Meditation Effect on Human Brain Compared with Psychological Questionnaire

Mingqian Liu and Nugraha Priya Utama

***Abstract*—Mindfulness meditation has been taken as a method to release the short and long terms of stress and anxiety. A questionnaire was investigated to measure the effect of mental change as well as the changing of brain signals while doing the mindfulness meditation. Ten healthy-young participants were recruited to investigate the effect of mindfulness meditation compare with self-relaxation. Brain activities from participants were recorded during practicing mindfulness meditation using Electroencephalogram (EEG) with 10-20 system of electrode placements. A questionnaire with 30 questions was applied to estimate meditation depth. The differences between self-relaxation and mindfulness-meditation were analyzed according to meditation depth and brain activities recorded with EEG. Compared with self-relaxation, mindfulness-meditation reduces hindrance and increases the level of relax. Although subjects were subjectively unaware of the calmness during mindfulness-meditation practice, compared with self-relaxation, the recorded data suggested that mindfulness meditation reduces the short term induced tension, indicated by the significant increment of theta and alpha power spectrum of brain activities along the time.**

***Index Terms*—Alpha rhythm, theta rhythm, meditation depth, stress reduction.**

I. Introduction

Stress is regarded as an unpleasant feelings leads to upset, emotionally and physiological nervous behavior [1]. When the hormones level reaches certain levels, Cortisol releases in the hypothalamus. Neuron receptors combine neuronal network regulators changes neuronal adaption [2]. Sympathetic nervous system reacts rapidly to stressor triggers, however long-lasting stress level can change metabolism and eventually increase the risk of psychological diseases. In central nervous system, the prefrontal cortex can also be affected by stress. The prefrontal cortex is responsible for cognitive processes as problem solving, attention and interactions with other brain parts, which also sensitive to acute and chronic stress. Short term stress inhibits prefrontal activities for emotional process and reduces working memory, meanwhile amygdala activity increases under prolonged stress. The chronic stress can lead to structural change in prefrontal cortex [3].

As a subjective experience, mental control and consciousness state are difficult to be objective observed or measured using objective methods, which mindfulness meditation can be also called as a kind of consciousness. Small amounts of stress can motivate people and cause positive reaction to environment. "Fight or flight response" often occur together with sympathetic nervous system.

In psychology, negative stress state leads to increased risk of psychological diseases and changes emotional and behavioral response. Stressful life is taken as one of the major incentive to depressive disorder. Animal experimental work supports that stress increases the risk of cardiovascular disease [4].

Meditation comes originally from cultural and philosophical traditions, as a method to improve psychological personalities. After years practicing, meditation can improve body self-regulation, mental control as well as consciousness state [5]. Restful and heightened alertness are improved subjectively during meditation [6], [7].

Different types of meditation art are available and basically divided into mindfulness meditation and transcendental meditation. During mindfulness meditation no judgmental awareness should be occurred [8].

Among mindfulness meditation, Kabat Zinn [9] reduced religious part and developed the method a methods to relieve the stress and suffering both of body and mind, which is called mindfulness based stress reduction (MBSR). Under "mindfulness" condition, participates sense the surroundings present moment on purpose without subjective judgment [9]. MBSR have been applied among healthy people to investigate the immune interaction [10], Hoezel investigated the gray matter of long term MBSR participates [11], chronic pain condition during MBSR is investigated by Rosenzweig [12], Carlson compared different physiological parameters during MBSR [13]. Not only for mentally healthy people, MBSR also have a effect on depression, anxiety and psychological release subjects with chronic somatic diseases [14].

Many physiological have investigated effect of mindfulness meditation on human body. Cahn [6] summarized researches based on EEG event related potential and imaging studies, dorsolateral prefrontal cortex and anterior cingulate cortex activities changes during meditation. MBSR is especially effective to reduce patients' depressions during long practicing periods [15]. Besides central nervous system, Meditation can also affect autonomic nervous system. Heart rate variability heart cortisol level [16], [17]

In psychology, mindfulness meditation shows an effect to regulate attention, increase body awareness, regulate emotion and change perspective on oneself [15]. Life, sleep quality and symptom of stress have improved significantly for participants with breast and prostate cancer [13]. Changes in prefrontal cortex and anterior cingulate also support

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psychological studies [11]. Holzel [18] developed a questionnaire to evaluate meditation depth in terms of relaxation, hindrance, concentration, self-consciousness and emotions. Perceived stress scale and psychological strain questionnaire are also applied for meditation investigation [19], [20]. Besides emotion, psychological well-beings, mindfulness meditation can also reduce chronic pain condition [20].

II. Methods

A. Participants

A total of 10 university students of Universiti Teknologi Malaysia voluntarily participated in this study with an average age of 23.1 years (S.D= 1.47, range=21-25). No subjects were indicated to have mental illness based on the interview conducted prior to the experiment. All of them are nonsmokers and do not have experience in meditation. Prior to the experiment, all students have read the information sheet and signed consent form. Subjects were instructed to avoid eating and drinking except water an hour before the experiment.

B. Personality Assessment

C. Perceived Stress Scale

Perceived stress scale [21] is a 14 items self-report instrument to measure stress perceptions. Each item has a scale with frequency description "Never", "almost never", "sometimes", "fairly often" and "very often". Subjects' stress level relates to objective events caused in last one month. High degree of self-perceived stress indicates a risk of clinical psychiatric disorder. In mindfulness meditation perceived stress scale has been applied to classify subjects' stress level and regarded as reliable[20], [21]. In this study, we take Perceived stress scale as a reference to show that all subjects are mentally healthy and do not suffer a psychological disease.

D. Meditation Depth Index

Piron [22] set up a questionnaire with 30 different questions. All the questions can be classified into 5 clusters which show a uni-dimensional depth. Hindrances and relaxation are the first two groups. They explain personal emotional feelings from a restless and well feeling aspect. For further personal experience, "personal self" describes the meditators' feeling of oneself. With self-exploration, self-awareness, self-regulation and self-transcendence are applied to describe meditation state [23]. Then, following two groups are called "transpersonal". As a deeper side of meditation, it is considered as the consciousness goes beyond self without limitation of time and space [24]. 5 scales from "Never" until "Very much" describe each question. Participants choose one of the 5 scales, which most fit the description. In this study, meditation depth questionnaire were also applied during self-relaxation section so that subjective difference can be scaled using those 5 categories.

E. Physiological Measurement

This study used NEURO PRAX® from NeuroConn. Therapist is bind to EEG amplifier to one side, where the electrodes are connected. The maximum electrodes number is 32 on this amplifier with 1 for reference, 2 for ECG and 2 for EMG. The system used a 27 channel system based on 10-20 system. All electrodes have a fixed position. During the experiment, a modular recording cap from EASYCAP® is applied to keep the electrodes position fixed on the head. After the subject put on the cap, the hair in each ring adaptor is moved away carefully from the center until skin is clearly visible. After cleaning gel is injected, electrodes are fixed connected between adaptors on the cap and amplifier with corresponding channel number.

In the system both ears are taken as ground, reference is left mastoid. Signal is exported with an acsii form and analysis goes through Matlab®.

F. Procedures

The subjects arrived at 14:00, 14:00 to 15:00 EEG electrodes were connected to the subjects and other preparation works were done. First, a 2 minutes long EEG signal were collected as baseline, which subjects kept the eyes closed and sit still in the chair. Then subjects fill perceived stress scale. The whole experiment contains 2 sections. First section is relaxation section as control group. Subjects did a 15×15 word puzzle without solution to induce their stressor. The test takes 2 minutes. Then subjects relax themselves using their usual method for 10 minutes, in the middle of relaxation, EEG signal were taken again for 2 minutes. After the relaxation, subjects fill meditation depth questionnaire to survey their relaxation status, again a 2 minutes EEG signal is recorded as effect after relaxation.

Before the meditation section, subjects watched a video for 5 minutes about mindfulness meditation from Kabat Zinn [9] to learn the mindfulness meditation. Then subjects finished another different word puzzle again. The procedure for meditation section is the same as control section. Instead of self-relaxation, subjects use mindfulness based stress reduction according to the video. After the meditation, subjects answered meditation depth questionnaire again. Finally another 2 minutes EEG signal was recorded as effect after meditation.

G. Physiological Data Analysis

After data were exported to personal computer in text form, EEG signal were preprocessed with EEGLAB, an open source toolbox based on Matlab® [25].

Once EEGLAB is open, brain wave data can be imported and transferred into the data can be saved in EEGLAB. In order to represent the data in 2-D or 3-D format, proper channel location information is necessary to add to dataset.

The sampling rate is changed from 4098 samples/sec in NeuroConn to 256 samples/sec. Then a band-pass filter with bandwidth 1 Hz to 30 Hz is taken into account to get rid of noises. During the experiment reference is left mastoid, here averaging of all 27 channels ere used as reference.

After preprocessing, power spectrum of alpha wave and theta wave are applied compare the EEG activity. A wavelet transformation is used to see the difference of EEG active wave between meditation and relaxation.

Low-resolution electromagnetic tomography (LORETA) [26], [27] is a software for neuroimaging especially to

localize the activated brain area based on EEG data. This software is applied to investigate the active Brodmann area of the brain during meditation. Time line with high power spectrum in alpha wave was first detected in Matlab, then brain activity in this time period was shown to analyze the activated Brodmann area.

III. Result

A. Meditation Depth Questionnaire

All 10 students finish perceived stress test with an average value of 18.67 and standard deviation 2.24. We assume that all students are in the same stress level.

For each cluster we set up a hypothesis that there is no difference between emotional status after self-relaxation and after meditation. Students' T-test from SPSS is applied if Mean value of meditation section of each cluster is equal to mean value of self relaxation. Table I shows average for each cluster of meditation and self relaxation and Table II is statistical analysis.

TABLE I: Mean Value of Questionnaire

Cluster	Relaxation (STD)	Meditation (STD)
Hindrance	1.63 (0.47)	1.35 (0.30)
Relaxation	2.14 (0.47)	2.95 (0.59)
Personal Self	1.93 (0.69)	2.14 (0.58)
Transpersonal Qualities	1.52 (0.60)	1.89 (0.69)
Transpersonal Self	1.57 (0.93)	1.97 (0.57)

TABLE II: Statistic Analysis about Meditation Depth

		Paired Difference					t	Sig
					95% Confidence Interval of the Difference			
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper		
1	Hindrance	.28429	.28248	.10677	.02303	.54554	2.663	.037
2	Relaxation	-.80857	.60450	.22848	-1.36764	-.24951	-3.539	.012
3	Personal Self	-.21429	.33570	.12688	-.52476	.09619	-1.689	.142
4	Transpersonal Qualities	-.37286	.43995	.16629	-.77974	.03403	-2.242	.066
5	Transpersonal Self	-.40000	.79162	.29921	-1.13213	.33213	-1.337	.230

The mean value of hindrance reduces, the students feel themselves easier to relax and less restless. On the other hand, they feel their breathing more fluent and calm compare to relaxation section.

For the subjects without meditation experience, there is significant difference between relaxation effect and meditation effect according to hindrance (0.37) and relaxation (0.12). However there is no significant difference between personal self, and cluster in transpersonal level.

B. Localization of Alpha Activity

Changes in EEG power spectrum from meditation to self-relaxation were analyzed using a repeated-measures analysis of variance (ANOVA). It is conducted with meditation and self-relaxation session, right, left hemisphere and midline as within-subject factors, alpha, theta power spectrum as dependent variable.

There was a significant effect of session, $F(1,7)=9.92$, $p=0.005$, that power spectrum from 8 Hz to 12 Hz is higher during meditation than self-relaxation in midline (Fz). There was also a main effect in theta rhythm (5 Hz to 8 Hz) by meditation and self-relaxation session, $F(1,7)=4.35$, $p=0.005$.

In order to further investigate alpha and theta wave difference, we explored anterior and posterior power spectrum of alpha and theta during meditation and self-relaxation. Average signal of PF1, PF2, F7, F3, Fz, F4 and F8 is taken as anterior signal. Posterior signal consists of P7, P3, Pz, P4 P8, O1 and O2. Average signals' power spectrum of whole range was first calculated using function fast Fourier-Transformation from Matlab. Then average power spectrum of 5 to 8 Hz were taken as theta wave, and alpha wave is between 8 Hz and 12 Hz. Average (SD) for theta and alpha power spectrum are presented in Table III. Power spectrum has significantly increased both in anterior and posterior cortex and both in alpha and theta rhythms. Standard deviation for alpha wave during the meditation increased.

TABLE III: Mean Value of Power Spectrum for Theta and Alpha Rhythms for Self-Relaxation and Meditation

Region	Relaxation (STD)	Meditation (STD)
Theta		
Anterior	15.89 (10.8)	19.09 (15.9)
Posterior	15.52 (10.5)	18.93 (14.5)
Alpha		
anterior	45.47 (14.1)	71.49 (45.7)
Posterior	61.74 (16.0)	90.59 (62.1)

C. Frontal Alpha and Theta Activities

We focus on Fz analyze on the difference of EEG activity between Meditation and self-relaxation. After imported to Matlab, Fz channel is extracted from all other channels. To see the deviation of meditation from self-relaxation signals, difference between meditation and self-relaxation is first built. Then the new EEG signal is analyzed by continuous 1-D wavelet transformation with a windowed morlet signal. Morlet wavelet breaks down the signals into translated and scaled version along time and frequency. Wavelet transformation constructs a time-frequency representation of EEG signals. After transformation, the Fz signal is

demonstrated with time and frequency representation. Continuous wavelet transformation can be described with the following formal:

$$C(a, b; f(t), \psi(t)) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{a}} \psi^*(\frac{t-b}{a}) \, dt \quad (1)$$

Here *a* is scale parameter, b is position parameter on time interval, ψ is wavelet form. Signal frequency between 1 and 31 Hz is divided with 2 Hz interval.

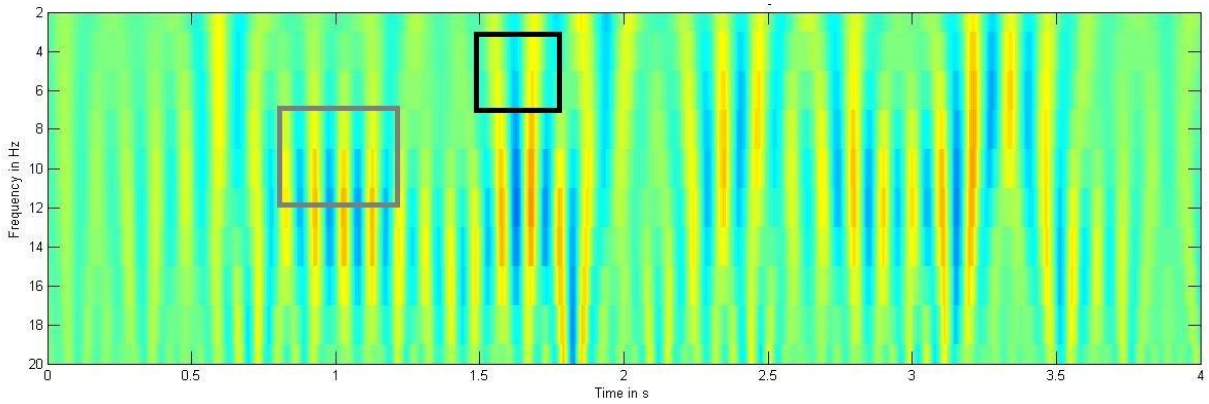

Fig. 1. Power spectrum difference between meditation and relaxation using wavelet transformation in different frequency during time.

As shown in Fig. 1, the gray-colored rectangular shows the oscillation pattern of alpha wave and black-colored rectangular shows the oscillation pattern of theta wave.

Alpha wave has a higher power spectrum in meditation than in relaxation. Power spectrum for the difference EEG signal varies during the time; meditation shows a stronger power spectrum then self-relaxation. A periodic oscillation of power spectrum in alpha and theta wave can be observed. Fig. 1 shows oscillation of a variety of wave rhythm during the time. The gray scale indicates a wave pattern in alpha wave (8 Hz to 12 Hz), this wave patterns comes in a period of 1.4s along time. Besides alpha wave, an oscillation of theta wave also occurs between 4 Hz and 6 Hz. Oscillation rate is around 1s.

IV. Discussion

Both neurophysiological and psychological studies also focus on possible mechanisms of mind-body interaction. Different meditative practice leads to different consciousness state, so meditation study help us to learn better about consciousness as well as self-experience [28]. According to Niedermeyer [29], consciousness consists of vigilance, mental state and selective attentiveness. The brain state such as hormone level varies with consciousness changes [5]. With awareness of breathing, central nervous system generates a neural network; it increases prefrontal cortex activity so that emotional control can be taken by neocortex using a top-down system.

Following the instructions of mindfulness meditation, subjects can better release themselves from stress than by self-relaxation, although the subjects are naive and had no experience in meditation. Meditation can be divided into focused attention, open monitoring and autonomic self-transcending [30] and mindfulness meditation belongs to open monitoring [31], during the practicing, cognitive system, participants are aware of an open background without certain attention. Many studies have shown that prefrontal cortex is more active during meditation [16,] [32]-[34].

Prefrontal cortex is involved in cognitive processing including memory [35], emotional processing [3], it is also very sensitive to stress. With depressive emotions neural activities between prefrontal cortex and auditory, sensory cortex are inhibited. Under the acute stress control of regulation can be overtaken by amygdala with rapid emotional reaction [3].

Hozel [11] describes Mechanisms thorough different components, including attention regulation, body awareness, emotion regulation and self-awareness. As the beginner for mindfulness meditation, subjective effects of increased self-concentration and self-awareness remain is statistic unclear. Attention regulation is associated with anterior cingulate cortex and (dorsal) prefrontal cortex plays an important role in emotion regulation, which can be analyzed using EEG.

During power spectrum analysis, power spectrum in theta range increase significantly, which also matches the effect from open monitoring effect [30], [36]. Increased power spectrum also occurs in alpha wave range. In sensory-motoric area, alpha shows high activity during simple tasks, and in association cortices alpha wave represents task requirement.

The wavelet transformation shows a periodic oscillation of alpha and theta wave in frontal area especially in Cz, which can indicates an periodic wave form from anterior cingulate cortex (ACC). ACC plays an important role in cognitive processing; it processes sensory, motor, cognitive and emotional signals before it is sent to prefrontal cortex. Those signals are integrated and processed first in ACC. Other brain parts can also be affected by motor, visceral responses [37].

Different wave forms can be generated not in separate single form. Together with other wave rhythms, signal activities EEG form can also come in a special wave form and its intensity also varies from time to time.

Stress level can be categorized by active theta wave, both limbic structure and neocortex can be the possible sources of theta activity. Theta rhythm plays a role in formation and recall of memory. Using EEG, strong theta activity can be observed at frontal midline area [38]. Theta power in

prefrontal cortex increases during mindfulness meditation, Takahashi [16] reported the active theta wave during mindfulness meditation, which indicates increased awareness of surroundings.

Mindfulness meditation affects both central and autonomic nervous system [17]. Strong theta spectrum indicates high activity anterior cingulate cortex and hippocampus; both areas are associated with autonomic nervous system.

Under mindfulness meditation, neural active connections differ from normal relaxation [11], [39], central nervous system acts as "a top-down" system. Participants follow the instructions to keep awareness of the environment. Prefrontal area keeps extensive connected with sensory and motor cortex. This signal pathway acts as regulation during alert, non-stress conditions [3]. Brewer's study [39] supports a different neural network between meditator and non-meditator. Stronger brain coupling in prefrontal cortex can be observed, which is responsible for self-monitoring and cognitive monitoring. Moreover, mind wandering also reduces significant [40], which suggests an improvement of attention in performance

V. Conclusion

To better understand the process of mindfulness meditation in relaxing the mind, further analyses such as source localization to investigate the activated area can be applied. The comparative study between the expert and the novice of practicing meditation can be done to see the prolonged effect of meditation for human health. This study concluded that meditation reduces stress in human and it is proven both from psychological and physiological data.

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