A Comparison Study of Synchronization Measures in Accessing the Neural Correlates of Selective Attention Using Electroencephalogram (EEG)

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To Amma, Appa and Akka. The reason for who I am.

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ABSTRACT

Friston models the brain as a large number of interacting nonlinear dynamical systems. According to the model, the interactions between the subsystems can be linear as well as non linear. Nonlinear interactions between brain regions may reflect the unstable nature of the brain dynamics. This project is to study and compare several measures in analyzing the synchronization reflected in the electroencephalographic (EEG) signals. In particular, a derivation of EEG called auditory late response (ALR) which is related to attention will be used in the investigation. There are several types of synchronization measures that have been proposed in EEG processing. These methods can be categorized into linear and non-linear methods. Among them are coherence, wavelet coherence, nonlinear interdependence and wavelet phase synchronization. It is unclear on the performance of each mentioned measures in examining the neural correlates of selective attention that reflected in auditory late response. By the end of the project, it is concluded the wavelet-phase stability is feasible to be used as objective evaluation compared to magnitude-squared coherence, wavelet coherence, wavelet-phase stability and non linear interdependence in the study of synchronization measures in accessing the neural correlates of selective attention using EEG.

ABSTRAK

Friston memodelkan otak sebagai sistem dinamik yang tidak berkadar terus yang luas dan boleh berinteraksi. Berdasarkan model in, perinteraksian di antara sistem ada kemungkinan untuk berkadar terus dan berkadar songsang. Interaksi yang berkadar songsang di antara wilayah otak menggambarkan ciri-ciri ketidakstabilan sistem dinamik otak. Projek ini dilaksanakan untuk mempelajari dan membandingkan beberapa ukuran isyarat electroencephalogram(EEG). Khususnya terbitan EEG yang dikenali sebagai auditory late response (ALR) yang berkaitan dengan perhatian akan digunakan dalam penyiasatan ini. Ukuran yang paling sesuai akan dicadangkan untuk analisa data. Terdapat beberapa ukuran penyegerakan yang telah dicadangkan untuk pemprosesan isyarat. Cara-cara ukuran tersebut boleh dikategorikan sebagai cara pengiraan linear dan bukan linear. Antara cara cara tersebut adalah kepaduan, kepaduan 'wavelet' , saling pergantungan yang tidak linear dan maklumat bersama. Ianya tidak pasti mengenai prestasi ukuran yang telah dinyatakan yang tidak begitu nyata dalam penyiasatan hubung kait neural dalam perhatian selektif yang mencerminkan dalam respons auditori lewat. Tujuan utama projek ini adalah untuk mengkaji dan membandingkan beberapa langkah untuk mengukur penyegerakan dalam otak dengan fungsi perhatian selektif dengan menggunakan EEG. Pada akhir projek, Ia membuat kesimpulan kestabilan ombak fasa layak untuk digunakan sebagai penilaian objektif berbanding dengan magnitud-kuasa kepaduan, ombak kepaduan, kestabilan ombak fasa dan saling bergantung bukan linear dalam kajian langkah penyegerakan dalam mengakses hubung kait neural perhatian selektif menggunakan EEG.

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ALR	-	Auditory Late Response
EEG	-	Electroencephalogram
ERP	-	Event Related Potential
GUI	-	Graphical User Interface

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CHAPTER 1

INTRODUCTION

Friston models the brain as a large number of interacting nonlinear dynamical systems. According to the model, the interactions between the subsystems can be linear as well as non linear. Nonlinear interactions between brain regions may reflect the unstable nature of the brain dynamics. This project is executed to study and compare several measures on the electroencephalographic (EEG) signals. In particular, a derviation of EEG called auditory late response (ALR) which is related to attention will be used in the investigation. The most suitable measure will be proposed based on the performance analysis of the data. There are several types of synchronization measures that have been proposed in EEG processing. These methods can be categorized into linear and non-linear methods. Among them are coherence, wavelet coherence, nonlinear interdependence and wavelet-phase stability. It is unclear on the performance of each mentioned measures in examining the neural correlates of selective attention that reflected in auditory late response. The main aim of the project is to study and to compare several measures for quantifying the synchronization in the brain due to selective attention task by using EEG.

The concept of synchronization goes back to the observation of interactions between two pendulum clocks by Huygens. Synchronization of oscillatory systems has been widely studied but it was not until recently that synchronization between chaotic motions received attention. A first push in this direction was the observation of identical synchronization of chaotic systems but more interesting has been the idea of a “generalized synchronization” relationship as a mapping between non-identical systems. One of these applications is to the study of electroencephalographic (EEG) signals, where synchronization phenomena have been increasingly recognized as a key feature for establishing the communication between different regions of the brain [1].

Selective attention is defined as the cognitive process of selectively concentrating on one aspect of the environment while ignoring other things. Without realizing it, we are constantly judging to which stimuli we will pay attention to and the stimuli that we will ignore due to limited resources of cognitive processing.

1.1 Problem Statement

There are several types of synchronization measures that have been proposed in EEG processing. These methods can be categorized into linear and non-linear methods. Among them are coherence, wavelet coherence, nonlinear interdependence, mutual information and phase synchronization, neural synchronization stability and phase locking index. It is unclear on the performance of each mentioned measures in examining the neural correlates of selective attention that reflected in auditory late response.

In this study, four methods will be analyzed; the methods are magnitude squared coherence, wavelet coherence, wavelet-phase stability and non linear interdependence. The best method among these will be proposed to be the most suitable for quantifying the synchronization in the brain due to selective attention task by using EEG.

1.2 Objective

The main objective of the project is to study and to compare several measures for quantifying the synchronization in the brain due to selective attention task by using EEG. To achieve the aim, few synchronization methods' performance analysis of the data will be analyzed. Finally, the most suitable method will be recommended. The synchronization measures that are to be analyzed are as below:

i. Magnitude-Squared Coherence
ii. Wavelet Coherence
iii. Nonlinear Interdependence
iv. Wavelet-Phase Stability

1.3 Scope of Work

The Project will focus on implementation of signal processing methods to access neural synchronization in the brain though EEG signal. The synchronization methods and the description of each method is described below:

- **Coherence:** also called magnitude squared coherence/frequency coherence. Linear correlations can also be quantified in the frequency domain by means of the cross spectrum
- **Wavelet coherence:** Wavelet coherence is a method for analyzing the coherence and phase lag between two time series as a function of both time and frequency.
- **Nonlinear interdependences:** It is related to the method of mutual false nearest neighbours but unlike this method it does not assume a strict functional relationship between the dynamics of the underlying systems X and Y.
- **Wavelet-phase stability:** introduced to quantify in a statistical sense the phase synchronization of two signals. It has been commonly used to process bio signals.

1.4 Thesis Organization

The thesis is organized as below.

- Chapter 1 (Introduction) - In this chapter, the problem statement is assured. With that stated, the objectives of the thesis are identified. The scope of work is also explained. Finally the thesis organization is listed.
- Chapter 2 (Literature Review) - This chapter elaborates the theories of selective attention. The Electroencephalogram (EEG) and Event Related Potential (ERP) are analyzed and theories regarding these terms are summarized.
- Chapter 3 (Methodology) - In this chapter, each method is analyzed in terms of its mathematical formula and its theory. Also, in this chapter, how the data is gathered is explained.
- Chapter 4 (Results and Discussion) - In this chapter, the results are listed down as per computed using the Matlab software. The formulas applied are as stated in Chapter 3. With results, the corresponding discussions are stated.
- Chapter 5 (Conclusion) - In this chapter, the thesis outcomes are concluded.

CHAPTER 2

LITERATURE REVIEW

2.1 Theories of Selective Attention

According to the general understanding, attention is a process of decision where a certain detail of event is admitted into consciousness. It is a process of extracting certain information from the surrounding despite the presence of so many other prominent and minute events and occurrences. In theory, the choice of information that is attended to may be arbitrary. However, humans are capable of making a selection of preference as well. For example, a student in a lecture room will be able to concentrate on the lecture given despite all the other happening around him. This mechanism which allows the student to specifically focus on the lecture is termed as selective attention.

In general, selective attention can be defined as a phenomenon where a particular stimulus or stimuli in the surrounding is absorbed despite of the occurrence and existence of other stimuli. This particular stimulus or stimuli may hold a higher rank of immediate priority compared to other stimulus. The famous *cocktail party effect* is a typical auditory example of one such situation. This example depicts of how a person is able to listen to one specific speaker while ignoring all the other conversation by the other guests and other occurrence in the event. Thus, a reliable communication process can occur in a chaotic environment [2].

However, the *cocktail party effect* can be observed as a structural model of attention where the concept of attention is assumed to be able to only act on one particular task at a given time which concedes that attention has a very narrow competence. According to this model, there are limitations for a parallel processing capacity beyond the bottleneck which relates to attention. The prime concern is to spot the occurrence of the bottleneck which implies the processing level of the auditory inputs from various sources varies according to its relevance. This issue has been discussed into a ongoing remained controversy known as early versus late selection.

Early selection theories state that there is an early filtering mechanism by which channels of irrelevant input could be attenuated or even rejected prior to full sensory processing.

Related to the topic, [3] have suggested that human listeners are able to confine their attention to a single auditory message within a noisy environment and to disregard equally intense but "irrelevant sound". This idea pictures attention to a single element while ignoring other components related or unrelated to the subject.

However, (Picton, 1974) recommends that a number of elementary features are represented in parallel in different topographic maps which results in the existence of a selective mapping from the early topographic representation into a more central topographic. The bottom line is that the idea implies that the function of selective attention is to fuse information from different maps into one coherent whole.

2.2 Electroencephalogram (EEG) and Event Related Potential (ERP)

An event-related potential (ERP) is the measured brain response that is the direct result of a specific sensory, cognitive, or motor event [5]. More formally, it is any stereotyped electrophysiological response to a stimulus. The study of the brain in this way provides a non invasive means of evaluating brain functioning in patients with cognitive diseases. ERPs are measured with electroencephalography (EEG).

2.2.1 Electroencephalogram (EEG)

The EEG (popularly known as brain waves) represents the electrical activity of the brain. A few important aspects of the organization of the brain are as follows: the main parts of the brain are the cerebrum, the cerebellum, the brain stem (including the midbrain, pons medulla, and the reticular formation) and the thalamus (between the midbrain and the hemispheres).

The cerebrum is divided into two hemispheres, separated by a longitudinal fissure across which there is a large connective band of fibres known as the corpus callosum. The outer surface of the cerebral hemispheres, known as the cerebral cortex, is composed of neurons (grey matter) in convoluted patterns, and separated into regions by fissures (sulci). Beneath the cortex lie nerve fibres that lead to other part of the brain and the body (white matter).

Cortical potentials are generated due to excitatory and inhibitory post-synaptic potentials developed by cell bodies and dendrites of pyramidal neurons. Physiological control processes, thought processes, and external stimuli generate signals in the corresponding parts of the brain that may be recorded at the scalp using surface electrodes. The scalp EEG is an average of the multifarious activities of many zones of the cortical surface beneath the electrode.

In clinical practice, several channels of the EEG are recorded simultaneously from various locations on the scalp for comparative analysis of activities in different regions of the brain [6].

With EEG it is possible to get a glimpse of neural activity from the whole cortex. This makes EEG a very potent tool to study the interaction between brain areas and different cortical networks. It is well–known that EEGs offer three distinct advantages:

a) **Noninvasive**. This implies that it can be used easily and without risk in humans. Of course, EEGs can also be acquired by inserting a microelectrode into the brain and is, therefore, limited to nonhuman species (or, in rare cases, human neurosurgery patients). However, the results from primate recordings are sometimes difficult to compare with human recordings due to the fact that human brains are different from primate brains.

b) **Excellent temporal resolution**. EEGs have a temporal resolution of 1 ms (or even better under optimal conditions) and its spectral content being in the range from below 1 Hz up to approximately 100 Hz, thus enabling the study of the dynamics of brain processes. These features make the EEG a very accessible and useful tool. It is particularly interesting for the analysis of high level brain processes that arise from the activity of large cell assemblies and may be poorly reflected by single neuron properties. Moreover, such processes can be well localized in time and even be reflected in time varying patterns (e.g., brain oscillations) that are faster than the time resolution of imaging techniques.

c) **Inexpensive**. EEG recording is much less expensive than the other functional techniques (e.g., functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and even single unit recording) and therefore very practicable.

Not only has that, EEGs also had two advantages compared to behavioural testing in the four contexts of attention research. First, they provide a continuous measure of processing between a stimulus and a response, making it possible to determine the stage or stages of processing that are influenced by attention. Second, EEGs provide a means of covertly measuring the processing of a stimulus, i.e., without requiring an overt response, which is very useful for assessing the processing of unattended stimuli.

2.2.2 Event Related Potentials

The term event related potential is more commonly and more likely to be termed as evoked potential, and includes the EEG in response to light, sound, electrical or other external stimuli. Short-latency ERPs are predominantly dependent upon the physical characteristics of the stimulus, whereas longer-latency ERPs are predominantly influenced by the conditions of presentation of the stimuli.

Auditory selective attention in humans has been investigated by using EEG and ERP. These recordings are able to noninvasively track with high temporal resolution the brain activity associated with different types of stimulus events. By analyzing changes in the ERPs as a function of the direction of attention, one can make inferences about the timing, level of processing, and anatonomical location of stimulus selection processes in the brain [7].

2.3 Neural Correlates of Auditory Selective Attention

The well–studied human auditory ERP components are N1, a negative component at around 100 ms (thus also called N100) and P2, subsequent positive wave peak at 160–200 ms (also called P200). In an early study of selective attention by, the N1 and P2 waves are considerably larger when the sound is to be attended than when it is to be ignored. In an intermodal attention task, the click–evoked N1–