Quantitative EEG parameters for monitoring and biofeedback during rehabilitation after stroke

Suresh Kanna, John Heng

***Abstract*— Stroke is one of the most disabling diseases that mankind has experienced. The disability caused after stroke can be effectively reduced when the patient is encouraged to undergo regular rehabilitation therapy.**

This paper studies the use of quantitative electroencephalogram (QEEG) feedback to motivate the patient during his rehabilitation phase by providing progressive information on neurological recovery.

Two different parameters are considered:

1. The alpha asymmetry of hemispheric stroke patients

2. The relative mean alpha band power and the delta alpha band power ratio (DAR).

QEEG can serve as a non-invasive, low cost alternative that can be used to measure the brain activity as the recovery progresses. It is not intended to replace the current gold standard of brain activity measurement (e.g. fMRI). The therapists can also use these parameters to design or modify therapy for specific patients. This paper explores the real-time monitoring of these parameters.

***Index Terms*— Brain plasticity, functional asymmetry, Quantitative EEG, Stroke Rehabilitation**

I. Introduction

This study is part of a long term project to develop a unified EEG/SEMG Multi-level interactive platform for interactive platform for stroke rehabilitation. Stroke rehabilitation is aimed at enabling the patient reach the highest level of independence. Structural and functional reorganization of the brain occurs during rehabilitation. This phenomenon is known as brain plasticity. Brain plasticity is the experience-dependent synaptic reorganization taking place in the brain due to environmental and pathological changes occurring in human beings [1].

Brain plasticity involves the production of different nerve growth factors and neurotrophic factors. Similarly endocrinal hormones also influence plasticity nature of the brain [2]. The syntheses of the nerve growth factors are suppressed when the patient is in a depressed state. Generally the antidepressant drugs are beneficial in promoting motor recovery as the drugs interact with the neurotoxins in the Central Nervous System (CNS). However few drugs have negatively influenced the motor recovery [3], [4].

The primary challenge for the therapists is to instill confidence in the patient by updating them on their recovery during the rehabilitation and recommending appropriate therapy for an individual. An emerging concept in brain plasticity is that the different activities of the human body compete for a territory in the human brain. During rehabilitation even a limited activity of the parts of the body other than the disabled activity would decrease the rate of recovery. So it is necessary for the therapists to design an appropriate therapy for obtaining optimum recovery [5] [6].

When the patient perceives the visible motor recovery, he stays motivated. However only after a considerable time there would be visible functional improvement. If the patient is able to monitor the brain activity and the functional recovery, then he can be motivated. EEG is a sensitive neurodiagnostic tool that can provide supporting information in identifying and monitoring different neurological deficit conditions [7], [8]. EEG Neurofeedback (NF) therapy is a technique that measures the real-time signal of the brain waves by the sensors present on the scalp. The signals obtained using the sensors gives information to the user about the brain activity, intensity of the signal, and coherence etc. EEG feedback training can be used to promote appropriate arousal and stability in the brain. Today's EEG feedback training has found application in different neurological disorder situations such as epilepsy, migraine and attention deficit hyperactivity disorder (ADHD) [9].

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Research has shown that NF helps reduce symptoms of several neurological and psychiatric disorders, with ongoing research currently investigating applications to other disorders and to the enhancement of non-disordered cognition. Researchers are trying to stimulate the generation of alpha and beta waves and inhibit the slow wave activity in stroke patients [10], [11], [12].

EEG feedback is often combined with psychotherapy to improve the recovery rate. Depending on the EEG feedback indices, the patient is generally trained to modify the brain activity.

As the patient/therapist is able to monitor the status of recovery attained during the rehabilitation through the feedback parameters, it increases the self confidence of the patient and thus recovery of the functional ability will be maximized. From the feedback parameters, the therapist is able to modify and redesign the therapy to optimize the recovery process. The Feedback parameters can also be used to control prosthesis for stroke rehabilitation. From this perspective it may be beneficial to identify the parameters that determine the recovery processes happening in the brain.

II. DISCUSSION

A. Brain asymmetry in stroke patients

Human Brain exhibits a marked symmetry across the sagittal plane between the two Hemispheres. Eventhough the two hemispheres are not exactly symmetrical, the degree of asymmetry between the two hemispheres is insignificant. The functions of one hemisphere are complemented by the functions of the other hemisphere. Left hemisphere is important for all forms of communication such as speaking and moving hands for showing signs and logical reasoning. Right hemisphere is important for perceiving auditory signals and imagination. Left hemisphere controls the right side of the body and processes the image right eye see. Similarly right hemisphere controls the opposite side of the body. So when a person is relaxed the functions of both the hemisphere will be symmetrical [13].

Stroke occurs when an infarct appears on a part of the brain due to the interruption of blood supply. This results in the asymmetry in the blood flow. The blood supply through an organ is proportional to the functions of the organ. As the blood supply through the infarction site decreases, the functions of the brain at the site of infarct are greatly reduced. Cerebral blood flow asymmetry is caused due to the blockage at the damaged site. This reduction in the blood-flow results in the reduced functions of the damaged site [14], [15]. As a result the functional asymmetry between the ipsilesional hemisphere and the contralesional hemisphere increases. The functions of the brain are reflected in the electroencephalogram. EEG activity has conventionally been described in terms of sets of frequency bands, usually defined as delta (1.5 to 3.5Hz), theta (3.5 to 7.5Hz), alpha (8 to 13Hz) and beta (13 to 30Hz). From the EEG parameters we can extract the information of the activity of the brain. The different types of waves are generated by the specific pacemakers present in the brain. Alpha rhythm is generated by the pacemaker neurons present in the thalamic system that is thought to interact with the neurotrophins in the alpha frequency range. Theta activity is generated in the limbic system and delta activity is generated from the thalamic region.

B. Relation between EEG parameters and disability scale

The EEG of the stroke patients differs significantly from that of the healthy persons. The alpha power and beta power of the ipsilesional hemisphere are significantly lower than that of contralesional hemisphere and the delta power and theta power of the ipsilesional hemisphere increases after stroke whereas in healthy controls there are no significant changes in the alpha, beta, theta and delta power over the two hemispheres. This result in slowing of the alpha waves in the ipsilesional hemisphere and therefore the slow wave generators becomes dominant. The mean alpha relative power has been reported to have significant correlation with the Activities of Daily Living (ADL) disability scale [16], [17]. The alpha band power and DAR is reported to have significant correlations with NIH Stroke Scale (NIHSS) [18], [20].

C. QEEG parameters to indicate stroke recovery

During rehabilitation, the alpha band power would increase and delta band power would decrease during recovery from stroke. The increase in the mean alpha relative power and the decrease in the mean DAR of the brain with respect to the baseline at the day of stroke indicate the functional diffusivity of the brain and hence it can indicate whether the brain is in plastic mode. The mean relative alpha power is calculated using the relation (1). Similarly the mean DAR is obtained using the relation (2). The mean relative alpha power of the control subjects will be higher than that of stroke patients. Similarly the mean DAR of the control subjects will be lesser than that of patients. Hence neurotherapy should be aimed at improving the relative alpha power and reducing the DAR to that of the healthy subjects of relevant age groups. In this perspective we are intended to create a profile of healthy subjects of relevant age group which can be used as a baseline for monitoring the functional improvement occurred in the brain.

$$\text{Mean relative alpha power} = \frac{\sum_{1}^{K} \sum_{8N/fs}^{13N/fs} P}{\sum_{1}^{K} \sum_{N/fs}^{25N/fs} P} \qquad (1)$$

$$\text{Mean DAR} = \frac{\sum_{1}^{K}\sum_{N/fs}^{4N/fs} P}{\sum_{1}^{K}\sum_{8N/fs}^{13N/fs} P} \quad (2)$$

For hemispheric stroke patients the affected hemisphere's function is significantly reduced as the alpha band power of the affected hemisphere of stroke patients is very less compared to that of unaffected hemisphere. Hence based on this information we developed an alpha asymmetry index (3) which is equal to the ratio of the difference between the relative alpha band powers of the two hemispheres to that of the sum of the relative alpha powers. As the patient recovers the functional asymmetry between the two hemispheres reduces. After recovery, the increase in the alpha band power in the affected hemisphere is expected to be higher than that of the unaffected hemisphere [19], [21]. So as the recovery takes place this alpha asymmetry index tends to decrease.

$$\text{Alpha asymmetry} = \frac{C^{\alpha} - I^{\alpha}}{C^{\alpha} + I^{\alpha}} \quad (3)$$

Where 'P' is the absolute power at a given frequency
'K' and 'N' represent the discrete number of channels and the NFFT.
'fs' represents the sampling frequency rate in Hertz.
'C^{α}' and 'I^{α}' are the mean relative alpha asymmetry of the contralesional and ipsilesional hemispheres respectively.

Apart from the above parameters peak alpha frequency (PAF) can be used in determining the emotional state of the mind. PAF is the frequency at which the magnitude of the alpha waves is maximal. PAF is found to be decreased during depression and during lower memory demands [20]. Similarly the functional difference between the right and left frontal cortex is indicative of emotions. During depression and negative emotions, the right frontal alpha power will be higher than that of the left [22].

We are designing the portable, low cost EEG device (Figure1) to capture and analyze the real-time EEG signal to constantly update the patient on his brain activity. We have developed the algorithm for real-time monitoring of the mean relative alpha power and the mean DAR of the EEG signal for a specified length of time. These parameters indicate the progress of recovery. Hence the patient would monitor the brain activity and its relation to functional recovery that can help the patient to modify the brain states and overcome deficiencies.

These Quantitative EEG parameters can be used to monitor repair mechanisms of focal abnormalities. Sensitivity and specificity of these parameters may not be comparable with the disability scale such as ADL scale as the disability scale is based on the observation of the patient, it will be a more accurate estimator of disability. However these QEEG feedbacks will be useful in the follow-up treatment of stroke and during rehabilitation.

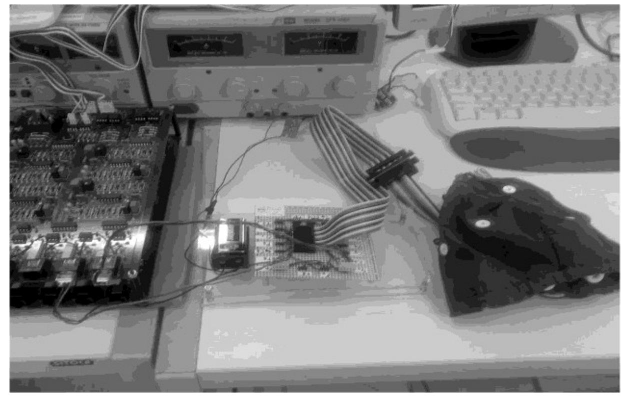


Fig.1 EEG device developed by the team connected to electrode cap

III. METHODS

A. Subjects

Five healthy subjects are assessed in this study. All the subjects do not have any prior neurological deficit. EEG recordings are taken during the daytime in a quiet room with the curtains closed. EEG samples are obtained from the subjects sitting at a relaxed position in the eyes closed condition with minimal artifacts (Figure2). The EEG sample between 16 to 30 seconds is considered for study for all the subjects.

B. Signal acquisition and processing

EEG recordings are captured using Mindset-24R. The electrodes are placed based on the international 10-20 system at Fp1, F7, F3,C3, T3, T5, P3, O1, Pz, Cz, Fz, O2, P4, T6, T4, C4, F4, F8, Fp2 with the Fpz grounded and ear electrode as references. The sampling rate was 256Hz and impedance was kept below 5kΩ using abrasive skin preparation gel.

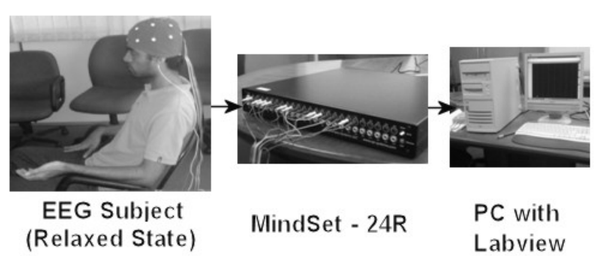


Fig.2 Subject sitting in relaxed state position and our EEG system Setup

The raw EEG signals obtained are then processed offline using NI Labview software. The EEG signals are band filtered in the frequency range of 1Hz to 25Hz. The power spectrum is obtained by using Spectral Measurements.vi (Virtual instrument) of Labview employing Hanning Window with 0.5Hz frequency resolution. Spectral

Measurements.vi uses Fast Fourier Transform based analysis to estimate the Spectral Power at a given frequency.

C. Data analysis algorithm development

EEG signal analysis is performed from the collected data (offline). The algorithm is designed to analyze the signal of specified length with the experimenter manually adjusting the starting sequence and the total length of the sequence. The data are analyzed at a frequency resolution of 0.5 Hz. The signals are regenerated from the collected data using build waveform function in Labview 8.0. Inorder to remove the noise effects contributed by high frequency waves, the regenerated signals are processed to remove frequency waves above 25 Hz by using filter express VI with the band pass filtering type in the range of 1 to 25 Hz. The fast fourier transform (FFT) based analysis is employed in determining the power spectrum of the filtered signals of the specified length.

The absolute power in the frequency range of 1 to 25 Hz of all the channels is calculated. Similarly the absolute power in the alpha frequency range of 8 to 13 Hz is calculated. The mean alpha relative power is obtained as the ratio of the sum of the absolute power in the alpha frequency range from all channels to that of the absolute power in the entire frequency range (1 to 25 Hz). Similarly the mean DAR is calculated by measuring the ratio of the total absolute power in the delta frequency range to that of the alpha frequency range.

We have developed an algorithm for online capturing of signal that can provide the real-time feedback of the patient. This VI would be incorporated to the EEG device which we designed to capture the EEG signal.

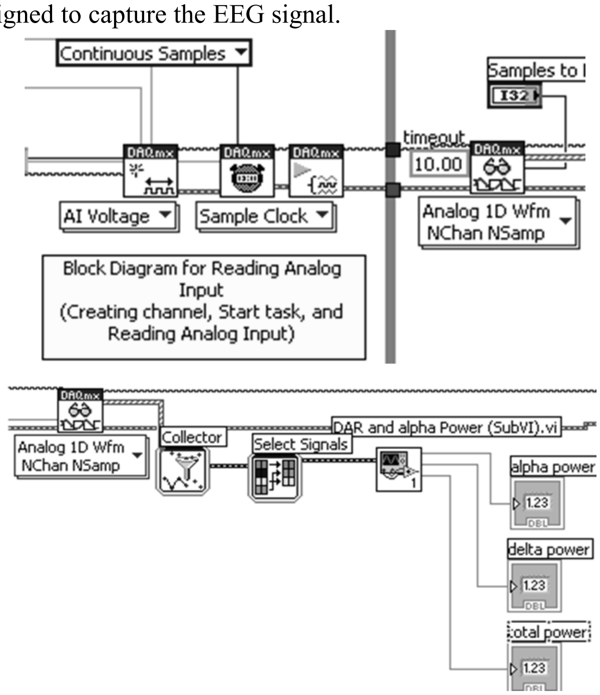


Fig3. Block Diagram of Virtual Instrument (VI) used in real-time monitoring of EEG signals

TABLE I
QEEG PARAMETERS OF DIFFERENT HEALTHY SUBJECTS

Healthy Subjects	Mean DAR	Mean relative alpha power
1	0.19	0.48
2	0.51	0.44
3	0.38	0.45
4	0.72	0.33
5	0.19	0.54

IV. RESULTS

A. QEEG parameters of healthy subjects

The EEG signals stored in the time domain is transformed into frequency domain based on the power distribution of each frequency. The power spectrum of a pair of channels T3 & T4 of the healthy subject is shown in figure4.

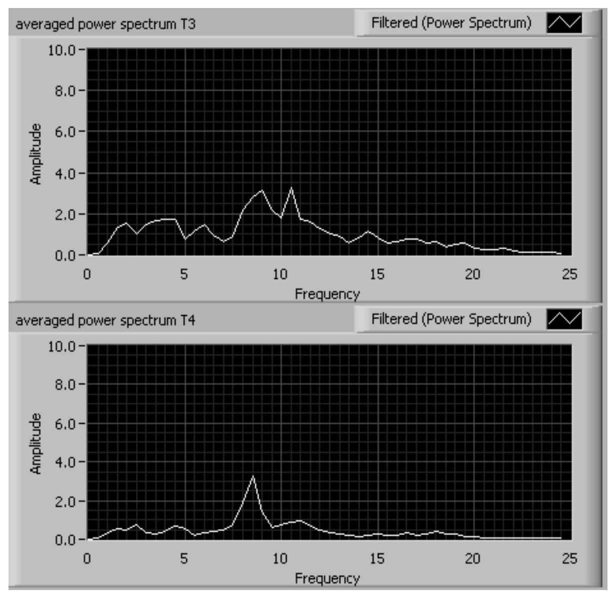


Fig.4 Power spectrum of a healthy subject

The mean relative alpha power and mean delta:alpha power ratio (DAR) of the healthy subjects are shown in table I.

The parameters are calculated based on the channels C3, C4, T3, and T4. The mean of the mean relative alpha power and DAR of the healthy subjects is found to be 0.4 and 0.56 respectively.

The functional asymmetry of the healthy subjects is found to vary from 0 to 0.09. The functional asymmetry index of the healthy subjects are calculated for 2 channel pairs and 8 channel pairs as shown in table II. From the results we can conclude that the sensitivity of the index varies with the number and location of channels considered.

TABLE II
FUNCTIONAL ASYMMETRY OF THE HEALTHY SUBJECTS

Healthy subjects	Functional asymmetry Index	
	2 channel pairs	8 channel pairs
1	0.087	0.019
2	0.053	0.034
3	0.043	0.092
4	0.017	0.068
5	0.046	0.050

B. *QEEG parameters of stroke patients*

The EEG data on stroke patients are obtained from the paper titled "EEG recordings during the course of stroke recovery" (19). They acquired the EEG within one month from the onset of stroke which they used as baseline and after 90 and 180 days from baseline. We considered the EEG obtained during baseline and on 90 days from baseline for study. The data is presented in table III.

TABLE III
EEG DATA OF THE STROKE PATIENT

Parameters	Injured hemisphere		Uninjured hemisphere		Mean of two hemispheres	
	T	T90	T	T90	T	T90
DAR	6.4	2.7	2.0	1.43	3.4	1.95
Relative alpha power	0.1	0.21	0.21	0.23	0.15	0.22
Functional asymmetry					0.36	0.22

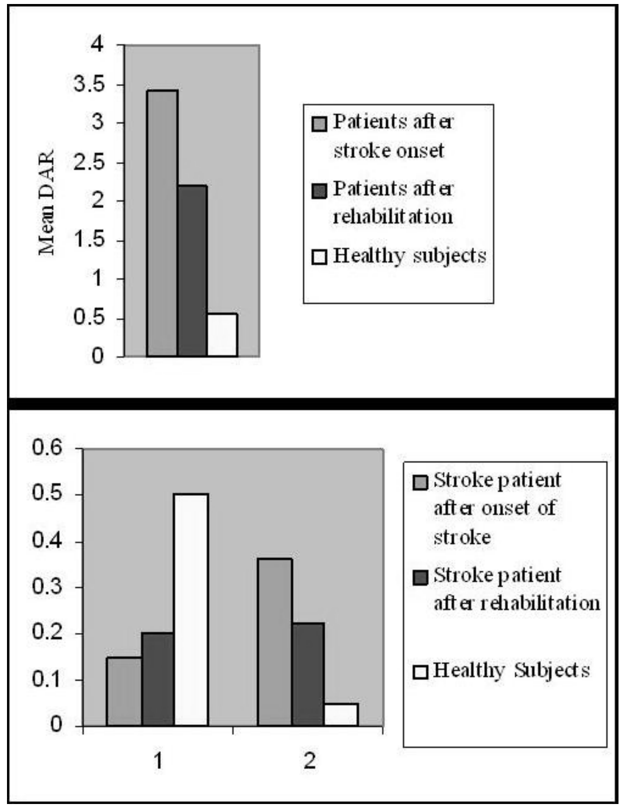
Based on these data, we calculated the QEEG parameters mean DAR, mean relative alpha power and functional asymmetry. The results are given in table IV.

As expected the mean relative alpha power increases with rehabilitation and mean DAR decreases with rehabilitation. The increase in relative alpha power and the decrease in the DAR of the injured hemisphere is more than that of the uninjured hemisphere. The functional asymmetry of the stroke patients' is found to decrease with rehabilitation (figure5).

TABLE IV
QEEG PARAMETERS OF PATIENT BASED ON STROKE ONSET AND RECOVERY

Parameters	Injured hemisphere		Uninjured hemisphere	
	T	T90	T	T90
Relative delta power	0.64	0.51	0.42	0.38
Relative theta power	0.16	0.16	0.17	0.18
Relative alpha power	0.1	0.16	0.21	0.25
Relative beta power	0.06	0.10	0.01	0.01

As the alpha power of the injured hemisphere has increased considerably higher than that of the uninjured hemisphere, the asymmetry is decreased.



Here '1' represents relative alpha power and '2' represents functional asymmetry

Fig.5 Variation of QEEG parameters for healthy individual, patients during Stroke onset, patient after rehabilitation

V. CONCLUSION AND FUTURE WORK

The healthy subjects are found to have high relative alpha power than that of the stroke patients. The stroke patient recovery can be assessed by relative alpha power as this value would increase after recovery. The relative alpha power of the uninjured hemisphere of stroke patient differs from that of healthy subjects. The mean DAR of the healthy subjects is less than that of the stroke patient. The mean DAR of the uninjured hemisphere is found to be higher than that of the healthy subjects. The alpha asymmetry index of the stroke patient is found to be higher than that of healthy subjects.

The QEEG parameters promise to be useful indicator of stroke recovery in this initial study. We are investigating the study on more healthy subjects to create a profile of healthy subjects based on different age groups for both genders. The profile of healthy person can serve as a better reference to quantify and improve the recovery during rehabilitation phase. We are designing low-cost EEG tool which can provide feedback to the patient about the functional improvement obtained during the rehabilitation.

The IRB application for testing on stroke patients is currently under review at Tan Tock Seng Hospital, Singapore.

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