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Cognitive Workload Assessment Using Event Related Potential Paradigm

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Abstract—*Here a pilot study is being presented to find unique brain wave patterns by the brain when the person encounters one particular kind of stimulus. In this context, the extraction of an ERP (Event related potential) has been proved to be extremely beneficial. An ERP is the measured brain response that is the direct result of some specific cognitive, sensory or motor event. In the study of ERP externally, it was found that the "P300"component extracted was elicited when the brain encountered a stimulus of special significance. The P300 component is a positive voltage potential maximal at the midline parietal scalp (Pz in the international 10-20 system) that peaks at 300 or more milliseconds at the onset of the eliciting event. The subject was given a set of alphanumeric characters to remember and he/she was asked to remember the string at the end of the stimuli presentation. Then the stimuli presentation was carried out. The sampling rate was kept to 256 SPS. Results indicated that problem outcomes could be correctly predicted from the combination of attention with cognitive workload with stimulus.*

Keywords: *Event related potential, P300, N100, Independent component analysis, PSD*

1. INTRODUCTION

The event related potential has always been regarded as an index of information processing for executive functions like selective attention, working memory, spatial memory etc. An event related potential is the measured brain response that is the direct result of some sensory, motor or cognitive event [2]. The event related potential can be easily measured by using the EEG (Electroencephalography). But since the EEG measures thousands of ongoing brain activities simultaneously, it is very difficult to measure the brain response to one single stimulus or event of interest in one single trial itself [1]. Henceforth, it is highly recommended that if at all the event related potential is to be extracted out from an EEG signal, then the EEG signal is to be acquired over a number of trials, then a suitable averaging technique is to be applied to it so that the relevant waveforms remain, then the ERP components can be extracted out for the required time frame [2].

The ERP waveform can be quantitatively characterized across three main dimensions: amplitude, latency and scalp distributions. In addition, an ERP signal may also be analyzed with respect to the relative latencies between its subcomponents [4]. The amplitude provides an index of the extent of neural activity (and how it responds functionally to experimental variables), the latency (i.e., the time point at which peak amplitude occurs) reveals the timing of this activation, and the scalp distribution provides the pattern of the voltage gradient of a component over the scalp at any time instant.

An analysis of the event related potentials, such as visual event potentials (also called visually evoked potentials (VEP)), within the EEG signals is important in the clinical diagnosis of many psychiatric diseases such as dementia. Alzheimer's disease, the most common cause of dementia, is a degenerative disease of the cerebral cortex and subcortical structures [3]. The relative sensitivity of the pathological changes in the associated cortex accounts for the clinical finding of diminished visual interpretation skills with normal visual acuity. Impairment of visuocognitive skills often happens with this disease. This means the patient may have difficulties with many complex visual tasks, such as tracing a target Fig. embedded in a more complex Fig. or identifying single letters that are presented briefly and followed by a pattern making stimulus. A specific indicator of dementia is the information obtained by using an ERP. The scalp recorded ERP voltage activity reflects the summation of both cortical and subcortical neural activity within each time window. The current source density maps are useful for forming hypotheses about the neural sources within the superficial cortex.

1a. Components of an ERP:

The different components of an ERP include:

1) N100: It is a large negative going ERP, which peaks between 80-120 ms. after the onset of a stimulus. It is usually prominent in the Fronto-central region of the scalp. It shows a link to a person's arousal & selective attention. Moreover, the N100 component is a more direct measure of the working memory.

2) The visual P200: Is a waveform component which has a positive going peak at around 150-275 ms. After the onset of a particular stimulus. It is usually prominent in the centro-frontal region or the parieto-occipital region. P200 is typically elicited as a part of the normal response to visual stimuli and has been studied in relation to visual search and attention, language context information and repetition effects.

3) LPC: The late positive complex has been important in studies related to explicit recognition memory. It peaks at around 400 to 500 ms.

4) P300: P300 is regarded as an index of information processing for selective attention and target discrimination. P300 is usually maximal at the parietal region (Pz). The positive going component peaks at around 300 ms. after the onset of a stimulus. It is usually elicited in a oddball paradigm i.e., a subject spots an infrequently occurring target stimuli among a bunch of frequently appearing non target stimuli.

2. METHODOLOGY DESIGN:

The pilot study was carried out on 5 subjects in a healthy state (mean age=24.8 years). The basic protocol followed in the pilot study were as follows:

1) The subject was given a set of alphanumeric characters to remember (e.g., AQ6713#$SXJQ) and he/she was asked to remember the string at the end of the stimuli presentation.
2) Then the stimuli presentation was carried out. The stimuli presentation was based on different emotions that a person perceives. Among a set of emotions, he/she was asked to pick out what he/she thought it was a "NEUTRAL" emotion and act accordingly (i.e., neutral emotion becomes the 'GO' event and the plethora of other emotions becomes the 'NOGO' event).
3) The stimuli presentation was in such a way that the "NEUTRAL" emotion was positioned in between 4-5 other categories of emotions. This would elicit a P300 signal for that particular "GO" stimuli.
4) The data acquisition was done using Nexus-10 Neurofeedback instrument. The recordings were done by placing the electrodes on Pz and Cz location (since the P300 signal is maximal at the parietal site). Stimulus duration was set to be 500ms and inter-stimulus interval was 1800ms. A total of 5 trials were taken per subject.
5) After every trial, the cognitive workload was increased.
6) In exporting the ERP components, the theta amplitude, alpha amplitude and the beta amplitude were considered. The sample rate was kept to 256 SPS.
7) Before starting off the actual experiment, baseline data was acquired. In the 24 seconds stimuli presentation, around 17 markers were sent to extract the ERP component.

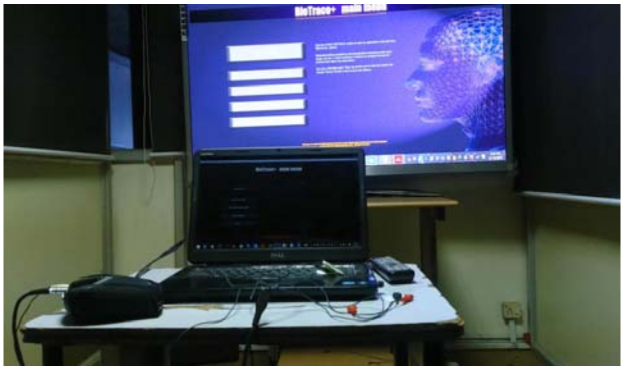

Fig. 1: Experimental setup

3. ERP AND ICA

ICA has also been used for the detection of ERP components by Winograd *et al*. Their work involved the application of a matched filter together with averaging and using a threshold technique for detecting the existence of the P300 signals. The IC corresponding to the P300 source is selected and segmented to form overlapping segments from 100 to 600 ms. each segment is passed through a matched filter to give one feature that represents the maximum correlation between the segment and the average P300 template. However, the very obvious problem with this method is that the ICA system is very likely to be underdetermined (i.e. the number of sources is more than the number of sensors or observations) since only three mixtures are used. In this case the independent source signals are not separable.

4. WAVELET DENOISING

The original ERP is to be decomposed in to different echelons of high and low frequency components. The level of decomposition is selected according to the frequency band of EEG signal. It is recommended that the signal is to be decomposed up to 6 levels. Noisy components were removed by thresholding process by setting a soft threshold. Reconstruction was performed by convolution of all the details and the last approximation with the inverse filter.

5. FEATURE EXTRACTION

Power spectral density (PSD)

The estimated PSD provides information about the structure of the random process which can be used for modelling, prediction or filtering. Power spectrum estimation can be divided into two categories, Non-parametric and parametric method. They are based on the estimation of autocorrelation sequence of the random process from the observed data. In this project, Welch method is used for PSD extraction. PSD is to be extracted for both alpha and beta bands. In the Welch method for calculating PSD, data is first segmented and then windowed prior to calculating PSD of the signal. The modified periodogram is given by

$$I_L^i(w) = \frac{1}{LU}\sum_{m=0}^{L-1} |(x_i(n) \times w(n) \times \exp^{-jwn}|^2$$

L is length of signal and U is normalization factor.

$$p_{xx}^w(w) = \frac{1}{m}\sum_{i=0}^{M-1} I_L^i(w)$$

$p_{xx}^w(w)$ is the welch power spectrum. M is the number of data segments.

Energy:

The second feature to be extracted is the energy of the signal. Energy of the signal is defined as sum of square of the signal at each instant of time. Here energy of ERP signal was extracted.

$$\sum_{t=-\infty}^{\infty} (f(t)^2) = E1$$

Entropy:

Entropy is a measure of randomness. Large value of entropy means signal is more complex and irregular.

6. RESULTS

It was crystal clear from the analysis that whenever the person encountered a familiar stimulus, the amplitude of the P300 signal was distinctively high. The amplitude of P300 for a "GO" stimulus was found to be much greater than that for a "NOGO" stimulus. As the cognitive workload was increased, the subject tended to concentrate more on the string to remember than the stimuli presentation. It was found that the ERP analysis was giving out chaotic values. It was also very evident that when the cognitive workload of working memory was not applied, the N100 component exhibited a frenzied amplitude.

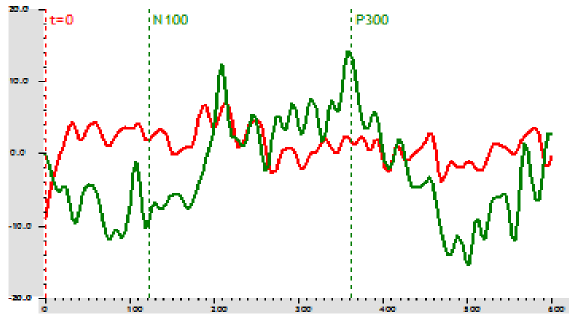

Fig. 1: The P300 and N100 elicited with low workload and relevant and irrelevant information (GO and NOGO events)

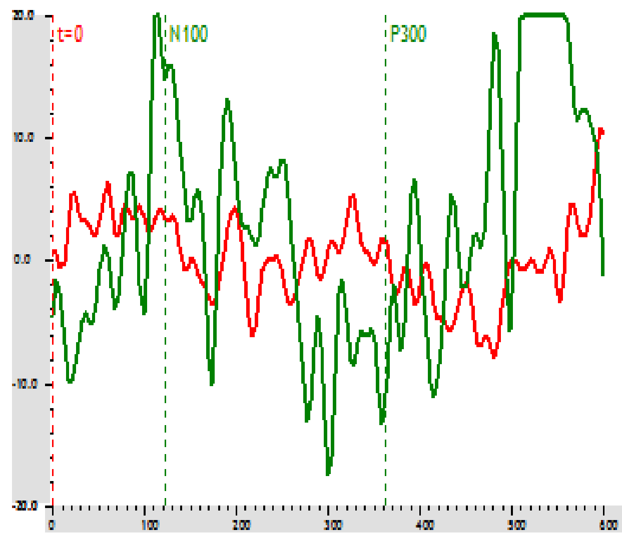

Fig. 2: The P300 and N100 signal elicited with high workload

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