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WAVELET FEATURE EXTRACTION AND J48 DECISION TREE CLASSIFICATION OF AUDITORY LATE RESPONSE (ALR) ELICITED BY TRANSCRANIAL MAGNETIC STIMULATION

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ABSTRACT

Nowadays, transcranial magnetic stimulation (TMS) has been used to treat major depression and migraine. Integrating transcranial magnetic stimulation and electroencephalogram (TMS - EEG) may provide beneficial information. This paper introduces the experimental design, experimental setup and experimental procedures to differentiate the repetitive transcranial magnetic stimulation (rTMS) and without TMS over N100 (N1) and P200 (P2) peaks with regards to auditory attention. New experimental design, setup and procedures are developed to elicit N1 and P2 through the recording of EEG signal with the excitation of neurons from TMS and pure tones. Wavelet transform is implemented as feature extraction for the selected data. Four features are used for the classification. The classification is based on J48 decision tree performed using WEKA to distinguish between without TMS and rTMS. The result between without TMS and rTMS (in attention condition) showed 98.85% accuracy meanwhile between without TMS and rTMS (no attention condition) showed 99.46% accuracy.

Keywords: TMS-EEG, N100, P200, wavelet transform, J48 decision tree.

INTRODUCTION

Transcranial magnetic stimulation (TMS) is known as non-invasive method and able to excite the neurons (brain cells) in the brain with its changing magnetic field. TMS comprises of three stimulation types - single pulse TMS (sTMS), paired pulse TMS (pTMS) and repetitive TMS (rTMS). The one that is used for treatment of major depression and migraine is rTMS. The electroencephalography is a well-known non-invasive method and possess high temporal resolution. Integrating TMS – EEG provide many advantages. For instances, able to find the relation of brain area affected by the task given and also interaction between one area with another area in the brain.

Selective attention is the ability to distinguish the relevant information with irrelevant information. It allows people to choose selectively their focus on different objects, stimulus or information that being conveyed in the environment. William James (1980) named "passive attention" towards so called distracting stimuli which can divert the attention [1]. Two theories that give influential to community are divided into early selection theory and late selection theory.

Event related potential (ERP) is brain responses evoked by external physical stimulation. In response to auditory stimulation, the EEG signal is known as auditory evoked potential (AEP). AEP can be categorized in three which are auditory brainstem response (ABR), middle latency response (MLR) and auditory late response (ALR). ALR is associate with N100 (N1) and P200 (P2) peak based on time. It is known as time-locked. The occurrence of N1 and P2 usually approximate at 100ms and at the range 150-275ms [2]. Both of them are generated from auditory cortex.

Wavelet transform is known as a suitable method to extract features from raw data in non-stationary signal. Thus, in this study wavelet transform is applied at the EEG signal for feature extraction. It allows the use of variable sized windows to give flexible time-frequency representation. There are many soft computing modelling (i.e. support vector machine (SVM), linear discriminant analysis (LDA)) for EEG signal analysis. Decision tree available in Waikato Environment for Knowledge Analysis (WEKA) is widely used and it is one of the most popular method of inductive inference algorithm. WEKA is an open source software which enables to perform classification. The WEKA software can be found here, http://users.aber.ac.uk/rkj/book/wekafull.jar. Decision tree has been successfully applied in various domains. It is the most powerful approaches in knowledge discovery and data mining [3].

The aim of the paper is to investigate the effect of magnetic stimulation in two conditions – attention and no attention in humans. Hence, feature extraction and classification are implemented to achieve the aim. New experimental paradigms for the research of TMS – EEG involving the auditory attention is also proposed. This paper organized as follows; in section 2, the experimental paradigm is described. Section 3, feature extraction and classification are presented. Section 4 is the experimental result and Section 5 is the conclusion of the study.

EXPERIMENTAL PARADIGM

The experimental design and experimental setup are proposed based on the research of selective attention of auditory stimulation.

Participants

Eight normal subjects (mean age: 26.13) are participating in the experiment. Beforehand, consent forms are handed to the subjects. None of them experience neurological disorder and they have normal hearing at the left ear. All subjects are right handed.

Experimental design

The experiments are divided into two sessions: with TMS and without TMS. Each session consists of two oddball paradigms which are active oddball paradigm and passive oddball paradigm. Table-1 shows the condition for both paradigms respectively. The auditory stimuli is the pure tone of three different frequencies [4] (1kHz, 1.5 kHz and 2kHz) which are generated from Matlab. Tone frequencies of 1kHz and 1.5kHz are the deviant tones whereas 2kHz is the target tone. The role of deviant tone is to distract the subjects' attention from target tone. Table-1 shows the conditions require for both active and passive oddball paradigms.

Table-1. Conditions of active and passive oddball paradigms.

	Active oddball paradigm	**Passive oddball paradigm**
Pure tone (stimuli)	1kHz,1.5kHz,2kHz	1kHz,1.5kHz,2kHz
Ratio of tone	40% : 40% : 20%	40% : 40% : 20%
Task	Click the event button in TMSI Polybench software	No behavioural response

There will be two different sets of 5-minutes tone that are delivered to the left ear in first and second session. The sequence and ISI of the tone are randomized. This is to ensure the subjects pay attention attentively to the target tone. Duration of a tone is 70ms due to the combination of stimulus plateau and stimulus rise/falltime. In order to elicit ALRs, the choice of tone parameter is very important. The tone parameter implemented for the experiment is summarized in Table-2.

Repetitive transcranial magnetic stimulation (rTMS) is applied to the subjects in the experiment. The rTMS parameter selected is shown in Table-3. This parameter follows the safety guidelines from Wasserman [5] and Rossi *et al.* [6].

Table-2. Tone parameter.

Parameter	
Stimulus type	**Pure tone**
Stimulus duration	70ms
Stimulus rise/ fall time	10ms
Stimulus plateau	50ms

Table-3. TMS parameter of repetitive transcranial magnetic stimulation (rTMS)

Parameter	
Site of stimulation	**Left temporal lobe**
Shape of coil	Figure – eight coil
Stimulation intensity	100%
Stimulation frequency	5Hz for 6s (30 pulses)
Interstimulus interval (ISI)	1 – 3s (random)
Intertrain interval (ITI)	minute

Experimental setup

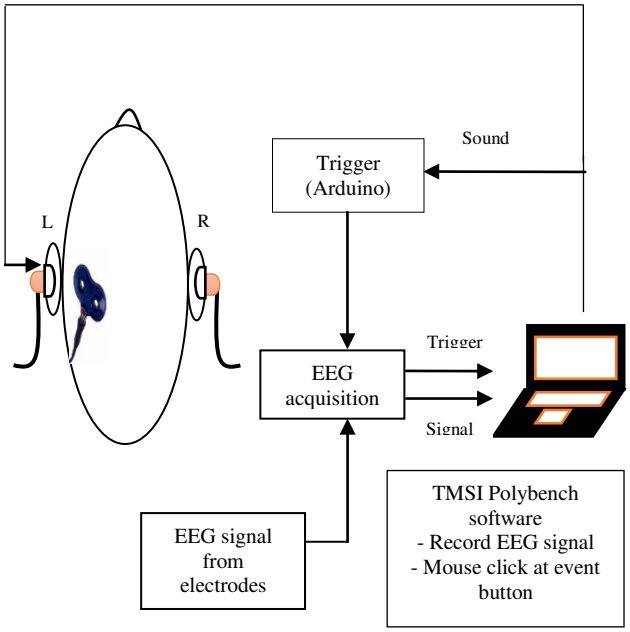

Figure-1. Hardware configuration.

The stimuli from laptop is delivered to the earphone at left ear and also to the arduino box as trigger. The trigger box is connected to TMSI Porti amplifier to send the trigger to laptop. As illustrated in Figure-1, the brain signal picked up from the electrodes are transmitted to TMSI Porti amplifier and recorded in TMSI Polybench software with the sampling rate 512Hz. The electrodes used are water based electrodes.

Experimental procedures

The whole experiment took place at Psychiatric Department, HUKM. The first session of the experiment was without TMS and followed by with TMS. The experiment took about two hours for each subjects. All the subjects were seated at a comfortable chair with closed eyes. The stimulator output of TMS was determined from left motor cortex where twitch at abductor pollicis brevis (APB) muscle was observed at the right hand. The coil position is 45° from the midline and tangential to the scalp. The experiment was recorded in TMSI Polybench software. Before the first session, a training was conducted to the subjects via GUI Matlab. This was to ensure they were able to recognize the target tone. Evaluation was performed by conveyed the training tone to the left ear only. Percentage of target tone hit was calculated and when only the subject achieve 80% - 100% correct, the first session will begin. Note that, twelve EEG electrodes including one reference were being used in the experiment as illustrated in Figure-2. The following were the steps taken when conducting the experiment.

a) Without TMS

1) Subject wear the head cap and water based EEG electrodes are fixed at the fittings of the cap. An earlobe plug is attached to right earlobe. The electrodes montage is shown in Figure-2. Then, subject will insert the earphone.
2) The tone is delivered to the left earphone while the right earphone is mute.
3) The recording of the EEG signal start when the tone start. The first experiment is active oddball paradigm. Subjects have to click the event button when hear the target tone.
4) The recording stop when the tone stop.
5) Next, passive oddball paradigm start after a short break of 1 minute. The tone is conveying to the left ear only. Subjects just need to hear the tone. Recording start when the tone start.
6) The recording stop when the tone stop.

b) With TMS (rTMS)

1) The site for TMS is locate as in Lorenz *et al*[7] by approximately 2.5cm upward T3 on the line between Cz and T3 and then 1.5cm in posterior direction perpendicular to the line T3 and Cz.
2) The electrode montage is as shown in Figure-2.
3) For active oddball, the recording start and TMS click will be delivered at the site of stimulation afterwards. Tone is delivered to the left ear only after the TMS click stop.
4) The subjects have to click the event button when hear the target tone. The recording stop when the tone stop.
5) Then, passive oddball started after 1 minute break. Subjects will only listen to the tone delivered to the left ear only. The recordings start as in 3) and stop when the tones stop.

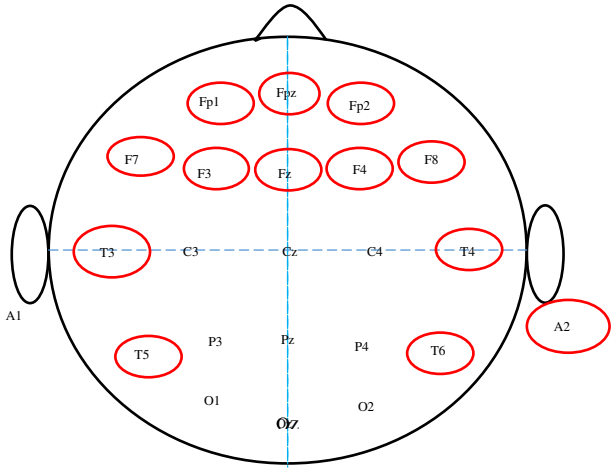

Figure-2. EEG electrodes montage indicated by red colour follows 10-20 system. A2 is the earlobe (reference).

FEATURE EXTRACTION AND CLASSIFICATION ALGORITHM

Preprocessing

The data are segmented according to the stimuli and a total of 92 sweeps are used for each subject. This is to ensure the number of sweeps for every subjects is the same. Each sweep underwent artefact rejection where the amplitude above 70uV the sweep is removed from further analysis.

Feature extraction

Only N1 and P2 peak ranges are considered. Feature extraction is then performed using Continuous Wavelet Transform (CWT) at N1-P2 range. Then, the coefficients of all scales are used to compute Energy, Power, Variance and Entropy of the selected data. These features will be used to classify between without TMS and rTMS for both attention andno attention. CWT can be expressed as

$$T(a,b) = \int x(t)\psi^*{}_{a,b}(t)dt \quad (1)$$

where$x(t)$ refer to the input signal. The $\psi_{a,b}$ denotes the complex conjugate and can be calculated by

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\psi(\frac{t-b}{a}) \quad (2)$$

where$\psi(t)$ represent the wavelet meanwhile both a and b denotes dilation and translation respectively. Four features selected are as follows:

a) Energy

The formula of energy can be expressed as:

$$E = T\sum_{n}^{N-1} x^2|n| \quad (3)$$

$N$is denotes as the number of samples while $x[n]$ represents number of sample of the signal at regular interval. $T$is refer to duration of the signal.

b) Power

The formula can be referred as Equation (4) below.

$$P = \frac{1}{N}\sum_{n}^{N-1} x^2|n| \quad (4)$$

$N$is denotes as the number of samples while $x[n]$ represents number of sample of the signal at regular interval.

c) Variance

$$V = \sum_{i=1}^{N} \frac{(x_i - \bar{x})^2}{N-1} \quad (5)$$

Variance of a signal is expressed as Equation(5) where N is the number of sample and $\bar{x}$represent the average of the signal.

d) Entropy

$$E(s) = -\sum_i s_i^2 \log s_i^2 \quad (6)$$

Entropy is represented by Equation (6) as above. s_i denotes the coefficients of the signal.

Classification

In this study, J48 decision tree classifier is used to distinguish the EEG signals between without TMS and rTMS. J48 decision tree can be found in WEKA. It is the implementation of algorithm Iterative Dichotomiser 3 (ID3) developed by the WEKA project team. J48 is a top-down decision tree which classifies instances by sorting from root to leaf nodes. Each node in the tree specifies a test of some attribute of the instance. Entropy is used in measurement of uncertainty in any random variable. It is used to calculate information gain. Information gain is to measure the amount of information contained in a dataset. It gives the idea of importance of an attribute in a dataset. The information gain is calculated as:

$$Gain(D, A_i) = H[D] - H_{A_i}[D] \quad (7)$$

where, original entropy, Equation (8) and expected entropy, Equation (9) are given as:

$$H[D] = -\sum_{j=1}^{|C|} P(C_j) \log_2 P(C_j) \quad (8)$$

Where C is the set of desired class.

$$H_{A_i}[D] = -\sum_{j=1}^{v} \frac{|D_j|}{|D|} H[D_j] \quad (9)$$

The decision attribute is selected based on the highest information gain.

Accuracy and area under ROC (Receiving Operating Characteristics) curve (AUC) are used to measure the performance. AUC provide more meaningful data compared to accuracy. AUC used the concept of sensitivity and specificity which related to the indices of true and false positives.

RESULTS

Figure-3 shows the grand averaged of without TMS (attention and no attention) and rTMS (attention and no attention) for eight subjects. Only result of Fz electrode is shown for the purpose of this paper. Number of sweeps is 92 and is the same for all subjects. From the result, peak N1 and P2 can be observed at the range 86ms – 90ms and at the range 176ms – 220ms respectively. One – way ANOVA test are performed between without TMS and rTMS (attention) as well as without TMS and rTMS (no attention). Noted that the $p < 0.05$. One – way ANOVA between without TMS and rTMS (attention) at N1-P2 peak shows significantly different ($p < 0.5$). For without TMS and rTMS (no attention) also shows significantly different where $p < 0.5$.

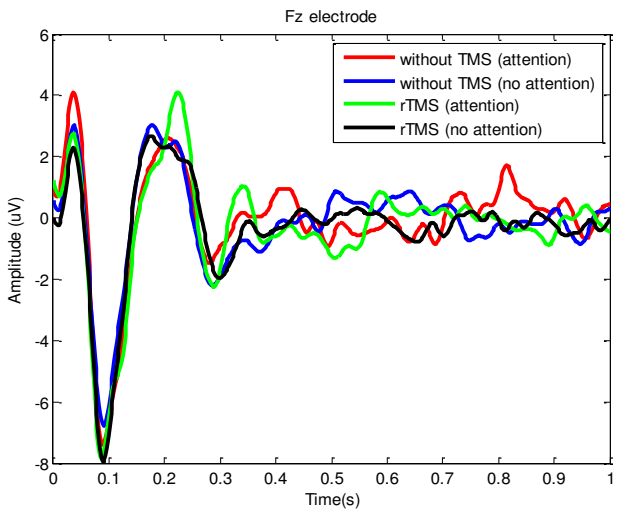

Figure-3. Grand averaged of 8 subjects.

Table-4. Performance of without TMS and rTMS in classification.

Groups	Accuracy	AUC
Without TMS x rTMS (attention)	98.85%	0.989
Without TMS x rTMS (no attention)	99.46%	0.998

The pre-processed data are classified using J48 with 10 fold cross-validation in WEKA. Table-4 shows the classification performance for attention and no attention. From Table-4, the classification accuracy and AUC for attention achieved 98.85% and 0.989 respectively while, the classification accuracy for no attention achieved 99.46% and the AUC is 0.998. The correct classification rate is illustrated as perfect classification when the AUC is 1 and a random classification when the AUC is 0.5 based on the positive rate.

From the result obtained, we can conclude that the classifier is able to classify between without TMS and rTMS based on the proposed experimental paradigm of auditory late response (ALR). The classification test is

performed through all electrodes (12 electrodes) as shown in Figure-2 of all subjects.

CONCLUSIONS

In summary, both N1 and P2 peak can be observed at Fz electrode. Based on the result of significance test, we can observe there are significant difference of N1 and P2 peak between without TMS and rTMS (attention) and vice versa. Moreover, the classification result shows high accuracy including the AUC in both groups. Thus, the proposed experimental paradigm able to elicit ALR which in turn shows high accuracy in classification. The proposed approach shows great potential to be applied in the studies of the auditory attention deficiency in schizophrenia patients in future.

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