Correlating Visual and Auditory Perception and Attention Level Using EEG Parameters

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***Abstract*—Focus, alertness level, and reaction time are key cognitive factors and are dependent on visual and auditory perception. Present work aims to study the functional changes in cortical regions; through frequency domain features of EEG, in correlation to perception and attention level (visual and auditory), using a computer screen-control task. Psychophysiological data consisting nine channel EEG for 26 subjects were recorded during three conditions; 5 minutes eyes closed (EC), 5 minutes visual focus on a red dot on dark screen (DOT), and approximately 10 minutes battery test consisting 3 visual and 3 auditory subsections (intrinsic, cross-modal phasic and unimodal phasic) through perception and attention functions: alertness (WAFA). Relative power spectrum density (PSD) of different activity bands for each epoch of one second have been computed; corresponding to each task. For WAFA task, mean reaction time (MRT, in milliseconds) and dispersion of reaction time (DRT, in milliseconds) have been registered. Correlation values between PSD of every EC, DOT and WAFA; and, MRT and DRT of WAFA assignment was registered. For task EC, correlation values are positive for theta, alpha, negative and positive for MRT and DRT consecutively, throughout the cortical region. For task DOT, correlation values negative for delta, theta and gamma; positive for alpha and beta. For task WAFA, correlation values are negative for delta and theta, but for different subsections of visual and auditory (intrinsic, cross-modal phasic and unimodal phasic) are either of positive, negative or uncorrelated for alpha, beta and gamma throughout the cortical region. EEG band activities are observed to be directionally correlated with visual and auditory alertness level.**

***Keywords*—EEG, alertness, visual perception, attention**

I. Introduction

Attention is the key cognitive process which when comes to perform complex mental task of visual or auditory selection and identifying specific objects and its perceivable information. Focused attention and perception is essential aspect of visual, auditory and other sensory cognition. In last few decades various studies on psychophysiological aspects of visual and auditory attention and perception have been done. Various visual perception disorders are classified and categorized based on subcortical or brainstem position, inabilities or disorders related to depth or color perception, face feature, places, text, motion vision, spatial frame, visual attention, memory or emotion and miscellaneous other factors [1]. Similarly there are disorders related to auditory perception based on sound localization, sound pattern and discrimination, temporal processing, perceiving degraded auditory signals and distinguishing one signal in competent to other [2]. Gradually, developments have taken place in field of cognitive neuroscience to evaluate attention and perception and to diagnose related disorders.

In significant visual stimulus experiments, synchronize between flickering light frequency induced as stimulus to eyes and EEG responses with coinciding frequencies has been found, the phenomenon called as photic driving [3]. Alpha, beta and theta correlates were found for absorbed meditative attention states and attentional stress factors [4], [5]. Because of the precise temporal resolution of electrophysiological recordings, the event-related potential (ERP) technique has proven particularly valuable for testing theories of perception and attention [6]. Such experiments have established major correlation between visual stimulus and physiological responses. Short-lasting changes in brain's excitability state are reflected with the relative alpha power of the EEG, which explains significant variability in perceptual processes [7].

Auditory and visual cross-modal cues have alpha suppressive effects in the parieto-occipital regions of cortex. Thereby, parietal region is capable of integrating various multiple sensory cues with subsequent deployment in visual attention [8]. The major attribute of alpha oscillation is suppressing attention on objects and features to be ignored and as well as focusing attention to or on objects and features to be specifically concentrated on [9].

In the present work, an experiment has been done to study the visual and audio perception and alertness level along with EEG derived psychophysiological parameters. A nine channel EEG is used to get frequency based features. The subjects were guided to perform three different attention based tasks (eyes closed, gazing a dot on screen and perception/alertness based task of Vienna Test System©, WAFA). While performing the task, EEG signal is recorded. The EEG frequency band features are evaluated and WAFA task scores are evaluated. The correlation between the EEG features and WAFA scores is evaluated for subject group to check the relationship between the EEG spatial parameters and alertness score.

II. Experiment set up and methods

A. EEG-based metrics for cognitive states

B-Alert X10® is a wireless hardware system for EEG and ECG acquisition with 9 channel EEG [10]. It follows 10-20 scalp electrode placement standard. The nine electrodes are fixed at F3, F4, C3, C4, P3, P4, Fz, Cz and POz, visually at frontal, central parietal and parieto-occipital regions of scalp. Electrode to scalp impedance is checked to be kept below 30KΩ throughout the recording. The sampling frequency for acquisition is kept at 265 samples per second and 16 bit resolution. For acquisition and analysis, Acknowledge 4.2 software of Biopac™ is used.

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B. WAFA

Vienna Test System© is a computer based psychological evaluation system [11]. Perception and attention functions: alertness (WAFA) is an attention evaluation test based on the attention model proposed by Zomeren and Brouwer [12]. WAFA comprises of widely two stimulus tests: visual and auditory. And each visual and auditory tests have three subtests for each, which can be categorized as visual: 1) intrinsic, 2) phasic (unimodal) and 3) phasic (cross-modal visual/auditory); and auditory: 4) intrinsic (auditory), 5) phasic (unimodal) and 6) phasic (cross-modal auditory/visual). Visual stimulus comprises of a solid circle blinking on screen at regular interval for intrinsic subtest, a solid square presided by solid circle for phasic (unimodal) and a low pitch sound presided by solid circle for phasic (cross-modal visual/auditory). Auditory stimulus comprises of a high pitch sound buzzing at regular interval for intrinsic subtest, a solid square presided by high pitch sound for phasic (unimodal) and a low pitch sound presided by high pitch sound for phasic (cross-modal auditory/visual). On every perception of stimulus, the subject has to respond by pressing a button. The reaction time of the responses are recorded for each subject and omitted if it exceeds 1.5 s. Total test duration is 12 minutes. Performance score of each test is recorded as mean reaction time (W1, W3, W5, W7, W9, and W11 for WAFA tasks 1 to 6) and dispersion in reaction time (W2, W4, W6, W8, W10 and W12 for WAFA tasks 1 to 6). Other performance results are number of omissions and commission errors which are not utilized in this study.

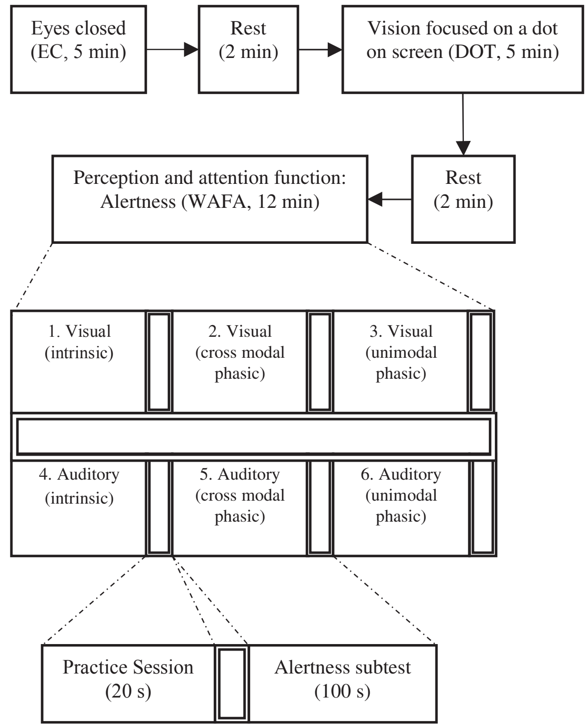

Figure: Sequential schematic of cognitive task performance of eyes closed (5 minutes), gazing on dot on screen (5 minutes), perception and attention function task (12 minutes)

C. Data acquisition, cognitive tasks and evaluation method

For alertness study, B-Alert X10 system's EEG electrodes were attached to the subject's head scalp. All three tasks are performed by all subjects in a relaxed sitting posture. The task progresses as: first 5 minutes of eyes closed (EC), then 5 minutes of focused gazing on a red color dot on a dark screen (DOT), then 12 minutes of performing alertness test(WAFA). First two tasks were performed in a dark environment, while the third one was performed in a bright environment. EEG is acquired and recorded throughout the task performance. After the completion of EC and DOT, a perception and attention functions task (WAFA) is guided to perform by subjects. Profiling of 25 subjects (21 males and 4 females) was done with their consent. All the subjects are healthy students from IIT Roorkee with clean medical records, no chronic diseases and age range of 24±5 years.

D. Features extraction: EEG Absolute Power and WAFA

In this paper, the EEG absolute power was estimated by first converting the EEG signal to frequency domain using fast Fourier Transform (FFT). The FFT was applied using a tapered Kaiser window of 512 samples with 50% overlapping. The power spectrum density is defined as (1)

$$\widehat{P}(f) = \left| \frac{\Delta t}{N} \sum_{n=0}^{N-1} h(n) x(n) e^{-j2\pi fn} \right|, \quad -\frac{1}{2\Delta t} < f < \frac{1}{2\Delta t} \tag{1}$$

Δt is sampling frequency and h(n) is window function. PSD feature was calculated for each epoch of second.

A sample of 512 points *x(n)* with 256 points overlap on each side was taken and windowed using *h(n)* and equation (1) is applied to get PSD for each epoch. Same is applied to all the nice channels of EEG. Features were computed for PSD between different frequency bands between 0.5-40 Hz, delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz) and gamma (30-40 Hz). Mean of each PSD was taken for every subject, to get EEG power features. From the WAFA test performed, mean reaction time and dispersion of reaction time is recorded as WAFA features for each subject.

E. Correlation between PSD and WAFA Features

To find any relationship between WAFA features and EEG power features, a correlation operation was evaluated. The PSD of 9 channels EEG in various frequency regions delta (0.5 4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz) and gamma (30-40 Hz) for task EC, DOT and WAFA was correlated with different WAFA task results, viz; W1-W12. The correlation coefficient with p-value less than 0.1 was only selected as an indicator of strong correlation between WAFA feature and EEG feature. Table X (a) is the collection of EEG features while performing 1: eyes closed task, 2: focusing on dot on a dark screen task, 3: perception and attention function: alertness task (WAFA) which are strongly correlated to WAFA features. The EEG features are examined for 3 conditions, where, in first case window length for EEG sample is 1s, in second case window length is 2 s and in third case window length is 4 s.

III. RESULT

Table I is representation of all positive or negative correlation between perception and alertness task scores as W1, W2, etc. with EEG based power spectrum features for EC, DOT and WAFA tasks (with suffix 1, 2 and 3) for each channels, which have p-value less than 0.1. From three tabulation results, it is evident that mean reaction time for task 1 to 6 are correlated to EEG parameters as: W1 score is correlated to alpha (DOT, WAFA); W3 is correlated to delta (DOT, WAFA) and beta (EC, DOT); W5 is correlated to theta (EC), alpha (DOT, WAFA) and beta (EC, DOT, WAFA); W7 is correlated to theta (DOT), alpha (EC) and beta (WAFA); W9 is correlated to delta (DOT), alpha (WAFA), beta (DOT, WAFA), gamma (WAFA); and W11 is correlated to b1, g1, a2, g1, b2, d3, b1, d1, d2, delta (EC, DOT, WAFA), alpha (DOT), beta (EC, DOT) and gamma (EC). Similarly dispersion in reaction time are correlated to EEG parameters as: W2 is correlated to alpha (DOT); W4 is correlated to delta (EC, DOT, WAFA) and beta (EC, DOT); W6 is correlated to delta (DOT, WAFA), W8 is correlated to alpha (DOT, WAFA), beta (WAFA) and gamma (WAFA); W10 is correlated to delta (EC, WAFA), theta (EC, WAFA), alpha (EC, DOT), beta (EC, DOT) and gamma (EC, DOT, WAFA); and W12 is correlated to delta (EC, DOT, WAFA), beta (EC, DOT) and gamma (EC, DOT) . Other EEG based PSD features are not correlated with WAFA performance scores with adequate p-value.

Table I. Table of EEG power features whose correlate with WAFA function W1, W2, ... W12 provides (p-value <0.1), for window length of (a) 256 samples, (b) 512 samples and (c) 1024 samples.

TABLE I. TABLE OF EEG POWER FEATURES WHOSE CORRELATE WITH WAFA FUNCTION W1, W2, ... W12 PROVIDES (P-VALUE <0.1), FOR WINDOW LENGTH OF (A) 256 SAMPLES, (B) 512 SAMPLES AND (C) 1024 SAMPLES.

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
W1	α2	Δ2, α2	α2		
W2	α2				
W3		Δ2			
W4	β2		β2		
W5		Δ2	Δ2		
W6			Δ2		
W7		θ2, β3			
W8	Δ1, θ2, γ3	θ2, α2, θ3	Δ1, Δ2, α2	γ1	γ1, Δ2, θ2, α2, γ2, θ3
W9	β2, β3	β2, γ3	γ3		
W10	Δ1, Δ3, θ3, γ3	Δ1, θ1, α1, Δ3, θ3	Δ1, θ1, α1, Δ2, Δ3		α1, Δ2, Δ3
W11				β1	
W12					

	Channel 6	Channel 7	Channel 8	Channel 9
W1			α2	Δ1, Δ2
W2	α2		α2	α2
W3	Δ3			
W4			β2	
W5	Δ3		β3	
W6			β3, γ3	β3
W7	θ2	Δ2		
W8	β2, γ2, θ3	β2, γ2, θ3, β3, γ3	θ3	α2
W9			γ3	Δ2
W10	Δ1 , θ1, γ1, Δ3, θ3	θ1, θ3	Δ1, θ1, α2, Δ3, θ3	θ1, α2, Δ3, θ3
W11	γ1, α2	γ1		β2
W12	Δ1, β1, γ1	Δ1, β1, γ1, Δ2		

Δ – Delta frequency (0.5-4 Hz), θ – Theta Frequency (4-8Hz), α – Alpha Frequency (8-12 Hz), β – Beta Frequency (12-30 Hz) , γ – Gamma Frequency (30-40 Hz), suffix-1: Eyes closed task (EC), suffix-2: Focusing on a red color dot on dark screen task (DOT), suffix-3: perception and attention functions task (WAFA).

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
W1	α2, α3	α2	α2	α2, α3, β3	
W2	α2			α2	
W3	Δ2, β2		Δ2, β2		
W4	Δ1, Δ2, β2	Δ1	Δ1, β1, Δ2, β2	Δ1	Δ1, Δ2, Δ3
W5	α3	θ1	α3	α2, α3	α3
W6				α2, Δ3, α3, β3	
W7		θ2	β3		α1
W8		θ2, α2, θ3	θ2, α2	Δ1, β1, γ1, Δ2, β2, γ2, θ3, γ3	γ1, θ2, α2, γ2, θ3
W9	γ3	γ3	γ3		
W10	θ3, γ3	θ1, α1, θ3	θ1, α1, θ2	Δ1, θ1, β1, Δ2, γ2, θ3	α1
W11	Δ3			α2	
W12	Δ3			β1	

	Channel 6	Channel 7	Channel 8	Channel 9
W1			α2, α3	α2, α3
W2			α2	α2
W3				
W4			Δ1, Δ2, β2, Δ3	Δ1, Δ2
W5			α3	α3
W6			Δ3, α3, β3, γ3	α3
W7	θ2			
W8	β1, γ1, Δ2, β2, γ2, θ3	Δ1, β1, γ1, Δ2, β2, γ2, θ3, β3, γ3	θ3	α2, θ3
W9		α3	γ3	
W10	Δ1, θ1, β1, θ3	Δ1, θ1, β1, θ3	θ1, α2	θ1, θ3

W11	β1, γ1, α2	γ1		Δ3
W12	Δ1, β1, γ1, Δ2	Δ1, β1, γ1, Δ2		

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
W1	α2, α3	α2	α2	α2, α3, β3	
W2	α2			α2	
W3	Δ2, β2	Δ1, β1	Δ1, β1, Δ2, β2		
W4	Δ1, β1, Δ2, β2	Δ1	Δ1, β1, Δ2, β2	Δ1	Δ1, Δ2, Δ3
W5	α3	θ1, β1, β2	θ1, α3	α2, α3	α3
W6				α2, α3, β3, γ3	
W7		θ2		α1	
W8		α2, θ3	θ2, α2	Δ1, β1, γ1, Δ2, β2, γ2, θ3, β3, γ3	γ1, θ2, α2, γ2, θ3
W9		γ3	γ3		
W10	γ3	α1	θ1, α1, θ2	Δ1, θ1, Δ2, β2, Δ3	α1
W11	Δ3			β1, α2	
W12				Δ1, β1, Δ2	

	Channel 6	Channel 7	Channel 8	Channel 9
W1			α2, α3	α2, α3
W2			α2	α2
W3				
W4		Δ1	Δ1, Δ2, β2, Δ3	Δ1, β1, Δ2, Δ3
W5	θ1		α3	α2, α3
W6			α2, Δ3, α3, β3	α2, α3
W7	θ2			
W8	Δ1, β1, γ1, Δ2, β2, γ2, θ3	Δ1, β1, γ1, Δ2, β2, γ2, Δ3, θ3, γ3	θ3	α2, θ3
W9		α3	γ3	
W10	Δ1, γ1	Δ1, β1, θ3	α2	θ3
W11	Δ1, β1, γ1, Δ2, α2	Δ1, β1, γ1, α2		
W12	Δ1, β1, γ1, Δ2, β2	Δ1, β1, γ1, Δ2		

IV. Conclusion

From the above study it is evident that EEG frequency band based parameters are related to perception and alertness task based performance parameters such as reaction time. Thus EEG frequency bands can be utilized to evaluate the visual and auditory alertness and attention level along with reaction time.

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