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The Effect of Mindfulness Training on Creativity in Healthy Subjects: A Pilot EEG Study

Abstract: Many studies have investigated the relationship between mindfulness and creativity; however, there are a limited number of studies on the neurological basis of this therapeutic approach using electroencephalogram (EEG). This study aimed at evaluating the effect of mindfulness on improving the creativity of healthy individuals. In this study, 7 healthy subjects (1 male and 6 females) with a mean age of 40.37 years and a standard deviation of 14.52 years received group mindfulness training for 8 weeks. They had no experience of mindfulness training up to that time. Before and after mindfulness training, EEG signal was recorded from all participants in eyes-closed and eyes-open conditions on Fz, C3, C4, and Pz electrodes. After data preprocessing, wavelet coefficients were extracted from each frequency band of EEG signal and evaluated using paired sample t-test and correlation methods. The gamma-band on C3 ($t = 2.89$, $p = 0.03$) and Pz ($t = 2.54$, $P = 0.04$) significantly increased as a result of mindfulness training. Also, significant correlations were found between the anxiety and the gamma band in Pz ($r = 0.76$, $P = 0.04$) and Fz ($r = 0.75$, $P = 0.04$) channels and between arousal and the gamma band in the Fz channel ($r = 0.88$, $P = 0.008$). Mindfulness training to promote creativity leads to the increase of gamma bands in the central and parietal regions.

Keywords: *Mindfulness; Wavelet; Creativity; Anxiety*

INTRODUCTION

Meditation is a method that leads to mental concentration and self-control. It also brings harmony among the body, mind, and emotions, and helps people easily achieve concentration. Research findings show that meditation physiologically reduces metabolic activity and peripheral vascular resistance, enhances the integration and coordination in brain function, and increases cerebral blood flow (Rubia, 2009). Meditation is a method that has been credited with improving psychological disorders, such as anxiety and depression, and in maintaining mental health (Kelly, 2008). It is noteworthy that meditation is performed in a variety of ways, the simplest of which is the concentrative and mindfulness method. The accuracy of the senses experiences an increase through mindfulness training. Moreover, in this method, disturbing thoughts and the information already received from the five senses spring in the human mind without the need for any deliberate thinking; therefore, a person sitting quietly can

experience the elimination of pressure imposed on his/her mind and five senses (Michael Murphy, Steven Donovan, 1997). Mindfulness refers to one's attendance at the moment with all the current belongings without judging and commenting on what is happening; in other words, it is some kind of fixed real-time conditions free of prejudgment wherein all the thoughts and feelings resulting from paying attention are accepted without any change (Kabat Zinn, 1990; Rokke & Robinson, 2006). Meditation and mindfulness exercises lead to an increase in self-awareness and self-acceptance among patients (Baer, 2003).

A large number of studies have been conducted on the effect of mindfulness on electroencephalogram (EEG) signals. One of these studies assessed the effect of short-term mindful deep breathing on chronic ankle pain. The number of 12 individuals within the 18-to-25-year-old age range participated in this study and was divided into three groups, each with four participants. In the first group, the ones with chronic pain received mindfulness intervention for six weeks, while patients with ankle pain in the second

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group received no intervention. Finally, healthy people with no history of chronic pain constituted the third group, i.e. the second group also received no intervention. Before and after three minutes of deep mental breathing, an EEG signal was recorded from them. According to the obtained results, mindfulness exercises brought about significant changes in the delta, theta, alpha, beta, and gamma bands of the occipital lobe (Ramalingam, Cheng, Sidhu, & Foong, 2019). Moreover, prior studies have shown that mindfulness increases the power of alpha and theta, which is representative of the positive effect of mindfulness on increasing people's relaxation and mental health (Lomas, Ivztan, & Fu, 2015). In this regard, research undertaken by (Aftanas & Golocheikine, 2001) has also shown that the emotionally positive state is significantly associated with anterior and frontal midline theta and that internalized attention is related to lower alpha and theta. Similarly, (Wong, Teng, Chee, Doshi, & Lim, 2018) measured the functional, mental, and electrophysiological changes in a 36-nurse group during a 20-minute performance on psychomotor vigilance task before and after the 8-week protocol of mindfulness-based training. It should be noted that EEG was recorded from the participants and the results indicated that mindfulness training along with neuropsychological changes increased sustained attention and reduced the power of alpha.

In addition, many studies have claimed that meditation reduces stress and anxiety in people (Dehghani, Amini, Shakibazade, Faghihzade, & Hashem zade, 2015). In one study, the degree of anxiety in women undergoing breast biopsy after the meditation was examined. 30 subjects practiced mindfulness and 30 went for focused breathing in one session for 10 minutes, while 16 subjects also participated in the control group. The results showed that the mindfulness group experienced lower degrees of anxiety than the control and focused breathing groups. In the same way, an increase in beta activity in the insula and anterior cingulate cortex was observed in all groups; and a reduction in delta activity was observed in the mindfulness and focused breathing groups compared to that in the control group (Ratcliff et al., 2019). In the same vein, 12 metastatic cancer patients took part in a study, and the effect of Tibetan singing bowls on them was assessed (Bidin, Pigaiani, Casini, Seghini, & Cavanna, 2016). It is worthy of mentioning that the Tibetan singing bowl is not a musical instrument, but it is a vibration-generated sound that is perceived by the patient and creates a state similar to what is obtained by meditation. It was revealed that skin conductance was reduced in these patients. Moreover, the evaluation of the patient's brain waves also revealed changes in the beta, alpha, and inter-hemispheric coherence of the anterior-frontal areas was putatively taken to reflect the reduction of anxiety, arousal, involuntary mental activity, and stress in patients (Bidin et al., 2016). Also, another study compared the impact of virtual reality and meditation on the level of anxiety between two test groups and a control group. The results indicated a reduction in the beta activity and an increase in the alpha activity in the anterior cingulate cortex for the

control group after meditation, which is representative of a decrease in arousal and anxiety in the participants (Tarrant, Viczko, & Cope, 2018).

Various studies have also been carried out on the effect of mindfulness on the increase of concentration and attention. Research findings have demonstrated that the individuals involved in mindfulness experienced a significant increase in the interaction of the prefrontal cortex and other areas responsible for executive functions, namely inferior frontal gyrus, supplement, middle frontal gyrus, superior parietal lobule, and middle temporal/ angular gyrus (Taren et al., 2017). In this way, it has been proven that mindfulness practice has had a great effect on the improvement of people's executive functions and attention by strengthening the connection among different parts of the brain responsible for such functions (Taren et al., 2017). Another study on 30 young people with ADHD showed that mindfulness led to the increased attention and reduced theta-to-beta ratio in the patients (Sibalis et al., 2019). Similarly, in another research, it was reported that mindfulness practices to optimize cognitive function and neurological efficiency have improved the healthy subjects' attention and executive skills and, thereby, their alpha-to-beta ratio has increased, which reflects a relative balance between relaxed thinking and active mentality (Crivelli, Fronda, Venturella, & Balconi, 2019). Also, previous studies demonstrated that gamma is involved in creativity. For example, Oh, Chesebrough, Erickson, Zhang, & Kounios (2020) revealed that gamma activity over the prefrontal cortex increases while subjects solve a problem with insight solutions. Insight is a phenomenon of creative cognition in which an idea suddenly emerges into awareness (Oh, Chesebrough, Erickson, Zhang, & Kounios, 2020). Furthermore, in another study, the EEG signals were recorded while subjects played jazz. When jazz was played with high-quality improvisation, and creativity, beta, and gamma activities were observed (Rosen et al., 2020). Also, a study on the analysis of the EEG signals in the context of creative thinking showed that gamma in addition to alpha and theta plays an important role in creativity (Stevens & Zabelina, 2019). In addition, a study was done to analyze the neural oscillations during meditation and creative imagination during three meditation sessions along with brain stimulation. The results demonstrated an improvement in creativity and an increase in the gamma during deep meditation in the occipital region (Luft, Zioga, Banissy, & Bhattacharya, 2019).

The main purpose of the present study is to evaluate the changes in brain waves of healthy people after mindfulness training sessions to promote creativity. In this way, the frequency components of brain waves are extracted by the wavelet method and, then, the changes in the frequency bands before and after mindfulness training are extracted. In addition, the study of the changes in the brain signal during mindfulness training provides us with useful information about brain function where recording these changes can lead people to perceive the effectiveness of mindfulness training in brain function.

METHOD

Participants

Seven healthy subjects (1 male and 6 females) with the mean age and standard deviation of 40.37 and 14.52 years old participated in this study. All subjects had no previous experience of mindfulness training. The participants were requested to complete a written consent form for participation in the research. It is also noteworthy that none of them had a history of specific diseases or of taking psychiatric drugs.

EEG recording

FlexComp 10 Channel Encoder made by the Canadian Thought Technology company was used to recording EEG signals. This device had a 64 Hz low-pass filter and a 50-Hz notch filter for eliminating the power line noise. Optical fiber has also been used to transfer data from the EEG device to the computer. The recorded signal has been sampled with a frequency of 256 Hz. The brain signal has been recorded from Fz, C3, C4, and Pz electrodes according to the international standard 10/20 system (Thought Technology Ltd., 2016). The recorded electrodes are of the cup electrode type, the skin surface is initially cleaned with Nuprep gel, and, then, the electrode is attached to the head using Ten-20 adhesive gel. The right and left ears have also been used as the ground and reference, respectively.

Procedure

At the outset, the participants were asked to carefully fill in the Irritability Questionnaire (Pour afrouz, A.Rajai, 2018). Thereafter, brainwaves were recorded from the subjects for 5 minutes in open-eyes condition and 5 minutes in closed-eyes condition while they were sitting comfortably on a chair in a quiet room. Following the completion of data recording, the participants received 8 weeks of mindfulness training by an expert meditator. Mindfulness training sessions included breathing practice, drinking, eating food, bathing, walking, listening, watching, mindful walking and conscious movements, goal setting, problem-solving, turning unpleasant events into pleasant ones and becoming aware of them during daily life, and practicing deep relaxation daily. Finally, the participants took part in EEG recordings after completing the mindfulness training sessions similar to the first session.

EEG Analysis

First, independent component analysis (ICA) was used to remove motion artifacts from EEG signals (Delorme & Makeig, 2004). In the next step, the method used by Rosso et al., (2001) has been employed to extract wavelet coefficients from EEG signals. Based on this method, it is necessary to decompose the signal of each session to different frequency levels using wavelet transform. B-Spline discrete wavelet transform was used as a mother wavelet because of its wide application in various studies on the brain (Abootalebi, Moradi, & Khalilzadeh,

2009; Ademoglu, Micheli-Tzanakou, & Istefanopulos, 1997; Demiralp, Yordanova, & Kolev, 1999; Sairamya, Premkumar, George, & Subathra, 2019) Therefore, the signal is first decomposed into 5 levels to calculate the wavelet coefficients. Since the sampling frequency has been considered equal to 256 Hz in the data recording, the decomposed levels are consistent with the frequency bands of the brain signal. Levels D1 to D5 have been respectively obtained in agreement with frequencies (64-128Hz), (32-64Hz), (16-32Hz), (8-16Hz), and (4-8Hz); and level A5 has been obtained with frequency (0-4Hz) (Ghoshuni, Firoozabadi, Khalilzadeh, & Hashemi Golpayegani, 2013). However, the coefficients of the D1 level have no useful information since they are filtered by a low-pass filter and, thereby, are excluded from the subsequent analyses. Furthermore, it is necessary to compute the energy distribution of the wavelet coefficients in each frequency bandwidth. In doing so, the mean value of the energy of wavelet coefficients in the j th scale (E_j) is obtained through Equation 1:

$$E_j = \frac{1}{N} \sum_{k=1}^{N_j} |C_j(k)|^2 \quad (1)$$

In this equation, C_j and N_j represent the wavelet coefficient and the number of wavelet coefficients in the j th scale, respectively.

Then, the total energy is obtained by summing the energies in all the scales, as in equation 2:

$$E_{tot} = \sum_j E_j \quad (2)$$

In the same way, the relative power of the wavelet coefficients in each scale is obtained through equation3:

$$p_j = \frac{E_j}{E_{tot}} \quad (3)$$

Matlab R2013a software and EEGLAB toolbox were used for EEG signal processing.

Irritability Questionnaire

In this study, the participants were asked to complete the Irritability Questionnaire (Pour afrouz, A.Rajai, 2018). The Irritability Questionnaire measures one's sensitivity to any stimulus. This questionnaire evaluates the sub-scales of anxiety, high arousal, hostility, haste, Incompatibility, lack of perseverance, non-concentration, impulsive act, dissatisfaction, and boredom (Pour afrouz, A.Rajai, 2018).

Statistical Analysis

To perform the statistical analysis, a paired sample t-test was used. (Beik, Taheri, Saberi Kakhki, & Ghoshuni, 2020). According to the normality of data (Shapiro-Wilk

test) and homogeneity of variance (Levene's test), a parametric test was used. Also, correlation analysis was used to investigate the relation between sub-scales of the Irritability Questionnaire and the energy of the wavelet coefficients in each scale. In this study, the SPSS (PASW Statistics 18) software was used for statistical analysis.

RESULTS

Results of Wavelet Transform

Significant changes in the energy and relative power of wavelet coefficients in each of the four electrodes and both open and closed eyes conditions have been investigated before and after mindfulness training via paired sample t-test (Table 1).

According to the results, the energy of C3 gamma ($t=2.88$, $P=0.02$) and Pz gamma ($t=2.53$, $P=0.04$) has

significantly increased in closed-eyes condition after mindfulness training (Fig. 1).

Correlation Results

In this section, the results of correlation between the percentage change in gamma energy in the open-eyes and close-eyes conditions and ten parameters of the irritability questionnaire before and after mindfulness training are presented. As shown in Table 2, significant correlations were found between the anxiety and the gamma band in Pz and Fz channels and between high arousal and the gamma band in the Fz channel. Also, in Fig. 2, correlations between the anxiety and the gamma band in Pz and Fz channels and correlation between high arousal and the gamma band in the Fz channel were plotted.

Table 1. Results of paired sample t-test for gamma energy before and after mindfulness training in eyes-open and eyes-closed conditions for Fz, C3, C4, and Pz electrodes. One asterisk indicates a significance level at $p < 0.05$.

Electrode	Condition	Gamma Energy (μV^2) (Mean \pm SE)		t-value	P value
		Before Mindfulness	After Mindfulness		
Fz	eyes open	76.11 \pm 28.22	125.62 \pm 68.79	1.48	0.19
	eyes closed	57.95 \pm 27.06	28.20 \pm 5.95	-1.03	0.34
C3	eyes open	245.07 \pm 106.49	291.80 \pm 123.50	0.37	0.72
	eyes closed	46.39 \pm 20.38	108.62 \pm 19.15	2.89	0.03*
C4	eyes open	201.17 \pm 68.08	250.95 \pm 80.21	0.47	0.65
	eyes closed	39.29 \pm 15.52	242.44 \pm 92.01	2.15	0.08
Pz	eyes open	109.12 \pm 39.58	125.62 \pm 39.78	0.62	0.56
	eyes closed	23.23 \pm 4.60	41.85 \pm 9.87	2.54	0.04*

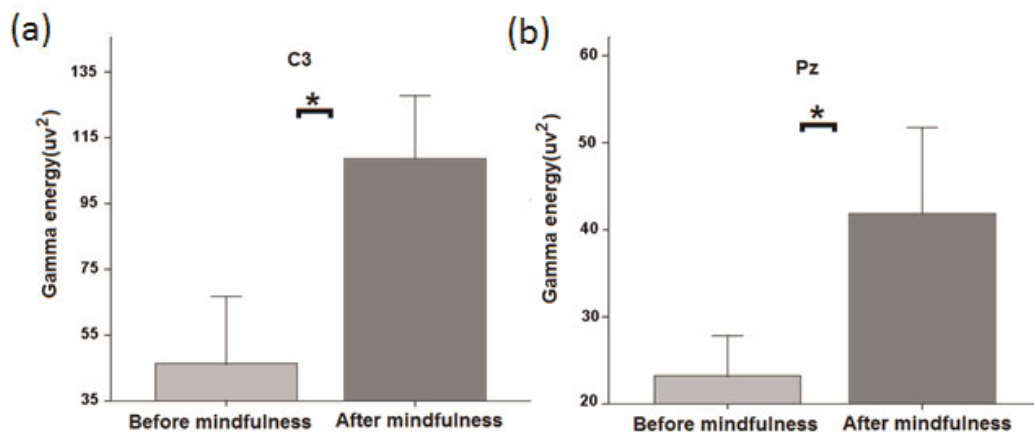


Figure 1. Gamma energy (μV^2) before and after mindfulness in the eyes-closed condition in (a) C3 and (b) Pz. One asterisk indicates significance levels at $p < 0.05$.

Table 2. Results of Pearson correlation between gamma energy and parameters of irritability questionnaire for Fz, C3, C4, and Pz electrodes. One asterisk indicates a significance level at $p < 0.05$.

Gamma energy (uV ²)		Anxiety	High arousal	Hostility	Haste	Incom- patibil- ity	Non- concen- tration	Lak of perse- verance	Impul- sive act	Dissatis- faction	Bore- dom	
Fz	eyes open	Pearson correlation	.75*	-.39	-.12	-.24	.54	-.52	-.18	.61	.63	-.20
		P value	.04	.37	.79	.59	.21	.22	.69	.14	.12	.56
	eyes closed	Pearson correlation	-.35	.88*	.30	.38	.25	.44	-.59	.09	-.15	.21
		P Value	.44	.008	.50	.38	.58	.32	.15	.83	.74	.64
C3	eyes open	Pearson correlation	.59	-.21	.09	.31	-.008	-.09	.006	.28	.59	.27
		P Value	.15	.63	.83	.48	.98	.84	.99	.54	.15	.55
	eyes closed	Pearson correlation	.26	.007	.51	.27	.42	.33	.10	.10	-.04	.48
		P Value	.56	.98	.23	.54	.34	.46	.82	.82	.92	.26
C4	eyes open	Pearson correlation	.65	-.57	-.22	-.05	.04	-.24	.38	.40	.33	.10
		P Value	.10	.17	.62	.91	.92	.60	.39	.36	.46	.82
	eyes closed	Pearson correlation	.74	-.08	.09	.26	.25	-.21	-.33	.42	.36	.20
		P Value	.05	.84	.84	.56	.58	.65	.46	.34	.41	.66
Pz	eyes open	Pearson correlation	.76*	-.67	-.11	-.23	.11	-.64	-.07	.13	.25	-.20
		P Value	.04	.09	.80	.62	.80	.11	.87	.87	.57	.66
	eyes closed	Pearson correlation	.15	.43	-.16	.42	.005	.30	-.11	.54	.10	.34
		P Value	.74	.33	.73	.33	.99	.50	.81	.20	.82	.44

DISCUSSION

In this study, the brain parameters associated with mindfulness training aiming at promoting creativity were evaluated. According to the current findings, the energy of gamma has experienced a significant increase after mindfulness. Prior studies have also reported the presence of a significant correlation between mindfulness and anterior gamma activity as well as posterior gamma activity (Berkovich-Ohana, Glicksohn, & Goldstein, 2012).

In addition, physical and mental relaxation is also achieved during meditation, which has physiological effects, such as the increased alpha and theta activity in the EEG signal (Ivanovski & Malhi, 2007; Kasamatsu and Hirai 1966; Harne and Hiwale 2018). In this study, mindfulness training reduced anxiety in individuals, but no significant changes were observed in alpha and theta band activity.

Furthermore, in the current study, significant correlations were found between the anxiety and the gamma band in Pz and Fz channels and between arousal and the gamma band in the Fz channel. In a similar study, the effect of virtual reality meditation on individuals' anxiety was examined where reduced beta activity was observed in the anterior cortex and an increase was observed in the alpha band after meditation and these correlate with

reduced anxiety (Tarrant et al., 2018; Cahn, Polich, Cahn, & Polich, 2013) have also shown that the increase of alpha activity in meditation is correlated with decreased anxiety.

Therefore, mindfulness training leads to the increased gamma in the central and parietal regions and, as a result, creativity increases in healthy people. On the other hand, as a correlation result, subjects with a higher increase in the gamma bands experienced a lower reduction in anxiety and high arousal scores. Accordingly, mindfulness training to enhance creativity results in increasing the high-frequency power of the brain wave in the central and parietal regions and will not have a considerable effect on reducing anxiety and arousal in people.

CONCLUSION

According to the correlation results, for subjects whose gamma energy did not increase after mindfulness training, their anxiety and high arousal scores were further decreased, and vice versa, in subjects whose gamma energy increased, their anxiety and high arousal scores had less decreased.

So, we can conclude that if creativity enhancement is achieved through mindfulness training (increased gamma energy), it will be less effective in reducing anxiety and arousal.

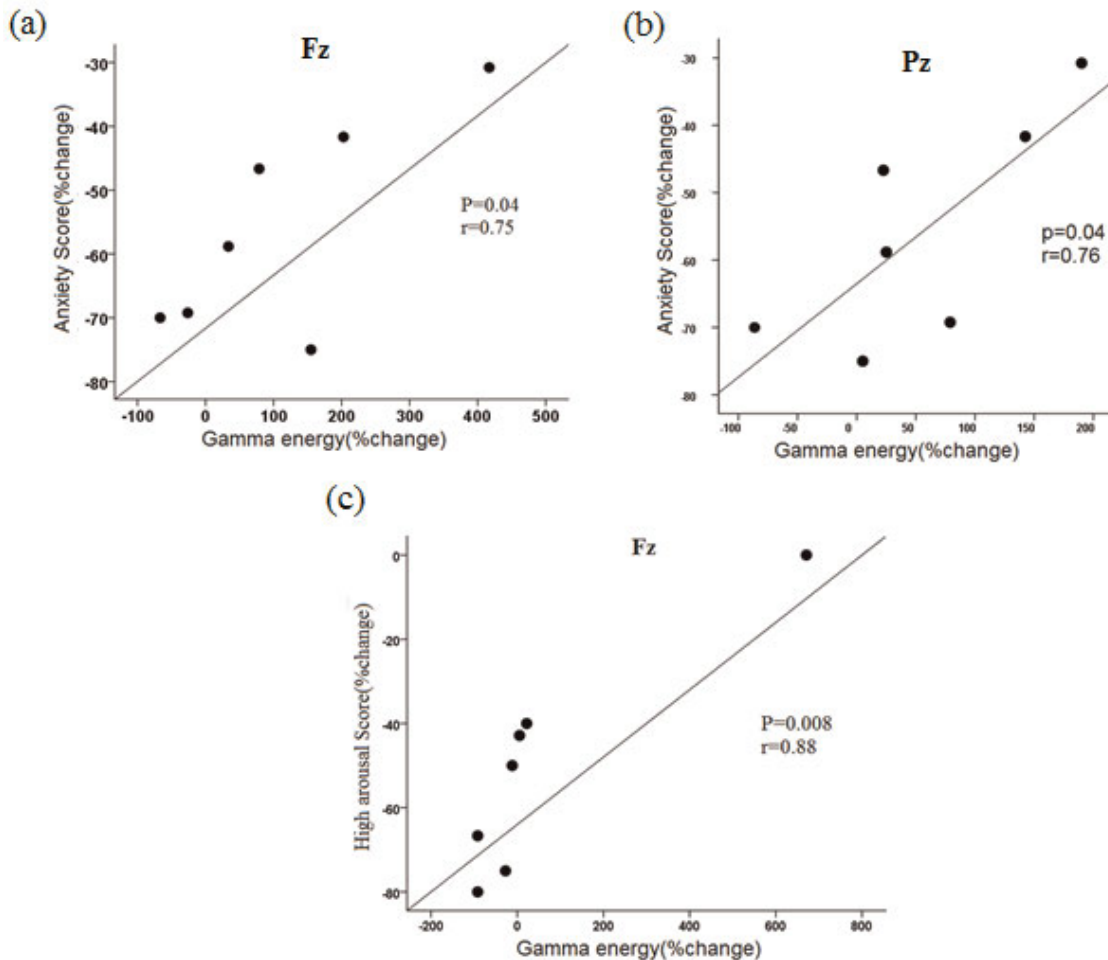


Figure 2. The correlation between percentage change of gamma energy and anxiety score before and after mindfulness training in the eyes-open condition in (a) Fz and (b) Pz. (c) The correlation between percentage change of gamma energy and high arousal score before and after mindfulness training in the eyes-closed condition in Fz.

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