exposure to the T4 region in an eyes-open condition results in a remarkable increase in the alpha band in the Cz and F4 regions. Shafiei, Firoozabadi, Tabatabaie, and Ghabaee (2011) also found that applying the 45 Hz LSELF MF exposure to the F3 region in the eyes-open condition results in a decrease in the theta band at Cz. When exposure intensity was 240 μT, applying the 45 Hz LSELF MF exposure to the F3 region in the eyes-open condition results in a decrease in the alpha band at Cz. Increasing the intensity to 360 μT resulted in a decrease in the theta band. Shafiei et al. (2012a) exposed five points on the head (F3, F4, Cz, T3, and T4) to local sinusoidal ELF by five separate coils at different frequencies (45, 17, 10, 5, and 3 Hz), in five separate sessions. The published magnetic field intensity was 100 μT and a significant reduction in the alpha-1 band was observed at frequencies of higher than 5 Hz in the eye-closed state. Previously, Shafiei Darabi et al. (2010) and Shafiei et al. (2011) indicated that local sinusoidal exposure of ELF MF affects brain activity. They investigated 240 μT exposure of LSELF MF at F3, F4, Cz, T3, and T4 sites by 45, 17, 10, 5, and 3 Hz frequencies. EEG variations in central regions were observed. Amirifalah, Firoozabadi, and Shafiei (2013) and Amirifalah, Firoozabadi, Shafiei, and Assadi (2011) examined the local pulsed exposure to central regions C3, C4, and Cz by intensity 200 μT when ELF MF exposure frequencies were 10, 14, and 18 Hz. They found that local pulsed ELF MF significantly decreases the beta band power in all three regions during the exposure

(7.9%–11.6%) when compared to preexposure measures with 95% certainty.

In comparison to local exposure, if the whole head is exposed, the changes in the EEG bands are more dispersed and are not necessarily limited to the exposure region. Whole-head exposure may alter many of neurons of both cortical and subcortical origin. This may be due to complex connections between different brain neurons. By localizing the exposure, the induced region is minimized. For example, local exposure does not necessarily cause alteration of the EEG rhythms where the applied MF is placed; however, the changes made on EEG rhythms are limited to the exposure region and may not be observed in distant points.

Magnetic local exposure induces an electrical current that stimulates neurons beneath the exposed region. Based on the difference between the induced current and neuron's stimulation threshold, different biological effects might be observed. Therefore, local exposure does not alter the EEG rhythms according to the frequency of MF. In addition, the changes made in EEG are not limited to the radiation point and may also be observed in other points. The dependency of stimulation frequency and the Larmor frequency may stimulate the neurons. Therefore, these effects are observed beneath the stimulation point or its circular magnetic field lines and directions.

Although there are many studies on ELF MF effects on EEG and relative brain activities such as cognition and perception, they are insufficient and unclear, and additional investigation is needed. As described, there is some clear evidence that both pulsed and sinusoidal ELF MF after local or global brain exposure have direct effects upon EEG.

LSELF MF exposure leads to more effective phenomena by changing the EEG in the desired region of effect and can be used for selective brain effects. The purpose of this study is to choose a proper and efficient method of magnetic field exposure considering nonlinear dynamic feedback to find the optimum local method to control EEG signal variation to affect human brain activities (in this article, attention and in future research, cognition and perception, etc.). The factors obtained from MF effects on the human brain are accumulated and new strategies are presented in order to use these factors across brain control systems.

In recent years, one of the purposes of NF training has been to examine whether neurofeedback training can positively influence cognitive performance in areas such as attention. Some of the protocols and improvements in NF systems have been applied to attention improvement and related disorders. Traditional NF requires the individual to learn and modify some aspects of cortical activity. But there are the two disadvantages of *"learning by subjects"* and *"aspects of EEG rhythms tuning"* during NF training (Hammond, 2005, 2007; M. Thompson & Thompson, 2003; Vernon, 2005). As presented, these methods encountered many problems such as the confounding role of the client's intelligence, the need for multiple treatment sessions, lack of a proper index to accurately determine the clients' status during the NF procedure, and the need for treatment protocols that achieve the desired effects more quickly. Ochs (2006a, 2006b) has used the LENS method, which is completely independent of client characteristics (2006a, 2006b), and like passive NF, does not require any conscious effort on the part of the subject. In active NF, subjects unconsciously learn the feedback and acquire thought patterns and manage them consciously.

This research is aimed at obtaining a logical and accurate relationship between LSELF MF exposure and its effects on the brain in order to apply it in a NF system that decreases (not eliminates) the role that a subject's intelligence plays in treatment efficacy so that the desired effects are acquired faster and the number of required sessions is decreased. This clinical investigation is a combination of NF and LSELF MF exposure to achieve an effective method based on EEG signal rhythms in the case of local sinusoidal ELF effectiveness upon EEGs. Implementation of this idea in traditional NF can be called the Neuro-LSELF MF or LSELF MF-NF system.

If the Neuro-LSELF application leads to the desired results, more efficiency in biological control is expected. It seems that by emphasizing the LSELF MF effects on EEG rhythms, a novel NF approach that is both passive and active has been developed and is explored further in this study. Furthermore, it seems that this new system, known as Neuro-ELF, is a treatment modality that improves traditional NF systems by decreasing the effect of volition on results and decreases the number of sessions required to see improvement.

THE KEY IDEA

The key idea is to develop a modified and improved NF system, which we call Neuro-LSELF MF. Different NF protocols do affect specific EEG changes and have positive effects on behavior (Arns et al., 2009; Egner & Gruzelier, 2001, 2003, 2004; Vernon, 2005; Zoefel, Huster, & Herrmann, 2011). Some research shows (Egner & Gruzelier, 2001, 2004; M. Thompson & Thompson, 2003; Vernon, 2005) that enhancement of the beta (15–18 Hz) band while inhibiting theta (4–7 Hz) and high beta (22–30 Hz) results in improved attention after 10 sessions. Much research has shown that increases in the Sensory Motor Rhythm (SMR) or beta rhythms of healthy subjects results in improved perceptual sensitivity and a decline in commission errors on the Conners' Continuous Performance Test (CPT). It has also been found that increasing SMR results in a general enhancement of attention, and 16–20 Hz training results in increased arousal. Vernon et al. (2003) indicated that SMR or beta enhancement and theta and high beta inhibition is related to decreases in attention in healthy volunteers. In his next review, Vernon (2005) showed that the same protocol correlated with attention change in many studies. The idea in the current study is to induce or inhibit rhythmic activity in the cortex by a brief series of LSELF-MF exposures upon the EEG frequency. For example, magnetic field exposure changes the individual alpha frequency and other brain rhythms such as theta and beta in an attempt to increase or decrease relative brain activity. For instance, a decrease in the theta-to-beta ratio has been shown to correlate with improvements in attention or an increase in the individual alpha frequency that results in improved cognitive performance (Vernon, 2005; Vernon et al., 2003). Therefore, the key idea of this study is to determine the LSELF MF effects on EEG rhythms that increase attention levels by affecting theta or beta rhythms or both.

The factors obtained from the MF effects on the human brain were measured, and new strategies are presented to use in conjunction with NF systems. For more analysis on performance and subject's scores, we used a wavelet packet transform (Gao & Yan, 2011; Liu, Ling, & Meng, 1997) and other more precise investigations that are not discussed in this article.

MATERIALS AND METHODS

Subjects

Twenty-two (four female, 18 male) right-handed volunteers of average-to-above-average intelligence ($IQ > 105$), between the ages of 20 and 30 years (M age $= 25.11 \pm 3.57$ years), in good physical and mental health, attended 10 sessions for this study. They were properly and ethically informed about ELF exposure and the experimental procedures. No women attended during their menstruation period to avoid interference of the hormonal fluctuations of the menstrual cycle. Two other right-handed men, 26 and 27 years old, attended 12 sessions. The body mass index of all volunteers was in the normal range. Criteria for exclusion were verified by physical examination and a health questionnaire that obtained information about the following: psychiatric diagnoses, diabetes, central nervous system disorders, epilepsy, alcohol intake, drug intake, smoking, and cerebral metallic implantation. None of them had previously taken part in studies involving MF exposure, and they had never had surgery. All subjects were asked to refrain from drinking coffee and tea for 24 hr before attending the experiment sessions.

The volunteers were recruited through advertisements at the Clinical and Bioelectrical

Lab of the Biomedical Engineering Department. The ethics committee of the university approved the protocol and all volunteers gave informed consent for the ELF procedure.

Procedure

Subjects participated in testing between 8:30 a.m. and 3:00 p.m. Each subject participated in 10-min sessions with at least a 2-day interval between sessions in both the exposure and sham groups. All subjects were led to believe that they would be exposed to a magnetic field, but just one group was actually exposed. The main experimenter was unaware of the type of exposure (exposed or sham) and thus, group assignment. The volunteers were randomly assigned to one of the two groups according to the type of exposure (real or sham). Sixteen subjects were in the exposed group, and eight were in the sham group. They were required to complete a computerized questionnaire verified by Sina Psychiatric Institute (http://www.sinapsycho.com/ or http://ravantajhiz.ir/), a CREE test related creation assessment, an EQ test related Emotional Intelligence, and a CPT at the following times: at the first session, before starting the test, at the end of 10th session, and after attending the test. This information was used as qualified indexes to compare quantified features (e.g., theta-to-beta ratio) extracted from the EEG to investigate subject characteristics. More detailed analyses on qualified methods and the CPT results will be published in the future. Some other parameters were obtained pre- and postexposure in each session. The subjects completed the Profile of Mood States–Short Form as a pretesting assessment (McNair & Douglas, Retrieved 2 October 2011; Profile of Mood States; Jopie Van Rooyen Partners SA [PTY] LTD) to determine normal mood before attending the NF. All of the subjects completed the self-assessment consent questionnaires (experiment content) and filled in the general form consisting of five questions that they rated on an 11-point scale from 0 (*minimum satisfaction with their sense of attention level changes*) to 10 (*maximum satisfaction with their sense of attention level changes*). The two groups of subjects indicated their expectations about the effects of the designed system on their attention performance questionnaire (posttesting expectations).

Experimental Setup

We used the available magnetic field exposure system consisting of a circular coil that was used and described in Shafiei and colleagues (Shafiei et al., 2012a, 2012b; Shafiei Darabi et al., 2010) and Amirifalah and colleagues (Amirifalah et al., 2013; Amirifalah et al., 2011). The coil's position was under the flexible band. The coil and electrode of the EEG device are illustrated from a top view, as shown in Figure 1. To detect and record the exposed ELF, an aluminium shield covers the coil, and a wire is connected between the earth and the aluminium cover. To observe the generated pulses, a wire is connected simultaneously to

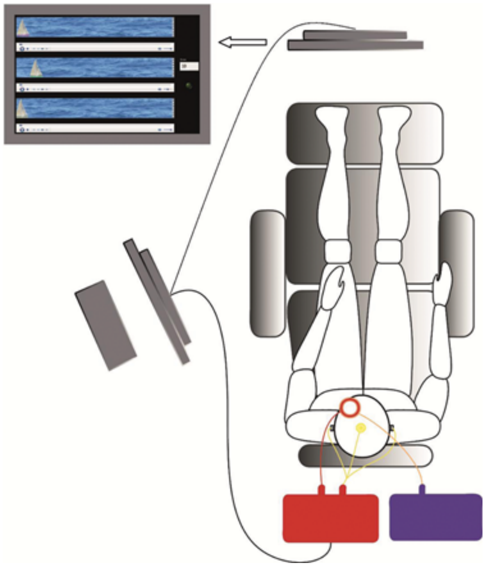

FIGURE 1. The 10/20 International System of electrode placement was used, with the common reference electrode placed at the left ear lobe and the ground placed on the right ear lobe using ear clip electrodes. *Note*. An active electrode (yellow, bottom) was placed on Cz and the coil (orange ring) was fixed on F3. An aluminium shielded wire above the coil (red wire) was used to detect the exposure signals and exposure times simultaneously. The EEG recording device is shown with a red box, and the ELF exposure system is shown with a blue box. The NF system monitor and operator monitor were placed in front and beside the volunteer, as shown. (Color figure available online.)

one of the input channels of the EEG NF recording device.

The magnetic field exposure system is capable of ON and OFF output signals. It is used as a switch via a microcontroller (AVR). An EDC-1630 Digital L.C.R Meter, EQ model ($L = 63.65 \pm 0.025$ mH; $C = 0.9846 \pm 0.001$ μF; $R = 16.13 \pm 0.04\Omega$) was used to measure the coil characteristics. Considering the coil properties and the low-frequency range of the signal generator (0.5–100 Hz), inductance effects were ambiguous. One of the limitations of this study was the coil response to the effect of MF transitions when the MF was switched ON and OFF. The measurement showed that after turning the signal generator off, the current of the coil rapidly dampens and so is negligible.

A Tesla meter (Triaxial ELF Magnetic Field Meter, TES-1394, serial number: 040704120, U.S. Pat. No. Des. 446,135) at 1.2 cm below the Plexiglas ring at the axis showed the intensity of ELF-MF as 360 $\mu T_{\_rms}$. Because MF is not uniform, this Tesla meter is based on rms of ELF-MF in the 3-axis directions using three internal coils. There is approximately a 1.2 cm distance between the radiated point and the target effect point to account for the skull and its lower layers. Thus, the adjustment of the signal generator settings was so that the exposure intensity was set at 360 μT at the desired stimulation point. For this purpose and for more precision, we set the coil on a piece of human skull obtained from a cadaver and then measured the desired intensity as *rms*.

The EEG recording device (FlexComp Infinity, Thought Technology Ltd, serial number: DA2068, Model: SA7550 M, made in Canada) has two specific channels for EEG recording. The 10/20 International System (IS) of electrode placement was used with a common reference electrode placed at the left earlobe and a ground site placed on the right ear lobe using ear clips, as shown in Figure 1. An active electrode (EEG-Z T. T. Ltd, Model: SA9305, Z5417) was placed on Cz and the coil was fixed on F3, as illustrated in Figure 1. The resistance measured between the electrode and the scalp was below 1kΩ (measurement abilities of FlexComp Infinity NF system).

For the purposes of this study, a combination of NF and LSELF MF magnetic exposure was performed. To implement a real-time, de-noising and processing algorithm for EEG affected by LSELF induction, the LSELF exposure signal was recorded with a second channel of the EEG NF device. The two channels of data were synchronously sent to LabView (National Instruments, Austin, TX). A dedicated algorithm was implemented in LabView coded by Matlab (R2012a; Ver. 7.17.0.739) for online de-noising and processing of EEG rhythms during both exposure and nonexposure times. The implemented system is shown in Figure 2.

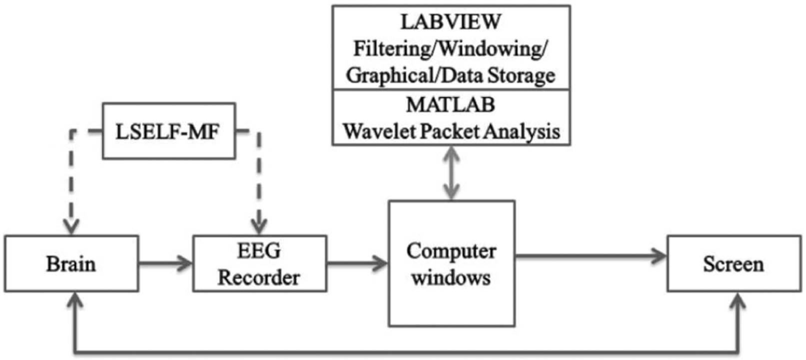

FIGURE 2. A block diagram of the data acquisition system. *Note.* The LSELF magnetic stimulator is connected to a coil placed upon the head. The EEG electrode was placed under the coil.

EEG Rhythms Investigation

Traditional spectral analysis that is applied during NF training is based on Infinite Impulse Response Filters, Finite Impulse Response Filters or FFT (Thakor & Tong, 2004), which are not suitable for this study's purposes. As time-domain analysis of EEG does not provide frequency details, frequency-based analysis would be useful. As FFT analysis does not show at what times the frequency changes occur, time-domain analysis of EEG does not provide frequency details, either. Moreover, EEG signals have nonstationary and transient dynamics corrupted with noise. However, the traditionally used spectral analyses are not accurate, and more precise scrutiny of both frequency components and the times at which they occur is needed. Wavelet packet (WP) analysis can provide a powerful analyzer of when and to what degree transient and component events occur in EEG signals (B. Liu et al., 1997; Tazebay & Akansu, 1995).

In contrast with the FFT method, wavelet packet transform is a precise bio-signal processing method. Because the extracted WP coefficients provide a compact representation that shows the energy distribution of the EEG signals in time and frequency, we can get more precise information through the analysis of the WP coefficients, which could be used to produce more accurate results in the traditional FFT analysis. First, we applied the WP to decompose the EEG signals, and then selected the specific subband of energy. By doing this, it is possible to detect the LSELF MF effects on EEG rhythms so that only the desired information that has been identified to feed back to the NF system is retained. The range that is sufficient to extract the brain activity involved in attention, concentration and perception is found in five main EEG subbands: delta, theta, alpha, beta, and gamma. M. Thompson and Thompson (2003) discussed these EEG rhythms and related brainwave activity as shown in Table 2.

To determine when and how the frequency content changes over space or time, both wavelets are transformed and WP can

TABLE 2. Correlation of Bandwidth to Mental States (Thompson & Thompson, 2003)

Correlation of bandwidth to mental states	
Frequency bands	Correlations
0.5–3 Hz Delta	Movement or eye blink artifact, brain damage, learning disabilities. The dominant frequency in infants.
3–5 Hz Low Theta	Tuned out or sleepy
6–7 Hz High Theta	Internal orientation. Important in memory recall. Can be very creative, but may not recall ideas for very long after emerging from this mental state unless these ideas are consciously worked on and developed. Not focused on external learning stimuli such as reading or listening. The dominant frequency in young children.
7.5–8.5 Hz	Visualization
8–10 (or 11) Hz Low Alpha	Internally oriented and may be observed in some types of meditation. It is possible, but rare, to have a dissociative experience when totally in this state. Adults (eyes closed) have Alpha as the dominant frequency.
12 Hz to (11–13 Hz) High Alpha	Can correlate with a very alert broad awareness state. This can be a readiness state seen especially in high-level outlets. Persons with high intelligence often demonstrate a higher peak Alpha frequency.
13–15 Hz SMR	When this corresponds to the sensory motor rhythm (only over the central cortex: C3, C4, Cz) it can correlate with decreased motor and sensory activity combined with a mental state that maintains alertness and focus. Appears to correlate with a calm state. Decreased anxiety and impulsivity. It may also correlate with decreased involuntary motor activity.
16–20 Hz Beta	Correlates with active, problem-solving cognitive activity. More Beta is required when you are learning a task than when you have mastered it.
19–23 Hz	This may correlate with emotions including anxiety.
24–36 Hz	Can correlate with rumination, which is most often negative.
∼27 Hz (Elevated in the mid 20 s)	May correlate with a family history of addiction.
38–42 Hz Sheer (Gamma)	Cognitive activity- related to attention, and increasing it may help to improve learning disability. It is also referred to as a ''binding'' rhythm. May also be seen at the moment of balance correction.
44–58 Hz	Reflects the effect of muscle activity on the EEG.
50 or 60 Hz	Usually electrical interference

be used. However, using wavelet transform didn't result in the extraction of desired EEG rhythms. Furthermore, more flexibility in defining the frequency bands of the decomposed EEG can be obtained by using a WP that is a generalization form of wavelet transform. Selection of a suitable wavelet and the number of levels of decomposition is very important in the analysis of signals using WP.

In the current analysis, the Daubechies (Db4) wavelet was used. The number of levels of decomposition was chosen based on the dominant frequency components of the EEG to obtain the EEG rhythms discussed in Table 2 for the purposes of this study but were based on NF training. As discussed, because the EEG contains several subbands that are naturally departed, the number of levels was chosen to be *eight*. By using WP analysis, it was determined that theta, beta, and high beta NF training rhythms would best correlate with the corresponding subband signals. For EEG rhythm extraction, wavelet packet EEG decomposition and reconstruction were performed. The result of decomposing eight levels of WP analysis and its related EEG sub-bands is presented in Table 3.

The energy of special subbands and the corresponding coefficients of WP decomposition were selected to feedback based on the NF training protocol. To obtain the EEG subbands, the EEG signal was decomposed into progressively finer and more precise details by means of WP coefficients. After eight levels of decomposition using 4th order Daubechies WP, the EEG components retained were theta (4–7 Hz), beta (15–18 Hz), and high beta (22–30 Hz). A reconstruction of these components (shown in Table 2) corresponds to the physiological EEG subbands theta, beta, and high beta, precisely. Minor differences exist in the boundaries between these components and the boundaries between the EEG subbands in some physiological studies; however, the nature of the brain activity is the same.

Neuro-LSELF MF System Implementation

A schematic diagram of the Neuro-LSELF MF system is described in Figure 2. For the purposes of this study, sinusoidal local ELF was presented as 2 s ON and 3 s OFF (DS[1] = 40%; Shafiei et al., 2012a, 2012b; Shafiei Darabi et al., 2010). Each of the 16 subjects of the exposure group was exposed to magnetic exposure-altered brain electrical activity for 2 s ON and 3 s OFF of during the time of stimulation. In the sham group, the coil was on the head, but no exposure occurred.

The EEG monitoring was done by a monopole electrode placement at Cz, according to the 10/20 International System of electrode placement. As described, the electrode placement had a common reference electrode placed at the left earlobe and was grounded to the right ear lobe using ear clips.

As described, sinusoidal local ELF were exposed as 2 s ON and 3 s OFF. During the 2 s of exposure, the 45 Hz LSELF MF at F3 affected brain cortex activity according to this study's purposes. Therefore, during exposure times, the brain was affected by LSELF MF exposure while the NF system reinforced the EEG rhythms in each subject. In the sham group, the same training protocol of NF training and coil position was performed; however, there was actually no exposure.

The data acquisition sampling rate was 256 Hz, and band-pass filtration was performed from 2 Hz to 38 Hz with a 50 Hz notch filter. Both hardware and software de-noising was used. Recording was done with an EEG electrode using the FlexComp system via a USB port with a laptop running Microsoft Windows XP software. Although EEG data are widely used for the identification of different mental activities of the human brain, these signals were captured to investigate characteristics during specific events. However, due to windowing of a signal that causes spectrum and frequency specification changes, a 1-s Hanning window was used for analyzing the EEGs.

Recently, the significant role of oscillations in brain functions and behavior, as well as for attention, concentration, and cognitive performance, have become increasingly obvious (Egner & Gruzelier, 2001, 2003, 2004; Vernon, 2005; Vernon et al., 2003; Vernon

TABLE 3. Third to Eighth Level of Wavelet Packet EEG Decomposition to Achieve the EEG Rhythms

Frequency of EEG Subbands																																Level
0–32 Hz																																3
0–16 Hz																16–32 Hz																4
0–8 Hz								8–16 Hz								16–24 Hz								24–32 Hz								5
0–4 Hz				4–8 Hz				8–12 Hz				12–16 Hz				16–20 Hz				20–24 Hz				24–28 Hz				28–32 Hz				6
0—2 Hz		2—4 Hz		4—6 Hz		6—8 Hz		8—10 Hz		10—12 Hz		12—14 Hz		14—16 Hz		16—18 Hz		18—20 Hz		20—22 Hz		22—24 Hz		24—26 Hz		26—28 Hz		28—30 Hz		30—32 Hz		7
0—1 Hz	1—2 Hz	2—3 Hz	3—4 Hz	4—5 Hz	5—6 Hz	6—7 Hz	7—8 Hz	8—9 Hz	9—10 Hz	10—11 Hz	11—12 Hz	12—13 Hz	13—14 Hz	14—15 Hz	15—16 Hz	16—17 Hz	17—18 Hz	18—19 Hz	19—20 Hz	20—21 Hz	21—22 Hz	22—23 Hz	23—24 Hz	24—25 Hz	25—26 Hz	26—27 Hz	27—28 Hz	28—29 Hz	29—30 Hz	30—31 Hz	31—32 Hz	8

et al., 2004). In this study, the goal of NF training was to examine whether this training can positively influence cognitive performance, especially attention. Some research has shown that enhancement of the beta band (15–18 Hz) while inhibiting theta (4–7 Hz) and high beta (22–30 Hz) in the central regions of brain, results in improved attention after 10 sessions (Egner & Gruzelier, 2001, 2004; Lubar, 1997; Vernon, 2005).

Neurofeedback Training

For visual feedback, three boats, the forward movements of which were related to an increase in beta and a decrease in theta and high beta, were designed using LabVIEW software. The feedback consisted of a 3 Boats Race Video Game, as shown in Figure 3. Each subject was asked to drive the middle boat in three-boat tournament. For this NF training, the middle boat is related to beta and the upper and lower boats are related to theta and high beta, respectively. In this design, if the subject continues to increase the beta band and decrease the theta and high beta bands, higher and lower than the defined levels, respectively, the middle boat is the winner. Therefore, the subject was requested to imagine himself or herself as the middle boat (proportional to the beta band) and win the race. In other words, when the subject attains these three conditions, the desired variation (theta-to-beta ratio) decreases. In fact, the aim is to induce the desired alteration in attention level based on the theta-to-beta ratio.

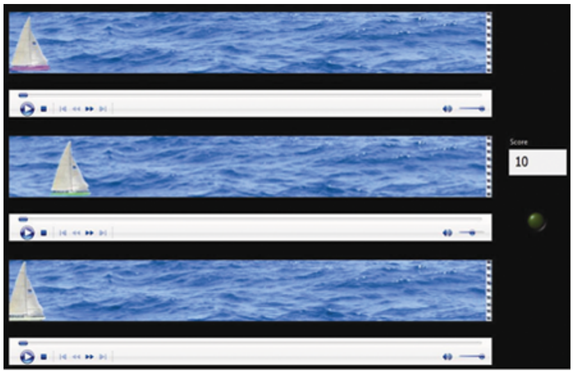

FIGURE 3. Monitor screens showing three boats. *Note.* Each boat advances when the corresponding EEG rhythms extracted from wavelet packet analysis are over the threshold. The goal is to make the middle boat, which is connected to the reward channel, advance while keeping the other two boats from advancing. When the middle boat reaches the finish line (right edge), a light (reward) turns ON to indicate the winner. The score tab is not discussed in this study. (Color figure available online.)

In the first, second, and third sessions, a 60-40-40-reinforcement algorithm was used. This means that if the beta band was higher than the defined level 60% of the time, and the theta and high beta bands were lower than the defined level 40% of the time, then the middle boat moved forward. These reinforcement levels for the three bandwidths were defined before each race. This setting was defined in the first session by the levels obtained during the baseline recording while in a relaxed state and was defined at the beginning of the remaining sessions by using the mean of the previous session. The time interval of all recordings was 1 s. The reinforcement level for all the subjects on Sessions 4 to 6 was 70-30-30, and was 80-20-20 for Sessions 7 to 10. It should be mentioned that all the subjects were of average-to-above average intelligence and were studying for their bachelor's, master's, and PhD degrees in engineering.

Statistical Analysis

EEG rhythm extraction was based on WP analysis. The obtained EEG signals were saved during the EEG recording (online), preprocessing (offline), and postprocessing of each session, and henceforth are simply referred to as DURING, PRE, and POST. This allowed assessment of theta-to-beta ratio variations during LSELF MF. The information was calculated from the energy of EEG rhythms obtained by WP analysis. The mean amplitude of the theta-to-beta ratio was subject to a statistical significance level set at .05. As described, EEG data were saved and collected at three statuses of each volunteer in each session: before exposure (labeled as PRE), 2 min after exposure (labeled as POST), and offline during NF training (labeled as DURING) in both groups (sham and exposed).

Offline EEG rhythms were saved and analyzed with a repeated-measures analysis with three within-factor variables (exposure condition, session number, and trial state). Two conditions were considered for exposure: SHAM and LSELF MF EXPOSURE. As to the trial state, three levels—PRE, DURING, and POST—were considered with regard to theta-to-beta ratios. For EEG rhythm parameters, *t* tests were applied to compare exposure conditions (i.e., Sham and Exposure) containing the three states before (PRE), during (DURING), and after (POST). All analyses were run with statistical IBM SPSS Statistics ver.21 software.

RESULTS

WP analysis was also used to compare the differences in the theta-to-beta ratios of PRE, DURING, and POST states of LSELF MF exposure and sham (offline). The mean and standard error (*M* ± SE) of the difference between the RP (power as WP coefficients energy) of each status, PRE and POST to DURING, of the exposure and sham groups are presented in addition to the significant changes. The Shapiro-Wilk and Kolmogorov-Smirnov tests showed that the theta-to-beta ratios in some statuses do not belong to a normal distribution; therefore, Wilcoxon tests were adopted across the three statuses of PRE, DURING, and POST. These three statuses consist of PRE versus DURING, PRE versus POST, and DURING versus POST. A Mann-Whitney *U* was used to compare theta-to-beta variations between two groups.

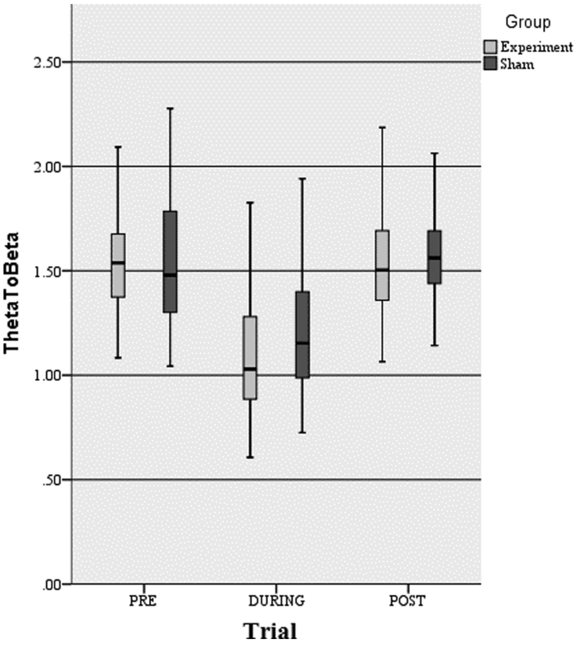

FIGURE 4. Ratios of the mean amplitude for the training frequency relative to the theta-to-beta ratio for each of two groups, collapsed across the three statuses.

Figure 4 shows the theta-to-beta ratio extracted by WP in offline processing of before (PRE), during (DURING), and after (POST) exposure in both groups (exposure and sham), and there are some obvious differences in the three statuses called PRE, DURING, and POST. This figure shows the theta-to-beta ratio of different statuses of the two groups in all sessions. The results of the comparisons of PRE versus DURING, PRE versus POST, and DURING versus POST are summarized in Table 4. The results indicated that NF training decreased the theta-to-beta ratio, which has been shown to correlate with improved attention. Variations in the theta-to-beta ratio of all the subjects for the exposed and sham groups are classified in Table 4.

The results of the comparison of the three statuses (PRE, DURING, and POST) in each group are summarized in Table 5. Also, Figure 5 shows the results of the comparisons of the theta-to-beta ratios between the three states (PRE, DURING, and POST) in each group. Table 5 and Figure 5 show that the theta-to-beta ratio of DURING in both the NF training (sham) group and NF training with LSELF MF exposure (experimental) group

TABLE 4. Theta-to-Beta Ratio of Rhythms Obtained from Offline WP Processing

		Trial states								
		Pre			During			Post		
		M	*SD*	SE of *M*	*M*	*SD*	SE of *M*	*M*	*SD*	SE of *M*
Group	Exposed	1.53	.23	.02	1.09	.29	.02	1.52	.24	.02
	Sham	1.53	.28	.03	1.22	.32	.04	1.55	.21	.02

TABLE 5. Theta-to-Beta Ratio Investigation of Three Statuses in Each Group by Test Statistics (Wilcoxon Signed Ranks Test)

	Exposed DURING – Exposed PRE	Exposed POST – Exposed PRE	Exposed POST – Exposed DURING	Sham DURING – Sham PRE	Sham POST – Sham PRE	Sham POST – Sham DURING
Z	–9.530[a]	–.961[a]	–9.291[b]	–5.499[a]	–.613[b]	–5.695[b]
Asymp. Sig. (two-tailed)	.000	.336	.000	.000	.540	.000

[a] Based on positive ranks.
[b] Based on negative ranks.

differed significantly in comparison to PRE and POST ($p < .001$). The theta-to-beta ratio in the sham and experimental groups did not differ significantly ($p > .05$) between the PRE and POST statuses of the two groups. This means that the effects of NF training and NF training with LSELF MF exposure didn't differ significantly when comparing the PRE and POST status in each group.

The results of the comparison of the three statuses (PRE, DURING, POST) between two groups are summarized in Table 6. Also, Figure 6 shows the results of the comparison of the theta-to-beta ratio between three statuses—PRE, DURING, and POST—between the two groups. These results indicate that the theta-to-beta ratio of DURING in the NF training (sham group) is higher than the theta-to-beta ratio in the LSELF MF exposure (experiment group). This ratio in the DURING status differed significantly in comparison to PRE and POST ($p < .001$) between the two groups. The theta-to-beta ratio did not differ significantly between PRE and POST statuses of the two groups ($p > .05$), indicating that the effects of NF training and NF training with LSELF MF exposure didn't differ significantly in PRE and POST statuses between the two groups.

TABLE 6. Theta-to-Beta Ratio Investigation of Three Statuses Between Two Groups by Test Statistics

	Theta-to-Beta-PRE	Theta-to-Beta-DURING	Theta-to-Beta-POST
Mann-Whitney U	6017.000	4038.000	5267.000
Wilcoxon W	9177.000	14623.000	17670.000
Z	–.450	–2.854	–1.144
Asymp. Sig. (two-tailed)	.653	.004	.253

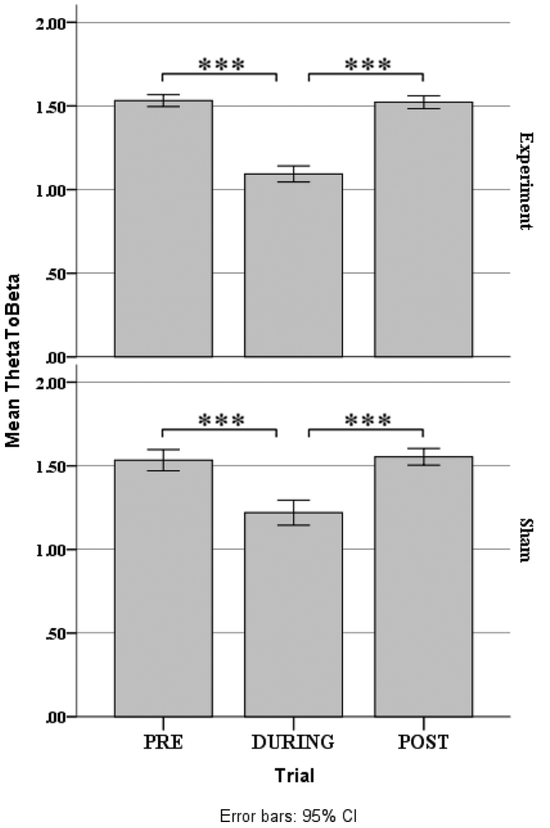

FIGURE 5. Comparisons of the theta-to-beta ratio for each of two groups, collapsed across the three statuses.

It is apparent that the theta-to-beta ratio of the sham group is higher than of the experimental group. As Figure 6 shows, the NF training for improvement of attention results in a decrease in the theta-to-beta ratio in both the sham and exposed groups. Egner and Gruzelier (2001, 2004) showed that healthy participants are able to learn to selectively enhance their SMR or beta activity, which is consistent with our research results.

Figure 7 shows the EEG results in terms of theta-to-beta ratios for 10 sessions. These

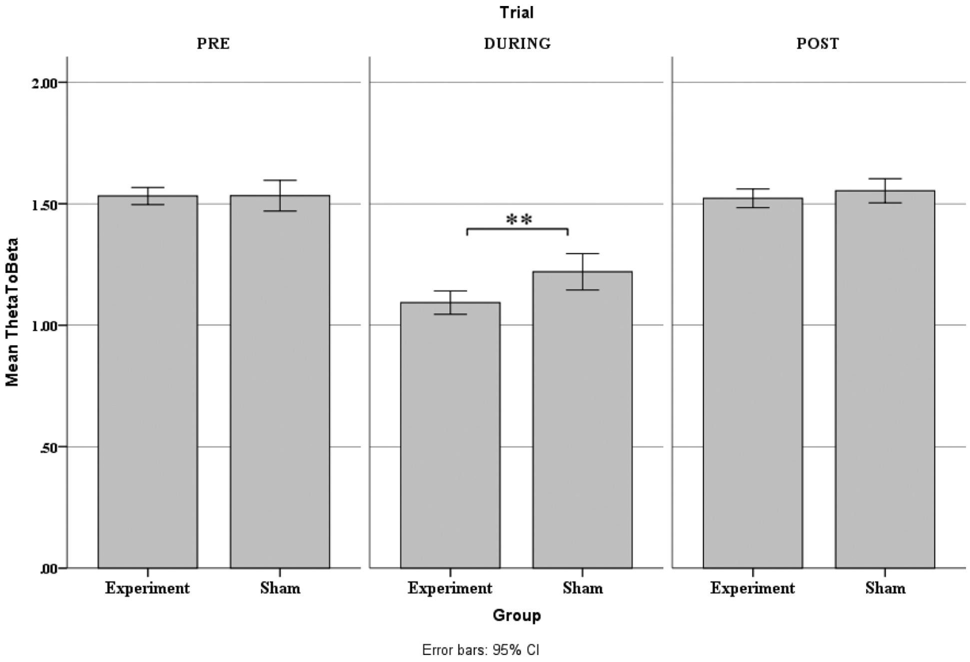

FIGURE 6. Comparisons of the theta-to-beta ratio between the two groups, collapsed across the three statuses.

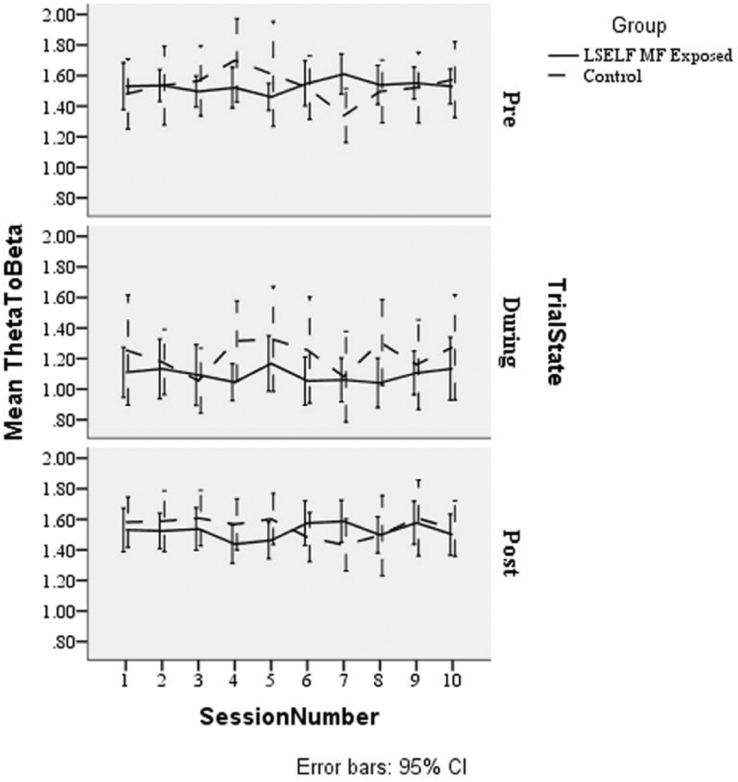

FIGURE 7. Ratios of the mean amplitude for the training frequency relative to the theta-to-beta ratio for each of two groups in all sessions.

results suggest that in comparing the two groups, the theta-to-beta ratio of the exposed group was much lower than in the sham group, and the amplitude and frequency of the theta-to-beta ratio of most volunteers was reduced after LSELF MF exposure. Thus, the conclusion is that LSELF MF exposure has certain effects on brain. The LSELF MF exposed during NF group showed clear evidence of decreased theta-to-beta ratios, in contrast to the group that received only NF training. In contrast, the PRE and POST conditions failed to show significant changes. Furthermore, the DURING state with LSELF MF exposure exhibited effective changes in attention and the self-assessment tests; however, all participants showed improved accuracy, but more so in the exposed group.

Significant differences were not observed in delta and gamma bandwidths ($p > .05$); however, the energy of the theta band and the theta-to-beta ratio in the DURING status did differ significantly ($p < .05$). The results showed that theta-to-beta ratios were significantly reduced in the exposed group as compared to the theta-to-beta ratios of the sham group. There was also a significant change in the rate of theta-to-beta ratio change during the 10 sessions ($p < .05$) in the LSELF MF Exposed group in comparison to the sham condition. For 10 sessions, the theta-to-beta ratio didn't significantly change in PRE ($p > .05$) and POST ($p > .05$) statuses, but reduced significantly in the DURING status ($p < .05$). A summary of these results can be found in Tables 4, 5, and 6.

DISCUSSION

In this study, we described and verified a new system that is a combination of NF and local ELF effects on EEG signals. This system, called a *Neuro-ELF system,* was optimized using a proper index of performance that is based on EEG signal features. In other words, in this NF system, the effect of synchronization was explored by using an external magnetic field on specific EEG bands. Therefore, the control system has less dependence on person characteristics such as IQ, which have been shown to be disadvantageous in other biological control methods.

The present study sought to determine if exposure to LSELF MF decreases the theta-to-beta ratio power, which has been inversely correlated with attention level, and if it has a similar enhancing effect on cognitive performance. Future studies should focus on the effects of different local frequencies of ELF MF to obtain additional clinical protocols; therefore, more experiments are expected. More research is also needed because of the lack of LSELF MF studies that assess human performance and physiology.

This study also investigated whether local ELF (LELF) exposure leads to more effective change in the EEG in the desired region of exposure in order to target specific brain functions. The exposure of local ELF MF leads to noninvasive excitation or inhibition of some EEG rhythms. It was determined that Neuro-LSELF can alter and facilitate changes in the desired direction. More physiological investigation is needed to learn more about the specific ELF MF mechanisms of action. Long-term effects and maintenance benefits; therefore, could not be evaluated from this study. Using local coils to affect different regions may be helpful in clinical practice, especially for selective changes, though this was beyond the scope of this study.

ADDENDUM: ELF-MF EXPOSURE RISKS

Extremely low frequency magnetic fields are described as nonionization rays and their energy is expressed by the Plank constant, and it is expressed by an electron volt. Therefore, all kinds of fields with energy less than 12.4ev are nonionization rays, and they don't have any ionization effect from a bio-electromagnetic point of view. The result is that electric and magnetic fields of low intensity with ELF effects don't have any ionization effect on human biology because they don't have sufficient energy to change the chemical *structure* of molecules in biological tissues. The permitted intensity of ELF exposure is determined and defined by the International Commission on Non-Ionizing Radiation Protection as follows:

> ELF electromagnetic fields are known to cause biological (enzymatic) effects, but the implications for human health have yet to be elucidated. ELF fields are known to interact with tissues by inducing electric fields and currents in them. This is the only established mechanism of action of these fields. There is no consistent evidence that exposure to ELF fields experienced in our living environment causes direct damage to biological molecules, including DNA. International guidelines on exposure limits for all EMF have been developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)–a non-governmental organization (NGO) in official relations with WHO and a partner in WHO's International EMF Project. While the ICNIRP guidelines for EMF exposure are based on comprehensive reviews of all the science, the limits are intended to prevent health effects related to short-term acute exposure. These guidelines are intended to limit the potential health effects of extremely low frequency (ELF is all frequencies below 3 kHz) radiation exposure. The IRPA Interim Guideline is the best guidance available on ELF safety that is based on international scientific consensus. (www.uoguelph.ca/ehs/sites/uoguelph.ca.ehs/files/09-04.pdf; Ahlbom et al., 2001; Bernhardt, 1992; Duchelne, Lakey, & Repacholi, 1991; EVALUATIONP, 2002; Legislation; Tenforde & Kaune, 1987)

NOTE

1. Duty Cycle for this study.

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