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Full Paper

EEG activity in Muslim prayer: A pilot study

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Abstract: Almost all religions incorporate some form of meditation. Muslim prayer is the meditation of Islam. It is an obligatory prayer for all Muslims that is performed five times a day. Although a large body of literature exists on EEG changes in meditation, to date there has been no research published in a peer-reviewed journal on EEG changes during Muslim prayer. The purpose of this pilot study is to encourage further investigation on this type of meditation. Results of EEG analysis in twenty-five trials of Muslim prayer are reported. Some of the findings are consistent with the majority of the previous meditation studies (alpha rhythm slowing, increased alpha rhythm coherence). However, Muslim prayer does not show an increase in alpha and/or theta power like most of the results of other meditation studies. The possible cause of this discrepancy in meditation-related studies is highlighted and a systematic and standardised roadmap for future Muslim prayer EEG research is proposed.

Keywords: EEG, Muslim prayer, meditation, brainwaves

INTRODUCTION

Electroencephalography (EEG) reflects the action of the brain. It is the electrical activity produced by the firing of the vast number of neurons recorded from the scalp. EEG shows a variety of oscillations due to the summation of the synchronous activity of neurons. Since 1929, when Berger [1] showed that the alpha rhythm tends to decrease in amplitude during mental arithmetic performance, thousands of studies have been published regarding task-related modulation of human EEG. A large number of functional brain activities have been correlated with specific EEG changes. They have been

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related, for example, to emotion [2], dyslexia [3], anxiety [4], memory [5], drowsiness [6] and depression [7]. Notwithstanding the vast number of studies in this field, to date there has been apparently no peer-reviewed journal publishing research on EEG changes during Muslim prayer.

Islam obligates all Muslims to pray five times a day. Muslim prayer should be performed with particular genuflections or body movements and the recitation of specific religious phrases. It is one of the most important Islamic acts. Nevertheless, in the Islamic point of view the prayer is not the goal itself. The real goal is the remembrance of God and the training of attention during prayer to focus on God (for example: "*...and keep up prayer for my remembrance.*" [8]). A properly performed prayer will eventually extend the remembrance and the attention to God even when the prayer ends and during the course of everyday-life activities. Individuals praying correctly will feel and remember God at all times. A properly performed prayer from the Islamic point of view will produce a deep calmness and spiritual feelings of closeness to God, with its peak mostly occurring during the prayer ("*Those who have believed and whose hearts are assured by the remembrance of Allah. Unquestionably, by the remembrance of Allah, hearts are assured.*" [9]). According to the rules of Islamic prayer, the value of the prayer is mostly related to the attention of the individual on what he recites and on his focus on God. Without which, the individual does not benefit from the full effect of prayer. Improved focus will yield better results. That is why, from the Islamic point of view, research on the attention and concentration during prayer is of utmost importance.

All types of meditation share common features. It is a way to regulate and control the attention of the mind [10]. Meditation can be divided into two types─concentrative meditation and mindfulness meditation. In fact, there is a whole spectrum in between these two poles depending on the attentional processes involved [11]. This classification will be elaborated upon in the discussion section.

Our main objective is to develop a series of research on the neuroelectric changes during Muslim prayer guided by this pilot study. The lack of previous studies in this field has made us cautious to conduct large-scale research without a preliminary study to check whether neuroelectric changes occur during Muslim prayer. Therefore, it was logical to begin with a pilot study to provide the foundation for designing more comprehensive experiments.

METHODS

Design of Experiment

In order to identify the EEG changes resulting from the spiritual experience and the attention associated with Muslim prayer, it was necessary to compare the recorded EEG during the act of praying with that obtained during another two states by the same participant. The first was the resting state in which the participant was sitting on a chair with his mind wandering freely. This state may be regarded as the baseline for comparison with the EEG changes during prayer.

However, by its very nature Muslim prayer should be performed while maintaining a specific posture for a few seconds up to a few minutes. When the phrase or 'mantra' related to that posture has been completed, a body movement should be made to change to the next posture. There are four different postures in Muslim prayer, viz. standing (1-2 minutes), bowing (a few seconds), prostrating (a few seconds) and sitting (a few seconds up to 1 minute).

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Muslim prayer, as mentioned above, should also be performed while reciting certain religious phrases or 'mantra'. This presents a challenge of recording an EEG without muscle artifacts. Artifacts are always present, but EEG researchers are usually keen to decrease them as much as possible. To solve this problem, it was necessary to compare the EEG during prayer with the second state in which the participant was asked to move and speak similarly to how he would during Muslim prayer but without any real concentration (meditation) on God, and the participant was not allowed to use religious phrases in this state. This was done by asking the participant to repeatedly recite names of his first, second and third degree relatives that he could remember. The third state was the real prayer. The participant was asked to concentrate as much as he could on God when reciting the prayer.

In order to identify the EEG changes due to the attention and the spiritual factor of the prayer excluding any neuroelectric changes that occurred as a result of muscular activity of the eyes, body and tongue, we made two comparisons. The first was between the resting-state EEG and the prayer-state EEG (i.e. 'rest to prayer' transition). The second was between the prayer-movement-state EEG and the prayer-state EEG (i.e. 'prayer-movement to prayer' transition).

The EEG changes were not accepted as those resulting from the spiritual and concentrative efforts of the pray-er unless they met two specific criteria: the changes should be significant ($P<0.05$) and there should be also a significant change in the same EEG feature in the second comparison even though the magnitude of the changes might differ. This is to ensure that the changes were really due to the attention and spiritual effect during prayer. The resting state compared with prayer should register changes due to the pray-er's spiritual state, attention, muscular movements and recitation. The prayer-movement state compared with prayer should reveal changes due to the attention and the spiritual effect of the prayer proper as well as other factors such as voicing their wandering thoughts aloud. Thus, by taking into account the two comparisons, most if not all of the confounding factors should be eliminated.

The other benefit from this methodology is that it will decrease the chance of false positive results occurring due to the well-known statistical multiple comparisons problem (i.e. the multiple t-tests performed on the same data). In our analysis this would be 19 EEG absolute power t-tests + 19 relative power t-tests + 3×171 (combinations of all electrode pairs for amplitude asymmetry + coherence + phase lag) = 551 t-tests for each of the two states compared (i.e. transition). This would yield 27.55 significant false positive results ($P<0.05$) by chance alone for each transition, which is termed error type I.

Through our method of combining two baselines or control states (i.e. rest and prayer-movement) to be compared with the experimental state (i.e. prayer), the error type I would drastically decrease. The overall (i.e. familywise) chance of error type I appearing in the first and the second transitions combined would be the multiplication of the chance of type-I error in the first and the second transitions, which is $0.05 * 0.05 = 0.0025$ or 0.25%.

Thus, the overall number of significant false positive results by chance alone (if $P<0.05$ for both transitions) would be reduced from 27.55 to $551 * 0.0025 \sim 1.38$. Even less error type I would result if $P<0.01$for both transitions, i.e. well below 1 (~ 0.05).

EEG Recording Protocol

One male Muslim (aged 32, right-handed, no previous mental or chronic physical illness) participated in this pilot study. He was asked to evaluate himself concerning his everyday usual concentration level in his prayer. He chose to place himself in the medium grade, by which he meant that sometimes he would be distracted and his mind would wander and not concentrate on his prayer. Although his concentration was sometimes more or less than this average, this was normally the case for approximately half of his prayer time. Although he was asked to do his best to concentrate on his prayer during our experiments, he was not able to improve his concentration more than he did normally.

The EEG activity for all states was recorded for an average of 2-3 minutes at a time with the eyes closed. In the first state, the participant was asked to sit down on a chair and relax, letting his mind wander freely without any special mental or physical task. This state was identified as the resting state. The EEG of the second state was recorded while the individual was moving as if performing a Muslim prayer but reciting non-religious phrases. This state was referred to as the prayer-movement state. The third state was during the Muslim prayer. The participant was asked to concentrate as much as possible. This state was referred to as the prayer state. All three states were repeated 25 times in the sequence of resting, prayer movement then prayer. EEG recordings were performed at different times during the day. Each 2-3-minute recording of each trial was separated by 30-60 seconds of rest.

Collection of Data

EEG data were recorded from 19 channels according to the International 10-20 electrode system of scalp electrode placement [12] (Figure 1). The EEG data were recorded for offline analysis using a 40-channel Medelec EEG system (Oxford Instruments, Inc., UK) during 5 days randomly chosen in July-August 2010. All EEG recordings were done in the Biomedical Engineering EEG Lab of the University of Malaya. All channels were referenced to A2 (sampling rate = 512 sample/sec). They were remontaged into linked ears montage before offline analysis. The electrodes' impedance was checked before and after each recording and generally all electrodes were maintained at 5-10 kohm. The frequency response of the EEG amplifiers was 0.5-70 Hz without notch filter.

Eight auxiliary channels were used for recording the electromyography (EMG) of the muscles and eye movements, the use of which is mandatory in Muslim prayer. There were 6 bipolar EMG channels: two (right and left) channels were placed at 13 cm below the inion to record the activity of the neck muscles; another two (right and left) were placed at 3-6 cm below and anterior to the ears to record the masseter muscles' activity; one channel was used to record the vertical movements of the tongue (recorded between the nasion and below the chin), and the other was for the horizontal movements of the tongue (recorded between the right cheek and the left cheek). Two electrooculograph (EOG) channels were used to record the vertical and horizontal movements of the eyeballs.

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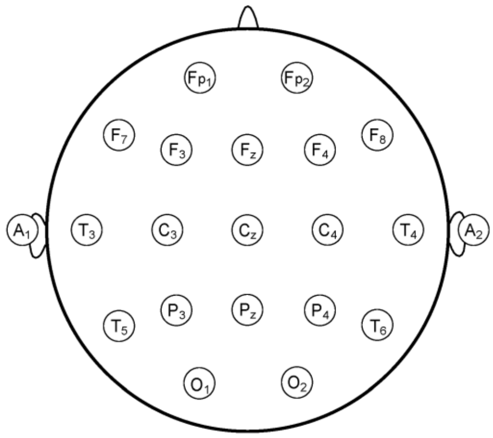

Figure 1. The international 10-20 system of electrode placement

Data Analysis

Offline EEG data were imported into the software 'NeuroGuide' (version 2.6.3). Usually, parametric statistical analysis is preferred to the non-parametric one. Parametric statistics has more power: it needs less sample size to draw conclusions with the same degree of confidence. This benefit comes at the cost of a more limiting assumption. It relies on the assumption that the data is sampled from a population with a Gaussian probability distribution (i.e. normally distributed population) [13]. In the real world of data sampling, this assumption will never be met completely. Nevertheless, one should try to make mathematical transformations for the data until the best normality is achieved. If the normality assumption could not be achieved, non-parametric statistics should be used. Previous literature showed that the EEG absolute power and phase in the normal population do not show Gaussian distribution. However, the other features of the EEG (coherence, amplitude asymmetry and relative power) have better normality and do not need any transformation to be used in parametric statistical tests [13]. Thus, the EEG absolute power and phase features were logarithmically transformed to fit the Gaussian distribution.

All the EEG data were revised to exclude any period (i.e. epoch) containing artifacts. This was carried out before the analysis of the EEG signals using the 'Neuroguide' software. A minimum amount of EMG artifacts due to tongue movements could not be excluded as they were the very act of Muslim prayer. Hence a low EEG contamination by artifacts was acceptable. It was just for the prominent artifacts that all the EEG for that contaminated epoch was excluded and rejected. This was done by a careful inspection for the whole EEG. After the exclusion of the epochs which were highly artifact-contaminated, the 'Neuroguide' software analysis was carried out. The frequency range of the remaining artifacts and the contaminated channels were identified and eliminated from the results before the interpretation of the analysis. This identification was carried out with the aid of topographical EEG analysis (Linked Ears and Laplacian montage) and with the help of the eight auxiliary channels that monitored when and what contamination was aroused from the muscles.

By rejecting the contaminated epochs, on average, sixty seconds of EEG remained from each trial to enter the analysis phase by the 'Neuroguide' software. For each trial, the average fast Fourier

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transform (FFT) for all the remaining epochs was calculated. Statistical analysis for two-group combinations (prayer trials group – rest trials group, prayer trials group – prayer-movement trials group) was calculated by independent t-tests. The following EEG statistical tests were calculated:

1. Topographical maps for FFT absolute power difference and relative power difference in 14 frequency bands (delta: 1-4 Hz, theta: 4-8 Hz, alpha: 8-12 Hz, beta: 12-25 Hz, high beta: 25-30 Hz, gamma: 30-40 Hz, high gamma: 40-50 Hz, alpha1: 8-10 Hz, alpha2: 10-12 Hz, beta1: 12-15 Hz, beta2: 15-18 Hz, beta3: 18-25 Hz, gamma1: 30-35 Hz, and gamma2: 35-40 Hz). Single Hz frequency bands (1-50 Hz) were also calculated.
2. FFT amplitude asymmetry difference, FFT coherence difference and FFT phase lag difference in 4 bands (delta: 1-4 Hz, theta: 4-8 Hz, alpha: 8-12 Hz, and beta: 12-25 Hz) for all 171 combinations of the 19 EEG scalp channels.

RESULTS

It should be recalled that a change (prayer - rest) was not regarded as acceptable unless the same change was also present in the second control difference (prayer - prayer movement). It was found that the delta band was highly prone to artifacts. This was consistent with the literature in that tongue movements (speaking during prayer) and eye movements produce artifacts mainly in the delta band [14]. This is why this band was excluded from our analysis.

Moreover, EEG during Muslim prayer will definitely be contaminated by EMG. Muscle movements are part of the Muslim prayer and cannot be avoided. EMG artifacts are mostly present in gamma and beta bands. We tried to exclude the contaminated EEG by editing the EEG data (discarding the most likely contaminated epochs) and being more cautious in interpreting changes in these bands by carefully inspecting the topographical distribution of the FFT absolute power gradient in these frequencies.

FFT Absolute and Relative Power Differences

The significant changes for both absolute and relative power differences were the same, so we focused on the FFT absolute power difference. Figure 2 shows the common significant changes in the two transitions, viz. prayer movement to prayer and rest to prayer. Any significant changes that were present in one transition and not in the other are not shown in the figure.

Most of the changes are highly significant ($P<0.01$) in the alpha2 band (see O1, O2, P3, P4, T5, and T6 electrodes in Figure 2). These electrodes cover the scalp over the occipital, parietal and posterior temporal areas of the brain. We found that in FFT absolute power and relative power analysis, it was important to divide the standard bands (delta, theta, alpha, beta and gamma) into several smaller bandwidths. This was because in certain cases, by averaging a whole frequency band range, there would be some positive changes in specific frequencies and negative changes in others, and each one would cancel the other. For example, in this study we did not find any significant change throughout the alpha band (8-12 Hz), but there was a highly significant EEG power decrease in specific frequencies if considered alone in a smaller bandwidth such as alpha2 (10-12 Hz) or a single (10 Hz) band. The alpha1 band also showed a less significant power increase in P3 and T5. The changes are listed below with '↑' indicating electrodes with increasing power change from rest and prayer movement to prayer transitions and '↓' for decreasing power change:

Alpha2 band (left hemisphere): ↓ O1, ↓ P3, ↓ T5
Alpha2 band (right hemisphere): ↓ O2, ↓ P4, ↓ T6
Alpha1 band (left hemisphere): ↑ P3, ↑ T5

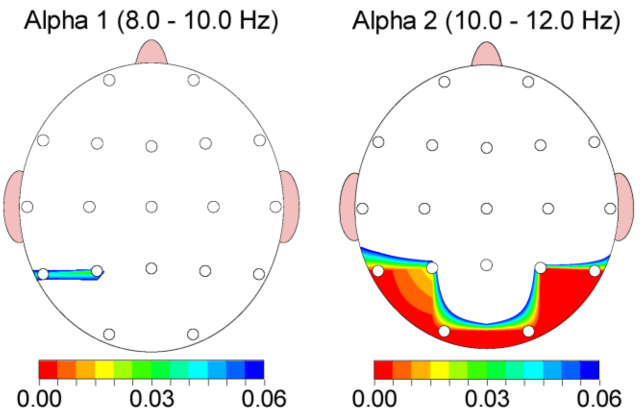

Figure 2. P-values for FFT absolute-power group independent t-test (common significant changes from 'rest to prayer' and 'prayer movement to prayer' in Alpha1 and Alpha2 bands)

FFT Amplitude Asymmetry Difference

The significant changes for the 'prayer movement to prayer' and 'rest to prayer' transitions are shown in Figure 3. For a list of significant changes that happened as shown below, the electrode pairs are written in bold font for changes that were common in the two transitions and which were both highly significant (P<0.01). They are written in italic font for changes that were in one case highly significant (P<0.01) and in the other case less significant (P<0.05). The other listed pairs with normal font were less significant in both cases (P<0.05). Electrode pairs that registered significant changes in just one case are not listed or are designated as 'no significant changes'. (These notations also apply to the next two sections.)

Theta band (left hemisphere): ↓ *FP1-P3*, ↓ *FP1-T5*, ↓ *F3-P3*, ↓ *F3-T5*, ↓ **C3-P3**, ↑ C3-F7, ↓ *C3-T5*, ↑ *P3-O1*, ↑ **P3-F7**, ↑ *P3-T3*, ↓ *O1-T5*, ↓ **F7-T5**, ↓ **T3-T5**
Theta band (right hemisphere): No significant changes
Theta band (homologous pairs): ↑ *P3-P4*, ↑ *T5-T6*
Alpha band (left hemisphere): ↓ *F3-P3*, ↑ *P3-O1*, ↑ **P3-F7**, ↓ *O1-T5*, ↓ *F7-T5*
Alpha band (right hemisphere): ↑ FP2-O2, ↑ F4-O2, ↑ *P4-O2*
Alpha band (homologous pairs): ↑ **P3-P4**, ↑ **T5-T6**
Beta band (left hemisphere): ↓ *FP1-F3*, ↓ **FP1-F7**
Beta band (right hemisphere): ↑ *F8-T4*
Beta band (homologous pairs): ↑ **P3-P4**

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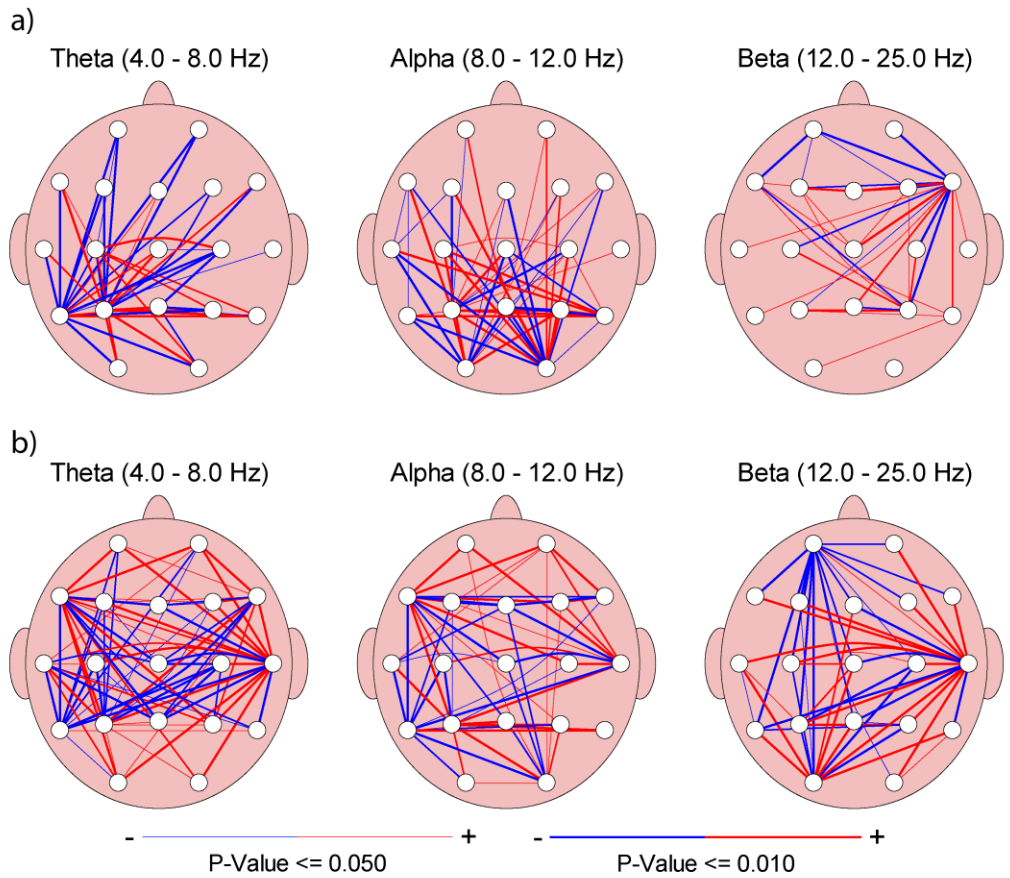

Figure 3. FFT amplitude asymmetry group independent t-test (P-value): a) from prayer movement to prayer, b) from rest to prayer; blue = decreased amplitude asymmetry in prayer compared to rest and prayer movement, red = increased amplitude asymmetry in prayer compared to rest and prayer movement

FFT Coherence Difference

The significant changes from prayer movement to prayer and from rest to prayer are shown in Figure 4. Their list is as follows:

Theta band (left hemisphere, right hemisphere, homologous pairs): No significant changes

Alpha band (left hemisphere): ↓ **F3-O1**, ↑ **C3-P3**, ↑ **C3-O1**, ↑ **T3-T5**, ↓ C3-F7, ↑ **C3-T5**, ↑ **P3-T3**, ↓ *O1-F7*, ↑ **O1-T3**

Alpha band (right hemisphere): ↓ *F4-O2*, ↑ *C4-P4*

Alpha band (homologous pairs): ↓ *O1-O2*

Beta band (left hemisphere): No significant changes

Beta band (right hemisphere): ↑ **F8-T4**

Beta band (homologous pairs): No significant changes

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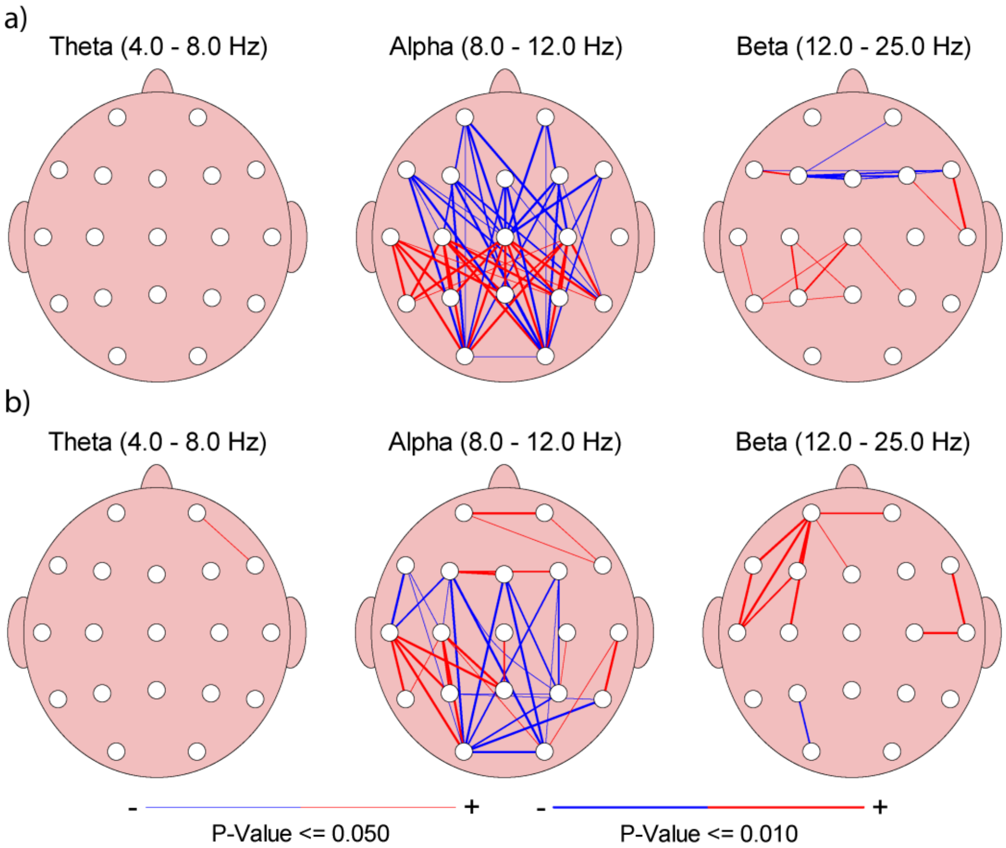

Figure 4. FFT coherence group independent t-test (P-value): a) from prayer movement to prayer, b) from rest to prayer; blue = decreased coherence in prayer compared to rest and prayer movement, red = increased coherence in prayer compared to rest and prayer movement

FFT Phase Lag Difference

The significant changes from prayer movement to prayer and from rest to prayer are shown in Figure 5. Their list is as follows:

Theta band (left hemisphere): ↑ *FP1-F3*, ↓ *O1-T3*
Theta band (right hemisphere): No significant changes
Theta band (homologous pairs): No significant changes
Alpha band (left hemisphere): ↓ *O1-T3*
Alpha band (right hemisphere): ↓ T4-T6
Alpha band (homologous pairs): No significant changes
Beta band (left hemisphere): ↓ FP1-C3
Beta band (right hemisphere): No significant changes
Beta band (homologous pairs): No significant changes

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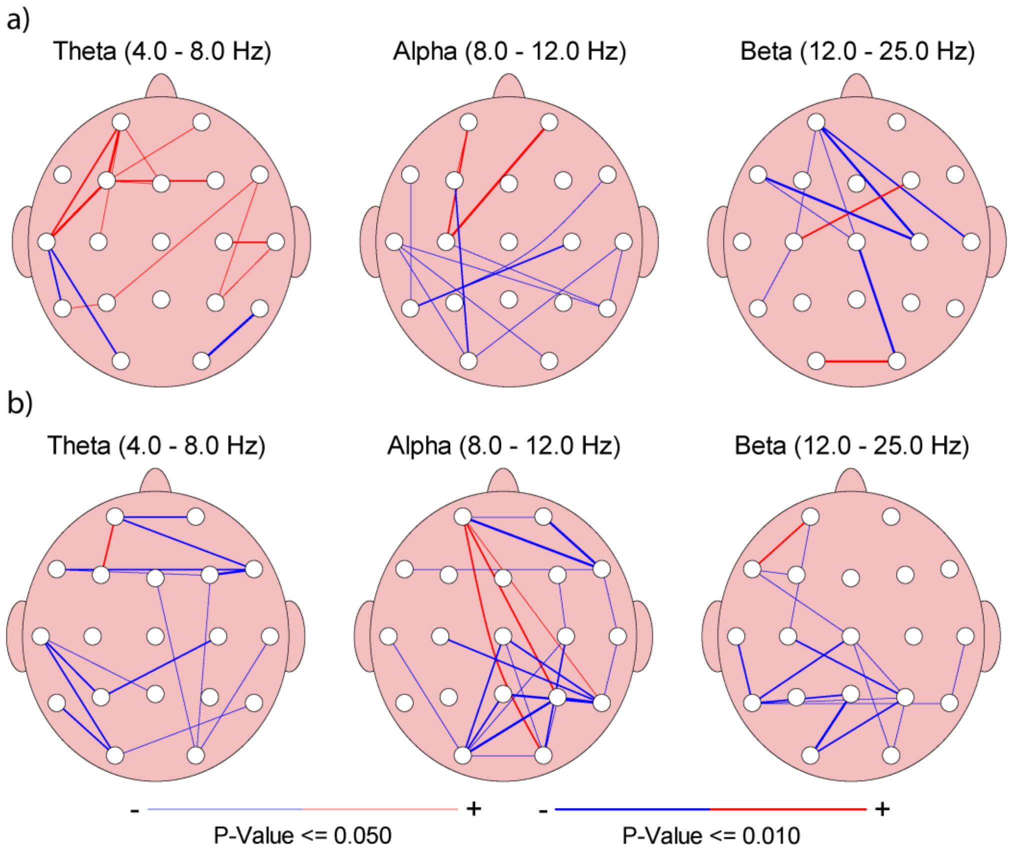

Figure 5. FFT phase lag group independent t-test (P-value): a) from prayer movement to prayer, b) from rest to prayer; blue = decreased phase lag in prayer compared to rest and prayer movement, red = increased phase lag in prayer compared to rest and prayer movement

DISCUSSION

Coherence is a measure of the stability of phase difference between two EEG signals. It is measured with pairs of electrode positions. It provides an indication of the functional coupling of the two brain regions. Coherence is positively related to the number and strength of the connections between neurons (Coherence = N*S, where N is the number of connections and S is the strength of connections). The connections can be either intra-cortical connections in gray matter (1-3 mm) or longer connections as 'U shaped' white matter fibres (30-60 mm) or long-distance cortico-cortical fibres (> 60 mm) [15]. Normally, the intra-cortical connections and the 'U shaped' white matter fibres are more in quantity than the long-distance cortico-cortical fibres in a normal brain. Thus, a short inter-electrode distance (adjacent electrodes) has a higher density of connective fibres, which means less delay (i.e. less phase lag) and more phase stability (i.e. higher coherence).

In previous EEG studies, EEG coherence change was related to several functional cognitive activities, e.g. intelligence [16], memory efficiency [17-18] and arousal level [19]. Increased alpha coherence in meditation was found in many previous studies [e.g. 20-23]. In our study (Figure 6), the coherence changes were highly significant ($P<0.01$), indicating more connection strength and/or increase in neuronal connections as well as reduced functional differentiation in the affected brain regions due to the new mental states in prayer. Previous literature showed that there are patients with abnormal mental or neural conditions, in whom EEG coherence are decreased [e.g. 24-28]. Some of those patients were treated with different success rates by training them to increase coherence in multiple neurofeedback sessions [29-35]. The prayer effect on coherence may thus be useful to counterbalance the decrease in coherence in those brain regions. This is a potential research field that has not been attempted before.

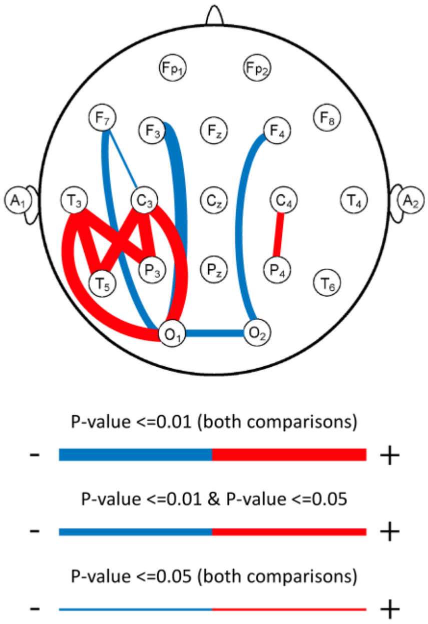

Figure 6. P-values of FFT alpha-band coherence group independent t-test (common changes from rest to prayer and from prayer movement to prayer); blue = decreased coherence in prayer compared to rest and prayer movement, red = increased coherence in prayer compared to rest and prayer movement

The EEG power changes in prayer were further analysed by a single Hz power analysis (Figure 7). The alpha2 band (10-12 Hz) power was decreased in prayer when compared with that in the prayer movement and rest states. The decrease was actually in the 10 Hz power in the occipital and posterior temporal and parietal areas of the brain. Furthermore, there was an increase in the 8 Hz power, mainly in the left posterior temporal and parietal areas.

The majority of previous research findings on EEG changes during meditation indicated increasing theta and/or alpha power [36-37]. However, in this study there was no significant change in the alpha power (8-12 Hz) unless the bandwidth was divided into alpha1 (8-10 Hz) and alpha2 (10-12 Hz) bands or into single Hz bandwidth analysis. This is because the change was not primarily on the power, but rather on shifting of the mean power of the alpha rhythm from 10 Hz to 8 Hz. This change was limited to the alpha bandwidth, hence no net effect on the alpha power as a whole range (8-12 Hz). The slowing alpha rhythm was consistent with some of the previous research findings on the effect of meditation on EEG [36-40].

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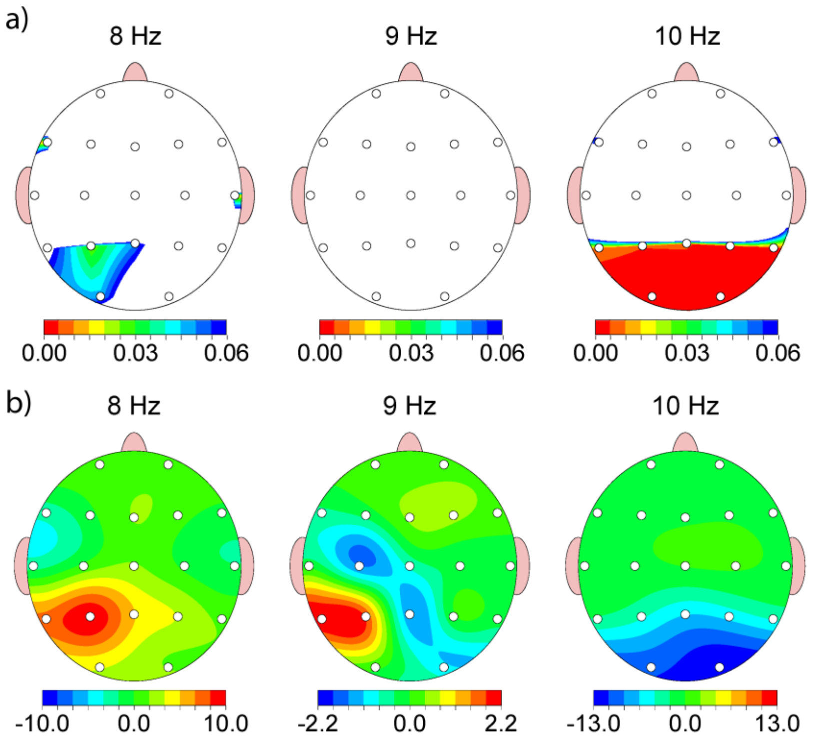

Figure 7. FFT absolute-power group single-Hz frequency analysis for 8-10 Hz (common significant changes from rest to prayer and from prayer movement to prayer): a) independent t-test (P-value), b) absolute power difference (uV^2)

Although considerable research has been done on meditation, most of the findings are dissimilar. We opine that unless there are some standards in categorising the factors that have direct effects on the EEG findings, there will be no consistent results. Although normal EEG changes significantly according to age and gender, no previous trials seem to exist that study a single meditation technique on different age groups or on a specific gender versus the other. Furthermore, the type of meditation determines the mental activity, which has a direct relationship with EEG changes. For example, the two extreme ends of meditative techniques─the yogic concentrative meditation and the Zen mindfulness meditation─cannot give the same EEG findings as the physiological changes in the brain are dependent on the action of the mind. Concentrative meditation involves the concentrative effort of the mind on a single sensory or mental action, whereas mindfulness meditation involves maintaining a passive state of attention and letting thoughts pass in or out of the mind without mentally processing the thoughts. The latter is a neutral observer technique. There are many other meditation techniques that lie between these two extremes. Another factor that has an impact on EEG findings in meditation is the level of experience of the meditator and the duration of his/her training. We cannot expect significant EEG changes in novice meditators who are unable to apply the technique correctly as their mind wandering (in which the default mode network of the brain is activated) will not differ from the resting state.

Muslim prayer is by no means different from other meditation techniques. Future studies concerning the mental and psychological effects on EEG changes should be categorised and standardised. Although many Muslims have been praying for decades, it does not mean that all of them are performing the prayer in a proper manner. The physiological effect of any mental action on the EEG is dependent on the content of this mental action. Praying for a long time does not guarantee proper concentrative effort. It is the choice and will of the individual praying that really determine the level of concentration in prayer. Although the value of prayer in Islam is on its concentrative strength and on the maintenance of concentration on the phrases, there will be a large proportion of Muslims who usually perform this prayer as a purely physical action without bothering to concentrate. This is because Muslim prayer is obligatory in Islam for all Muslims, and although performing the prayer in this manner may be acceptable, it is the least acceptable in terms of prayer quality. That is why even the time factor for Muslim prayer cannot be relied upon to assess the meditative experience. We propose that there should be a psychological questionnaire developed by experts, similar to other psychological scales (for example the mysticism scale [41]), to assess the level of concentration in Muslim prayer.

In sum, the roadmap for future studies on Muslim prayer should be based on controlling the confounding factors (age, gender, usual prayer concentration level, anxiety level during experiments, etc.) that result in discrepancies. It is hoped that this pilot study will encourage researchers to conduct further studies to analyse the inter-individual variability in EEG changes during Muslim prayer and to investigate the potential therapeutic effect on some abnormal neural and mental conditions. It will also be helpful in the future to study the phase shift and phase lock, which give a more physiologically fundamental measure than coherence. The change in coherence during prayer may be due partly to the very fast phase shifting or short phase lock and this may lead to hypotheses about GABA and/or glutamate excitatory loops as discussed by Buzsaki [42].

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