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ORIGINAL ARTICLE

Facilitation in Dyslexia Neurofeedback Therapy Using Local Influence of Combined DC and AC Extremely Low Frequency Exposure: A pilot study

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ABSTRACT

There is a consensus in bio-electromagnetic studies that combined parallel weak static and alternating magnetic fields causes a rapid change in the ionic current of brain neurons. Also, the neuroscientists try to change the brain activities by Neurofeedback therapy (NFT). This study investigated the effects of a weak local DC and sinusoidal extremely low frequency magnetic field (L-DC-S-ELF-MF) in dyslexia. Six children with dyslexia aged between 7 and 10 years were attended in 6 NFT sessions. Each session consisted of 4 statuses, PRE, DURING, NFT, and POST. In the DURING status, the coil was located on the all subject's head, while 3 of the subjects who were assigned to the experimental group were really exposed to local DC–50μT and 45Hz–400μT sinusoidal ELF-MF at P3 for 10 minutes. The duty cycle of sinusoidal exposure was 40% (2-second exposure and 3-second pause). Then in the NFT status, they reinforced to simultaneously inhibit delta (1-4Hz), theta (4-8Hz), and high beta (19-30Hz) activity, at the F3 site in a video game for 30 minutes. Two groups have improvement in score of Integrated Visual-Auditory (IVA) test, although more changes were occurred in the experimental group. The results indicate that theta rhythms in the exposed group decreased more significant in comparison to the sham (P<0.05). It is suggested that an increased performance to IVA in children with dyslexia was because of the magnetic field effect, although more investigation is needed for conclusive results.

Keywords*: Brain, Local Sinusoidal ELF, dyslexia, Neurofeedback.*

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INTRODUCTION

Dyslexia is characterized by difficulties with reading, spelling and writing, or any combination thereof [1]. This condition affects 5-17% of children. Intensive educational programs have produced positive results in attentional and reading abilities in dyslexic children; however, reading skills still remained lagged until adulthood [2]. Data suggests that there are differences between the brains of children with dyslexia and

normative controls [3]. Some studies suggest frontal cortex as an involved region of brain in this disorder. Magnetic resonance imaging has also shown that frontal gyrus activity decreases in these children [4]. In addition, it appears that posterior temporal cortex (PTC), superior and inferior regions are also important in reading skill. Injuries and lesions to PTC region have been shown to produce acquired dyslexia. Neuroimaging data has shown deficits in activity at the PTC which increases when reading difficulties subside [5].

Neurofeedback has shown promising results in the treatment of dyslexic symptoms [6-8]. Some researchers have tried to apply Neurofeedback as an effective method in modification of brain wave abnormalities in dyslexic children [9]. Some studies have reported positive effects of NFT on attention and working memory which are essential components of reading skill [10]. NFT is comprised of two aspects of active (traditional NFT) and passive [11]. In active NFT, some external factors can affect the training procedure, i.e. volition and client characteristics role such as intelligence quotient (IQ). In dyslexia, this dependency is more distinguishable [12-17]. Some developments in active NFT occurred which is called Low Energy Neurofeedback System (LENS) [18, 19]. However, in the case of LENS, volition has no role rather than the active one. In other word, the LENS is as a passive NFT and so does not require any conscious effort on the part of the client, and used low energy electromagnetic wave (i.e. radio, light) as a feedback, sending to the subjects and measures the returned waves. This developed method of NFT is based on the delivery of electromagnetic wave carrying the feedback signal down the electrode wire. The stimulus in this method is based on dominant EEG frequency [18, 20].

Furthermore, increasing of brain stimulation methods and approaches in affecting different brain regions eventually rose. Magnetic [11, 21-38], electromagnetic [39-43], and electrical [1, 44-46] stimulators are included in this kind of stimulation methods; such as, TMS (Transcranial Magnetic Stimulation), rTMS (repetitive transcranial magnetic stimulation), TDCS (transcranial direct current stimulation), ECT (electro-cumulative therapy), etc. Between these methods, there are many studies on the physiological and neurological effect of very low magnetic field at ρT range [47, 48].In recent years, there is an increase in studies that indicate evidences on positive effect of TMS and rTMS on several cognitive domains [49]. The wide range of magnetic brain stimulation to affect the brain indicates the ability of this stimulating method.

Another of these methods uses an extremely low frequency magnetic field (ELF MF) to perform brain stimulation [11, 21, 26, 28, 48, 50-53]. Data on weak magnetic ELF and its effects on human's brain activities such as attention, perception and cognitive process have yielded contradictory evidences stemming mainly from the magnetic field mechanism and different protocols. This data suggests that at particular frequencies, ELF MF causes reinforcement of the same frequency as the exposure field's one, in brain signals [23, 54-56]. Although, there is no consensus on the mechanism of ELF effects, there are some evidence that ELF exposure has important effects on human being, brain and brain activity [21, 26, 28, 50, 52, 57, 58].

Magnetic local exposure induces weak electrical current that stimulates neurons beneath the exposed region, and even at the other regions [11, 21, 59]. Also, there is a crucial surprising phenomenon that a low frequency AC magnetic field caused changes in calcium concentration in nervous tissue in the presence of a simultaneously acting DC magnetic field [25, 60-69]. These experiments investigated the combined action of weak (below 0.05mT) magnetic fields on ion channels behavior in the ''open field test'' revealed prominent influence of the cyclotron frequencies for calcium or sodium and other ions, and cell to detect depression or an increase in motor activity. They investigated the effects of the DC fields combined with an ELF AC magnetic field with respect to domination of a peak at the cyclotron frequencies, to its half width, and to arising frequency and amplitude windows.The ELF-MF effects do not require attention, concentration and attempt of person for its own brain wave modification.

Since, NFT heavily depends on individual characteristic such as intelligence, in this research; we used new NFT which called *Neuro-LSELF* [11, 52, 53]. Therefore, this new NFT may decrease the number of educational sessions, or may increase the education speed. In the present study, we hypothesize that reading ability is improved by reinforcement of frontal gyrus region by DC and AC 45Hz local sinusoidal extremely low frequency magnetic field.

MATERIALS AND METHODS

Subjects

Six children (3 female and 3 male) aged between 7 to 10 years (mean age of 8.33 years) were attend in the study properly and ethically informed about ELF exposure and experiment. None of them had previously taken part in studies involving MF exposure. All parents' subjects were asked to refrain the

children from drinking tea 2 hours before attending the experiment. The ethics committee of the Atieh Neuroscience Centre approved the protocol and all parents provided informed consent of ELF.

Procedure

Each subject underwent to this study in 4 statuses in either the exposure or the sham group. Table 1 shows the procedure for each subject in each session.

Table 1. The procedure for each subject in each session

Each session procedure				
	PRE	**DURING**	**NFT**	**POST**
Time (minutes)	2	10	30	2
status	EEG record at F3	Coil was located at P3	NFT (reinforced to simultaneously inhibit theta (4-8 Hz), delta (1-4 Hz), and high beta (19-30 Hz) activity, at the F3 site), EEG record at F3	EEG record at F3

At the first session, they were examined in the IQ (Stanford Binnet), IVA (IVA+PLUS), and 19 Channel QEEG assessment system (Mitsar-EEG-10/70-201, SN: 150015911) by Atieh Neuroscience Centre.

The mean of IQ of the subjects of the exposed group was 90, while was near to the sham group which was91. The mean of verbal IQ of exposed group was 92, and the mean of the performance IQ was88. The mean of verbal IQ of the sham group was 91, while mean of the performance IQ was90. The IVA consists of 4 subscales; visual attention (VA), auditory attention (AA), visual response control (VRC), and auditory response control (ARC) which each of the subscales varies from 90 to 109. The subjects were diagnosed according to DSM-IV interview in dyslexia and the QEEG assessment (increased slow activity (Delta and Theta) in the frontal and right temporal regions of the brain). Then, their reading abilities were assessed by Atieh Standardised questionnaire that consist of 40 score with 18±6 (mean ± SD). This questionnaire is similar to Dyslexia NAMA [70] and has been modified by Atieh panel expert. The IVA test was examined at the first and at the end of treatment procedure (the sixth session).

Experimental Setup

The EEG recorder device (ProComp 2, Thought Technology Ltd, made in Canada) has 2 specific channels for EEG recording. The 10/20 IS (International System) of electrode placement was used and the actual placement had a common reference electrode placed at the left ear lobe and was grounded to the right ear lobe using ear clips. An active electrode of EEG set was placed at F3 for NFT.

We have used the available magnetic field exposure system consisted of a circular coil [11, 52, 53, 59]. The magnetic field exposure system consisted of a circular coil. Also a circular magnet was fixed on the circular coil. The magnetic field exposure system was capable of the output signal ON and OFF. The coil characteristics measured by 1630DIGITAL LCR METER, EQ model (L=53.75±0.125mH). Considering the coil properties and low frequency range of signal generator (0.5 to 100Hz), inductance effects wasn't ambiguous. Tesla meter (TRIAXIAL ELF MAGNETIC FIELD METER, TES-1394, serial number: 040704120, U.S. Pat. No. Des. 446,135) at 2.5 cm (1.5 cm for maximum skull thickness and 1 cm for magnet thickness) below the Plexiglas ring at the axis showed the intensity of ELF-MF as 50μT for DC magnetic field and $400\mu T_{rms}$ for sinusoidal magnetic field. The sinusoidal local ELF exposed to exposed group as 2 seconds ON and 3 seconds OFF (Duty Cycle=40%).

Statistical Analysis

As described, EEG data was saved and collected at three conditions of each subject in each session: before exposure (labelled as PRE), after exposure (labelled as POST) and during NFT (labelled as DURING) in both groups (sham and exposed).Two conditions were considered for exposure: sham and L-DC-S-ELF MF. As to the trial state, three levels PRE, DURING and POST were considered for each EEG rhythms; for what concerns delta (1-4 Hz), theta (4-8 Hz), and high beta (19-30 Hz) rhythms. The Kolmogorov-Smirnov test showed that some EEG rhythms were not normally distributed, so Wilcoxon signed rank test across the statuses of PRE, DURING, and POST were adopted. Mann-Whitney *U* test was used to compare the 2 groups' the EEG rhythms.Also repeated measure analysis was used to investigate effectiveness of the *Neuro-LSELF* in changing the EEG rhythms in both groups. All analyses were run with the statistical IBM SPSS Statistics ver.21 software. The mean amplitude of amplified EEG rhythms was subjected to statistical with a significance level set at 0.05.

RESULTS

To compare the difference of theta to beta EEG rhythms, frequency analysis was used. Mean and Standard Deviation (mean (SD)) presented as well for significant change.

Using between-group comparisons there was no significant difference between the groups at pre-testing for age and IQ. The QEEG between group assessments was performed by NeuroGuide Deluxe Software (Neurostat 2.3.8 version) and Comprehensive QEEG Analysis (QEEG Report writing Service, Brattleboro, VT) between two groups before attending the procedure. The results show any significant difference between two groups before attending the procedure, and confirm the dyslexia too.

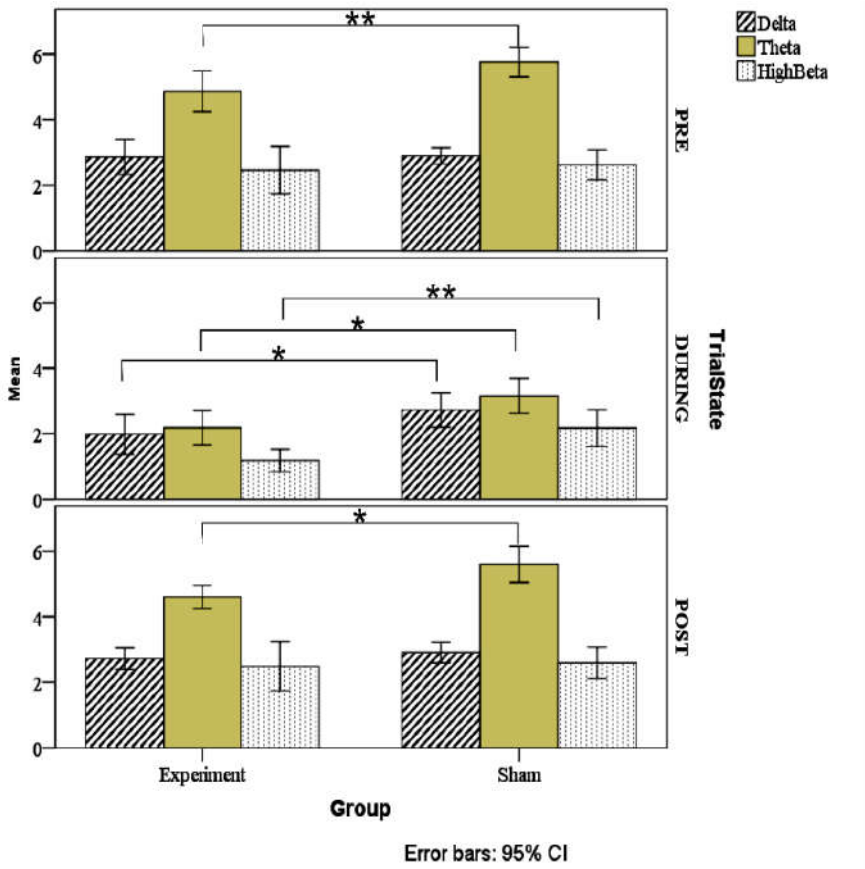

Fig. 1. The mean of amplitude for the training frequency relative to the inhibitory frequencies (delta, theta, and high beta) for each of two groups. (* 0.01<p<0.05, ** 0.001<p<0.01, *** p<0.001)

Between groups comparison was performed to investigate the EEG rhythms. The delta of PRE in LSELF-MF exposed group was 2.87 (1.08) which in comparison to Sham that was 2.90 (0.47) was not different significantly (P>0.05). The delta of POST in LSELF-MF exposed group was 2.72 (0.62) which in comparison to Sham that was 2.91 (0.62) was not different significantly, the delta of DURING in LSELF-MF exposed group was 1.99 (1.14) which in comparison to Sham that was 2.73 (1.02) was different significantly (P=0.015). The high beta of PRE in LSELF-MF exposed group was 2.46 (1.46) which in comparison to Sham that was 2.67 (0.89) was not different significantly (P>0.05). The high beta of POST in LSELF-MF exposed group was 2.55 (1.36) which in comparison to Sham that was 2.70 (1.00) was not different significantly, too (P>0.05). But, the high beta of DURING in LSELF-MF exposed group was 1.13 (0.64) which in comparison to Sham that was 2.20 (1.06) was different significantly (P=0.003). The theta of PRE in LSELF-MF exposed group was 4.87 (1.25) which in comparison to Sham that was 6.34 (2.62) was different significantly (P=0.005). Also, the theta of POST in LSELF-MF exposed group was 5.00 (1.77) which in comparison to Sham that was 5.60 (1.07) was different significantly (P=0.013), and the theta of DURING in LSELF-MF exposed group was 2.52 (1.50) which in comparison to Sham that was 3.16 (1.03) was different significantly, too (P=0.041). Therefore, it seems that, comparison of delta, theta, and high beta EEG rhythms recorded from the exposed and the sham groups shows significant in the theta in all three statuses. On the other hand, the mean of the theta rhythm of the sham and the exposed group, during the NFT, was significant different. The within group comparison was investigated too. As the results show, the theta decreases during NFT in comparison of PRE and POST states in both of groups. Although, this decrement was occurred in both groups, but there was a more decrease in the exposed group. In the experiment group, the delta comparison shows significant change between the PRE and

DURING statuses (P=0.015), and between the DURING and the POST statuses too (P=0.047). In the experiment group, the theta comparison shows significant change between the PRE and DURING statuses (P=0.002), and between the DURING and the POST statuses too (P=0.003). In the experiment group, the high beta comparison shows significant change between the PRE and DURING statuses (P=0.003), and between the DURING and the POST statuses too (P<0.001). Therefore, this results show in both groups, the three EEG rhythms was changed between the PRE and DURING, and also between the DURING and POST. These results may be occurred because of the NFT procedure. There was no significant difference between the PRE and POST statuses in both of groups. The mean of amplitude for the training frequency relative to the inhibitory frequencies (delta, theta, and high beta) for each of two groups collapsed across the three states are shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

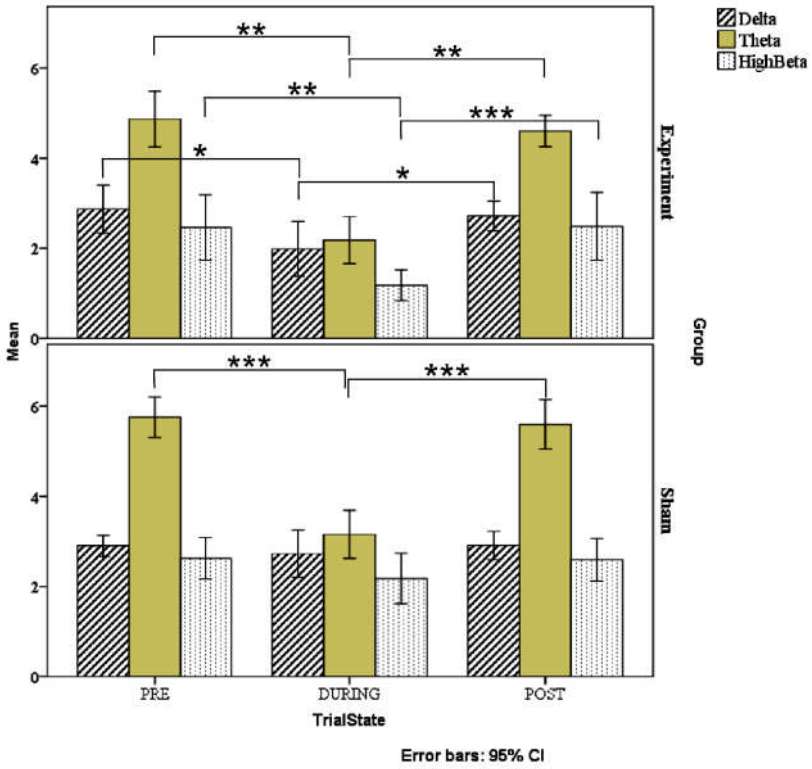

Fig. 2. The mean of amplitude for the training frequency relative to the inhibitory frequencies (delta, theta, and high beta) for three statuses. . (* 0.01<p<0.05, ** 0.001<p<0.01, *** p<0.001)

The mean of theta, delta and high beta for six sessions in the DURING status in each group was significantly different from the PRE and the POST statuses. It means that both methodology of NFT may result in desired EEG variations, but the results show more decrement in described EEG rhythms in the *Neuro-LSELF-MF* method which were investigated in this paper. The mean amplitude of the training frequencies relative to the inhibitory frequencies rhythms for each of the three states (PRE, DURING, POST), collapsed across the six training sessions are shown in Fig. 3.The results confirmed the previous discuss. The trend of mean amplitude for the training frequency relative to the inhibitory frequencies for each of two groups was shown, EEG rhythms were analysed with a repeated-measure analysis. As to the trial state, three levels PRE, DURING and POST were considered for each EEG rhythms; for what concerns delta; theta; high beta. Significant differences appeared in DURING of theta band (P <0.05).

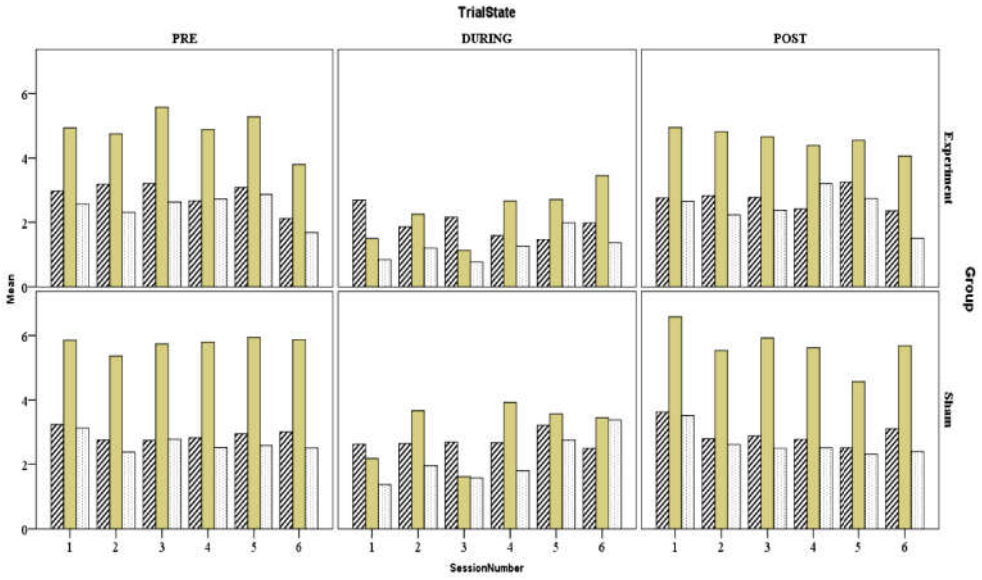

Fig. 3. The mean amplitude of the training frequencies relative to the inhibitory frequencies rhythms for each of the three states (PRE, DURING, POST), collapsed across the six training sessions.

Error! Reference source not found. shows the VA, AA, VRC, and ARC of three subjects of the sham and the experimental groups.

Table 2. The VA, AA, VRC, and ARC of three subjects of the sham and the experimental groups.

Average Domain: 90 to 109	Experimental Group						Sham Group					
	1st subject		2nd subject		3rd subject		1st subject		2nd subject		3rd subject	
Status	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
A-Response Control	104	108	97	115	102	106	100	103	99	118	100	110
V-Response Control	@	@	@	96	@	99	@	@	@	89	@	98
A-Attention	64	103	73	90	65	101	77	100	83	88	65	103
V-Attention	@	@	@	91	@	93	@	@	@	92	@	91

@: invalid

The result of the POST status of the reading ability by Atieh Standardised questionnaire shows relative improvement. According to the discussed mean and the standard deviation (18±6), the 1st subject improved 1 SD, the 2nd subject improved 2 SD, and the 3rd subject improved 1 SD. These results confirm the EEG rhythms results that are more discussed in future.

DISCUSSION

This study investigated the effects of a weak local DC and sinusoidal extremely low frequency magnetic field (L-DC-S-ELF-MF) in dyslexia. Our study demonstrated that subjects' reading ability improved; According to the mentioned standardized form, mean and the standard deviation (18±6), the 1st subject of the exposed group improved 1 SD, the 2nd subject of the exposed group improved 2 SD, and the 3rd subject of the exposed group improved 1 SD. Moreover, in the exposed group, IVA results revealed significant changes; in the 1st subject, all subscales, VA, AA, VRC and ARC improved significantly. AA and VRC subscales changed substantially in the 2nd subject, but VA and ARC did not change. In the 3rd subject, VA, AA and VRC increased moderately, however, ARC changed a little. The LSELF-MF-NFT group showed clear evidence in contrast of NFT learning as indexed by increased in clinical assessments. In contrast the PRE and POST failed to same significant changes as any indication of two methods NFT learning as described in this study. Furthermore, the DURING state exhibited effective changes along the LSELF-MF exposure in decrease of the desired EEG rhythms and self-assessments test, however, all participants showed improved accuracy in two groups both, but more effectively in exposed group. As the results indicate, may

by determining the brain *local* magnetic response in different regions to ELF frequency variation, based on the relation of EEG rhythms and behavior or electrophysiological and neurological fundamental changes, control brain is achieved [11, 27, 50, 52, 53, 71]. By localizing the effects and explanation the frequency magnetic response, the mechanism and effects could be clarified. The low amplitude of magnetic neurological and physiological effects and the concept of magnetic frequency response in biological system especially on brain can be used as a clinical instrument and brain control [22, 26, 48, 71]. Therefore, the attenuating and reinforcing effects of *Local* SELF MF and generally ELF MF fields might be produced by the decrement or increment of EEG rhythms. Based on theoretical view point of magnetic induction resonance effects on cerebral waves it is proposed to systematically impose meaningful changes on EEG signal, either actively or inactively [22, 48, 67, 68, 72], which needs more studies yet. To eliminate the effectiveness of individuals on results, ELF can be used, that leads to decreasing of treatment sessions and achieving a desired status. Thus simultaneously using ELF in a system with proper NFT protocol increased the efficiency of this method. These strategy of using composed methods and theoretical viewpoint in this project, is to eliminate the NFT deficiencies. In order to speed up and improve the method by the results of ELF MF exposure, the role of individual volition in treatment process is decreased; therefore the treatment sessions might be decreased as it is expected [11, 52, 53]. The result shows that the Neuro-LSELF-MF system may help in speed up the reinforcing the subjects in training.

LIMITATIONS

The most important limitation of the present study is small sample size. Long term effects or sustained benefits could not be evaluated from this study, although results showed an effective novel method in decreasing the EEG rhythms.

CONCLUSION

The present investigation studied the impact of ELF-MF with NF therapy simultaneously. Our results demonstrated that participants showed improved accuracy in both groups, but more effectively in exposed group. In fact, LSELF-MF-NFT group showed clear evidence in contrast of NFT learning as indexed by increased in clinical assessments.

Although, there is no consensus on the mechanism of ELF effects, but there are some evidence that ELF exposure has crucial effects on human being, brain and brain activity [11, 21, 26, 28, 48, 50-52, 60, 62, 71]. Although no intensive and systematic effect was determined yet, one of the purposes of this study was MF's estimating frequency approach so that have considerable influence on cerebral signals which can be designed and evaluated in protocols to treat some psychological diseases. Studies on MF effects on electrical activity of human brain and the conceptual effects of field exposure on cognition and perception are insufficient. Often, inconsistencies in test results are observed during these studies, which are the consequences of MF exposure protocols that discussed before [11]. Although these inconsistencies, it is proven that ELF MF has conclusive effects. Bell et al. [56] showed decreased EEG activity in the occipital region but not in the central or parietal regions after 10Hz MF exposure. It was concluded that a weak MF applied continuously to human subjects for *10 minutes* resulted in a reduction in brain electrical activity at the frequency of the MF during the one minute interval following termination of the field. Lyskov *et al*. [33, 34] found significant increases in beta (14-25Hz) activity after 15 minutes of 45Hz ELF-MF head exposure. Lyskov et al. [73] 45 Hz ELF-MF exposure causes decrement in the delta and theta EEG rhythms at the central parietal region. Also, the delta and theta EEG rhythms at the frontal regions decreased that confirms our result. The result of ELF-MF effect on neurons may was because of 45Hz effects on the calcium ions that described before. Finally, more researches are needed for conclusive and crucial effects.

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