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Right Sided Lateralization of Gamma Activity of EEG in Young Healthy Males

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ABSTRACT

Introduction: Functional asymmetry of the brain as studied on the electroencephalogram (EEG) can be used to obtain important information about the lateralization of brain electrical activity, which is closely related with sensorimotor, cognitive and behavioral functions. Thus frequency bands of the EEG trace can serve as potential markers of cortical functions in the sensorimotor, cognitive and behavioral domains. Previous studies have reported morphological asymmetry of the brain. However, the functional implication of morphological asymmetry of the brain is not been fully understood. The aim of the study was to investigate the lateralization of cortical oscillatory activity on the EEG in healthy humans.

Materials and Methods: Fifteen healthy males with an average age of 23.65 years (SD=6.12) participated in the study. EEG recordings were performed using two channel bipolar montage; F2–F4 (right brain hemisphere) and F3–F7 (left brain hemisphere).

Results: Gamma activity was significantly higher on the right side of the brain compared to the left side ($p<0.05$). There was no significant difference on other EEG waves between the left and right brain ($p>0.05$).

Conclusion: Right sided lateralization of gamma activity suggests that the right brain is concerned with cognitive and behavioral processing. The results of this study confirm previous reports that the right brain is cognitive. Thus gamma activity can be used as a useful marker of frontal activation in behavioral and cognitive training.

Key words: Lateralization, Brain asymmetry, Gamma activity, EEG, Cognitive processing

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INTRODUCTION

Several studies on the morphological asymmetry of the brain have been reported [1-8]. These studies focused on different regions of the brain including whole gray matter [1], central sulcus [2], planum temporale [3], inferior frontal sulcus, precentral sulcus [3], insula [4,5], cerebral ventricles [6], visual cortex area [7], and a number of axons in the optic nerves [8]. Furthermore, morphological asymmetry of other structures of the skull and face has also been reported [9-14]. Unfortunately, however, the functional implication of these morphological asymmetry studies of the brain is not fully understood.

To date, majority of studies on functional asymmetry mainly reported functional implications of morphological asymmetry of peripheral tissue, organ or systems in health and disease. For example, right-sided lateralization of skin temperature [15], asymmetry of femur bone mineral densities [16,17], peripheral asymmetry of cell-mediated immunity [18,19], and hearing asymmetry (right temporal hemisphere) [20] have been reported. Patients with disease such as schizophrenia were found to have a left temporal hemispheric dysfunction [21]. However little is known about the electrophysiological mechanisms of lateralization of hemispheric functions in healthy individuals. The pattern of electrical activity of the brain due to generated action potentials and multiple excitatory and inhibitory postsynaptic potentials mostly of the subcortical and cortical neurons of the brain can provide useful information underlying the phenomenon of functional asymmetry [22–25]. EEG is a useful electrophysiological recording that can be used to investigate brain electrical activity, and thus, is important in functional brain asymmetry studies [25,26]. More importantly, there is a paucity of data on asymmetry of brain electrical activity.

So far, functional brain asymmetry studies on EEG have focused on the frontal alpha waves. Asymmetry of frontal EEG alpha waves refers to the difference in the amount of cortical activity in one hemisphere relative to the other [27]. Alpha waves tend to decrease or disappear with increase in activity and alertness, attention and other cognitive processes [28,29].

In addition to alpha waves, the EEG frequency band that has been shown to play a definitive role in attention, cognitive and behavioral process is the gamma wave (30-80 Hz) [30]. Increase in gamma bands in EEG traces indicates mnemonic processes [29,31,32]. A couple of studies have revealed possible underlying mechanisms of generation of gamma rhythm [33-38]. However, little is known about the neurochemical and electrophysiological basis of these oscillatory waves in human cognition. Furthermore, almost little is known about functional brain asymmetry studies on gamma waves. Other major frequency bands of EEG trace include delta, theta, and beta. The delta and theta waves are related to sleep and disappear with wakefulness and they have not been shown to be associated with cognitive activities [39]. Beta wave represents sensorimotor processing related to cognition and motor control [40,41].

While EEG asymmetry (especially alpha bands) is increasingly been investigated in many pathological conditions in recent times [42], EEG asymmetry of other frequency bands (including gamma activity) in young healthy persons has not been unequivocally established. To this end, this study was conducted to investigate the lateralization of EEG frequency bands in young healthy humans.

MATERIALS AND METHODS

Participants

The experimental protocol was in line with the Declaration of Helsinki and approved by the local ethics committee. The aims and objectives of the study were explicitly explained to the participants. Fifteen healthy men (mean age ± standard deviation, 23.65 ± 6.12) participated in this study. All participants gave written informed consent to participate in the study a day prior to the commencement of the study. All participants were right-handed, according to self-report and confirmed by Edinburgh Handedness Inventory [43]. They had comparable education level (15–17 years). Exclusion criteria were willingness to participate, total abstinence from drugs, and the absence of health problems such as psychiatric, respiratory, metabolic, cardiac or central and autonomic nervous system disease, which may affect EEG tracing based on recent medical examination.

EEG recording

EEG recordings were performed twice around 8:00 AM–9:00 AM in all participants. To avoid artifacts in the EEG tracing, the participants were requested to relax comfortably in an arm chair. The study lasted for one week.

The EEG signal was recorded according to the standard international 10/20 system, with a sampling rate of 1 kHz. EEG data was recorded by two channel bipolar montage; F2–F4 (right brain hemisphere) and F3–F7 (left brain hemisphere) (Figure 1). The digital EEGs were recorded by using PowerLab 26T (AD Instruments, Bella Vista, Australia), a device used for multimodal monitoring of bio-signals. EEG frequency bands considered for analysis were delta waves (1–3 Hz), theta waves (4–7 Hz), alpha waves (8–12 Hz), beta waves (13–30 Hz), gamma1 waves (31–40 Hz), gamma2 waves (41–50 Hz) and gamma3 waves (60–80 Hz).

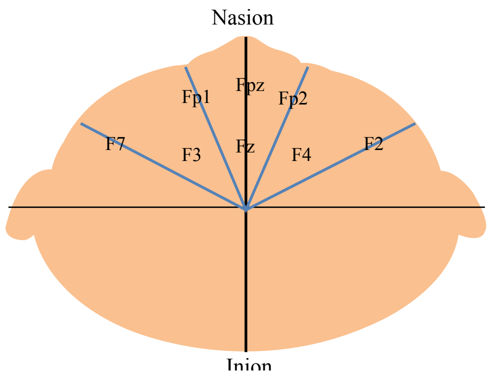

Figure 1: Location of electrodes used in the study

The electroencephalographic signal processing analyses were performed in MATLAB. The changes in frequency and amplitude of the EEG can be calculated by means of power spectral analysis. We used Discrete Fourier Transform (DFT) to calculate the power spectrum of time domain discrete EEG signal. Power spectral density (PSD) is frequency response of a periodic or random signal. PSD shows distribution of signal strength depending on the frequency. The EEG data were recorded in a time domain discrete signal.

Power spectral density can be expressed with equation 1:

$$P(\mathrm{k}) = \frac{1}{N}\sum_{i=0}^{N-1}\left|x_i(k)\right|^2 \qquad (1)$$

Where N is the number of samples and $x_i(k)$ is the Discrete Fourier Transform (DFT) of the time domain discrete $x_i(n)$ signal. $x_i(k)$ is calculated as shown in equation 2;

$$x_i(k)=\sum_{n=0}^{N-1}x_i(n)e^{-j(2\pi/N)nk} \quad (2)$$

Statistical analysis

Results are expressed as mean ± standard deviation (SD). Distributions were evaluated by using one sample Kolmogorov Smirnov test. Nonparametric Wilcoxon signed rank was used for comparisons. Differences were considered statistically significant at $p<0.05$. The SPSS statistical software package (SPSS, version 18.0 for windows) was used to perform all statistical calculations.

RESULTS

In the present study, beta, gamma2 and gamma3 powers (μv^2/Hz) were higher in the F2–F4 (right brain hemisphere) of the EEG (beta: $t=2.23$, $p=0.04$; gamma2: $t=2.34$, $p=0.03$; gamma3: $t=2.51$, $p=0.02$). Also, percentages of gamma2 and gamma3 waves were higher in the F2–F4 (right brain hemisphere) of the EEG than in the F3–F7 (left brain hemisphere) (Table 1, Figures 2-4). Powers (μv^2/Hz) of other waves (delta, theta, alpha and gamma1) were not statistically significant. Also, percentages of other waves (delta, theta, alpha, beta and gamma1) were not statistically significant.

Table 1: Powers of EEG frequency bands of the right (F2–F4) and left brain (F3–F7) hemispheres

Parameters	Left brain		Right brain		z	p
	Mean	SD	Mean	SD		
Total power (μv^2/Hz)	78.16	54.32	87.01	66.73	0.76	NS
Delta power (μv^2/Hz)	69.75	52.29	76.17	64.46	0.61	NS
Theta power (μv^2/Hz)	3.14	1.33	3.44	1.34	0.52	NS
Alpha power (μv^2/Hz)	1.42	0.89	1.57	1.04	0.77	NS
Beta power (μv^2/Hz)	2.41	1.25	3.69	2.34	2.23	0.04
Gamma1 power(μv^2/Hz)	0.89	0.66	1.21	1.11	1.42	NS
Gamma2 power (μv^2/Hz)	0.56	0.38	0.92	0.87	2.34	0.03
Gamma3 power (μv^2/Hz)	0.29	0.23	0.45	0.43	2.51	0.02

Note: SD–Standard deviation; NS–non-significant.

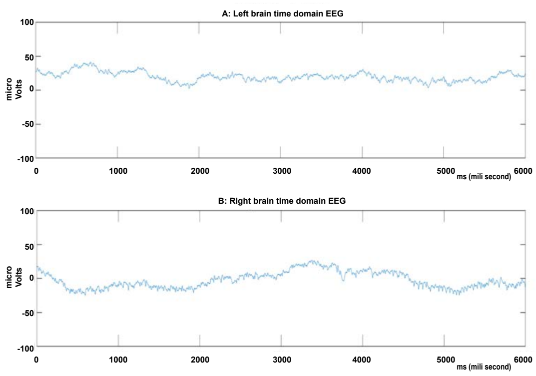

Figure 2: A) Left brain time domain EEG, B) Right brain time domain EEG

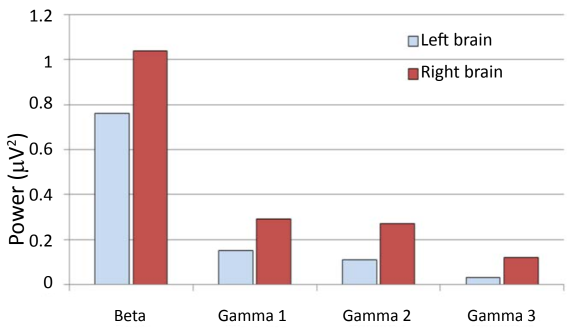

Figure 3: Left and right brain beta and gamma band powers

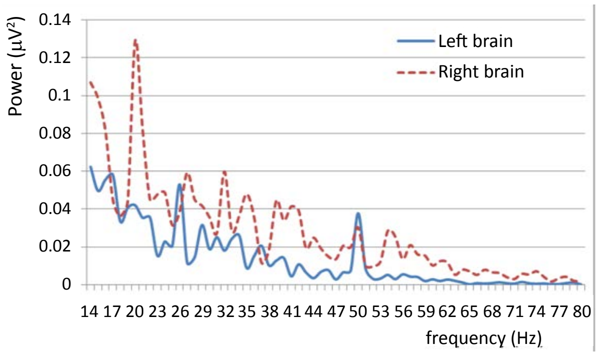

Figure 4: Left and right brain beta and gamma power spectral density

DISCUSSION

In the present study, there was a statistically significant difference between the right and left sides of brain in terms of gamma activity in the frontal EEG. This is the first study to report a right sided lateralization of frontal gamma activity in young healthy humans. This study did not find any statistically significant difference in other waves (alpha, beta, delta, and theta).

The majority of researches on brain asymmetry have focused on alpha waves and emotional lateralization [44–47] or right association of right-left hemispheric asymmetry with psychopathologies or neurodevelopmental disorders [48–54]. It is not exactly clear why interest has been directed towards alpha waves in emotional asymmetry of the brain. However, it can be suggested that the strong association of specific behavioral patterns with frontal activation of alpha waves reported by pioneering studies could be responsible. In addition, resting frontal activation of alpha waves is stable over time, especially among adult humans [54]. The studies on alpha waves asymmetry of the frontal cortex revealed approach (oriented, appetitive) and withdrawal motivational tendencies underlying emotion [45]. Greater left-sided activity is predominantly associated with approach motivational tendency and positive emotion, thereby activating behavior. In contrast, greater activity in the right brain is associated with withdrawal-motivational tendency and negative emotion such as fear and sadness [49]. Thus greater activity of right brain inhibits behavior [55].

Left-right brain asymmetry generally is associated with functional differences in the emotional, attentional, cognitive, sensorimotor domains of information processing [56]. Importantly, brain asymmetry studies provide data that could be used to predict or serve as a marker of behavioral responses, anxiety, mood or depressive disorder [57–59].

While studies on functional brain asymmetry mostly investigated the activity of alpha waves, little or almost nothing is known about the lateralization of gamma activity in the frontal brain in healthy humans. More so there are no reports on oscillatory gamma frontal asymmetry in healthy persons. The right sided lateralization of gamma waves observed in this study confirms previous study about the greater involvement of the right-brain in cognitive processes. A relatively recent report also identified a greater excitatory Schaffer gamma waves in the right hemisphere and hippocampal CA3–CA1 neurons [60]. Predominantly right sided activation of gamma waves in hippocampus has been reported elsewhere [61]. The dominance of these electrical waves in the right brain has considerable functional implication in real life. For instance, lateralized functions of the right-hemisphere, which include novel cognitive abilities, emotional, attentional processing, intuition, insight, mental updating, are all inevitable in successfully exploring our environment in real time [62–65]. Indeed the "gamma-band activity" is a multifunctional oscillatory brain wave that has a confirmed role in memory, selective attention, perception, motivation and other forms of behavior [66]. A relatively recent study also reported that a right-handed person exhibits superior visuospatial abilities, visual memory, and higher reaction time in visual memory tests [67]. The right handed participants in our study had greater right sided dominance of gamma activities, suggesting that the right brain is concerned mainly with memory, attention and other cognitive activities. This is keeping with previous reports about the relatively greater involvement of the right brain in cognitive processes. In contrast, left-lateralized functions of the hemisphere in right handed individuals include language and motor capabilities [62,68]. It should be mentioned, however that both hemispheres interact in an integrative manner to effectively drive neural processes [62,65]. Dysfunctions in brain lateralization are implicated in neuropsychiatric disorders including schizophrenia, and autism spectrum disorders [68].

Since the results of the present study have revealed that gamma activity is greater in the right hemisphere, unilateral stimulation of this hemisphere can be used to treat behavioral and cognitive deficits. Indeed stimulation of this hemisphere, complementary medicine techniques was found to increase gamma activity contra-laterally [69]. Thus the aim of behavioral and cognitive therapy should be centered on increasing the right brain EEG gamma activity with contralateral application of the therapy modalities.

Though the mechanisms of right sided gamma activity are not exactly clear, available evidences indicate, that gamma rhythm generation in particular, is related to dopamine signaling in the brain [70,71]. Right sided lateralization of gamma activity is associated with higher level of dopamine secretion in the right hemisphere than in the left hemisphere [72,73]. The mechanism for greater dopamine secretion in the right brain is thought to involve the activation of dopamine receptor type 4, which in turn affects the synchronization of electrical activities of fast-spiking interneurons via an NMDA receptor-dependent mechanism [70]. Previous studies have reported that these waves are mainly evident in the hippocampus, dentate gyrus, and CA1–CA3 system [74].

Given the facts mentioned above, a measure of gamma spectral power in the EEG can be used as a marker of cognitive and behavioral processing and also provide a useful measure to rate or evaluate the success of cognitive and behavioral therapy.

EEG noise was reduced in our study as much as possible by manually discarding EEG records with eyes movement and blink artifacts. Furthermore, 50 Hz band-stop filter was applied to EEG recording machine to eliminate 50 Hz power line noise. This study did not involve women due to certain physiological changes (e.g. active phase of the menstrual cycle) of the female body that may necessarily affect EEG tracing. Since there is gender difference in brain lateralization [75], future studies will test gender related features of brain asymmetry of gamma and other brain waves. Furthermore, investigation of developmental changes associated with EEG oscillations in different age groups will add meaningful results to the literature.

CONCLUSION

The brain electrical activity investigated in this study shows right lateralization only for gamma waves. No significant differences between the right and left brain were found for other brain waves. Right sided lateralization of gamma activity suggests that the right brain is concerned mainly with cognitive and behavioral processing, which confirms the results of previous researches about the greater involvement of the right brain in cognitive processes. Therefore gamma band activity can be used as an important marker of frontal activation in behavioral and cognitive training.

CONFLICT OF INTEREST

All authors declare that there is no conflict of interest.

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