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Neural modulation in action video game players during inhibitory control function: An EEG study using discrete wavelet transform

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ABSTRACT

The ability to attend relevant visual information, suppressing or inhibiting irrelevant information present in the visual field is a vital feature of human plasticity. To examine how long-term involvement in action video games modulates the neural processes of the inhibitory control mechanism is the aim of this study. The experiment involves quantitative analysis of brain signals of Action video game players (AVGPs) and non-AVGPs on an attention inhibition task, named Bivalent shape task (BST). Discrete Wavelet Transform (DWT) based features are collected from task-induced electroencephalogram (EEG) signals of thirty-five participants. Improved wavelet energy and entropy measures of alpha frequency band are observed indicating better inhibitory control with lesser irregularity in AVGPs. An average classification accuracy of 93.05% and 96.89% are obtained by considering all the EEG features of alpha, beta and gamma sub-frequency bands, with linear and non-linear SVMs respectively. These findings suggest that training on action video games voluntarily enhances neural control mechanism of interference suppression and the neural activity in the alpha frequency band can be a signature of active inhibitory control. The gaming environment of action video games might stimulate the same kind of inhibitory control mechanism as used in this particular task can also be inferred.

1. Introduction

Video game industry has shown a rapid growth in recent years. In today's digital era, various types of video games are available in the market, though action video games have gained much popularity among all age groups. This increased commercial popularity has put a thrust on the scientific society to explore its behavioral impacts. As first-person shooter game (FPSG) is a type of action video game involving first person's perspective, the player experiences the gaming environment through the eyes of the protagonist. It requires the all-around involvement of the player. The player controls a character or an avatar of the game which performs multiple tasks at the same time. He proceeds to achieve the goal while keeping an eye on the position of the character, its movements, firing the gun, the direction of the gun, enemy movement, enemy location, firing from the enemy side, obstacles present and so on. He needs to react through mouse, keyboard or joystick requiring fast hand-eye coordination and quick reflective actions. The game demands consistent cognitive engagement of the player to keep the character alive.

Research shows that these games have a stupendous effect on player's visual system. In several studies, AVGPs have outperformed the non-game players in visual information processing abilities [1] including selective attention [2–4], visual search efficiency [5], visuospatial attention [6–8] and contrast sensitivity [9]. A recent experimental study on children with dyslexia unveiled the improvement in reading abilities along with attention through only 12-hour training on AVGs [10]. In another study [11], enhancement in fundamental visual processing was observed in adults with amblyopic eye by playing video games (both action and non-action type) for a total of 40–80 h, 2 h/day.

Inhibitory control, the ability to suppress natural, habitual, or dominant behavioral responses to stimuli, is a strategy for selective attention and it is critical for goal-oriented behavior in everyday life [12,13]. Certainly, inhibitory control is not a singular function [14]. It involves two components- response inhibition and interference suppression [15]. Response inhibition is the ability to ignore a dominant or automatic behavioral response and interference suppression is the ability to suppress misleading or irrelevant information in a scenario of stimulus competition [15]. In children with attention-deficit/hyperactivity disorder (ADHD), lack of inhibitory control is often related to a deficit in attentional means [16]. Colzato and his group assessed the behavioral response of FPSG players on inhibitory control using a stop-change paradigm

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and observed improved working memory [17] and action cascading [18], but no effect on attention inhibition [17,18]. Mishra et al. [19] and Krishnan et al. [20], on the contrary, provided evidence that the interference suppression is partly responsible for the better performance of the gamers. They assessed steady-state visual evoked potential (SSVEP) in attended and unattended visual sequences and enhanced capability of target detection with suppression of distracting information was noticed in AVGPs.

With the development of high-performance sensors and instrumentation techniques, Electroencephalography (EEG) has evolved as a very reliable approach to understand the brain dynamics. Being a non-invasive measurement technique of cortical activity from the scalp [21], EEG provides very high temporal resolution. The event-related activity in spectral frequency components, i.e. delta, theta, alpha, beta and gamma oscillations are found to be sensitive to the neural activity corresponding to specific cognitive tasks [22,23]. Low-frequency delta EEG activity is associated with attention to internal processing [24], whereas high-frequency beta and gamma bands are related to attentional modulation in the visual system [25,26]. The ratio of theta/beta power has been reported to be a biomarker to trait attentional control [27,28]. Alpha frequency band, on the other hand, is the most widely analyzed EEG frequency component in the study of inhibitory control mechanism [29]. However accurate quantitative assessment of neural response in connection with task performance needs artifact-free EEG signals and precise feature extraction and classification techniques.

In literature, wavelet-based denoising and feature extraction techniques are broadly used for analyzing EEG signals. Correct assessment of an EEG signal is a challenging task due to the presence of various noise contaminations which includes power-line interference, Electrocardiogram (ECG), Electromyogram (EMG), Electrooculogram (EOG) and eye blinks [30]. Discrete wavelet transform (DWT) is found to be very efficient in depicting the non-stationary nature of EEG. It decomposes the original signal into sub-frequency coefficients enabling precise time-frequency analysis. Wavelet-based denoising method helps to preserve the signal characteristics while removing the unwanted noise by localizing to different scales [30]. Effective use of wavelet based denoising technique has been observed in removing ECG artifacts [31], EMG artifacts [32] and ocular artifacts [33]. Also, the extracted features of sub-frequency bands provide more accurate information than the original EEG. Relative wavelet energy (RWE) and wavelet entropy are two significant wavelet-based features which quantitatively characterizes the signal [34]. The relative energy of the sub-frequency bands of EEG is given by RWE whereas wavelet entropy gives information about the degree of disorder in the signal. The next step to feature extraction is to use proper classification technique. Over the last few decades, classification techniques like Neural Network (NN) [35], k-Nearest Neighbor (KNN) [36,37], Support Vector Machines (SVMs) [35,36] and Linear Discriminant Analysis (LDA) [35–37] have found extensive use in the field of EEG classification. Garrett et al. [35] compared linear classifier with non-linear classifiers to classify spontaneous EEG signals while performing five different mental tasks and observed the better performance of non-linear classifiers which may be due to the high dimensionality of the EEG signals [35]. Recently, successful application of SVM classification technique has been observed in EEG based motor imagery classification [38], epileptic seizure detection [39] and automatic emotion classification [40].

It is noteworthy that most of the cognitive studies on action video games are based on behavioral responses. Very little is known about EEG frequency response underlying the attentional control mechanism in FPSG trainees. It is conspicuous to understand the scope of this visuo-spatial training on the general neural behavior.

The present study is, therefore focused on examining the EEG activity of AVGPs and non-AVGPs in alpha, beta and gamma frequency range during a nonverbal selective attention task. Participants were required to attend to one of the response cues either to the right or to the left visual field, after inspecting the test size ignoring the color. The qualitative and quantitative analysis of EEG data was done using discrete wavelet transform along with SVM classification method.

The algorithm of EEG signal analysis has been described in Fig.1. Section 2 of the paper explains the methodology of the experiment including participants, task used, EEG recording specifications and analysis methods, Section 3 discusses the results and Section 4 is the conclusion.

2. Methodology

2.1. Participants

Thirty-five young healthy, right-handed, male participants aged between 18–26 years (mean = 20.9years, SD = 1.57years) have participated in the study. Out of these, 16 participants are regular AVGPs and 19 participants have not played any action video games till date. The AVGPs used to play different FPSGs including *Call of Duty 4, Medal of Honor* and *Counter strike* for 15–20 hours/week. They are engaged in playing either of these games for more than a year. All the participants are having a normal or corrected vision and they are not been diagnosed with any neurological illness. The purpose of this research is explained to them before starting EEG data collection process and they submitted written consent to voluntarily participate in the research work. None of the participants were familiar with the test battery or the task used.

2.2. Experimental design

All the participants, both AVGPs, and non-AVGPs performed the Bivalent Shape Task (BST) of the Psychology Experiment Building Language (PEBL) test battery developed by S. T. Mueller and A. Esposito [41].

Bivalent shape task (BST) is a nonverbal cognitive test of the ability to suppress cognitive interference [41]. The participant decides whether the test shape is a circle or a square and responds using the mouse. The response cues are provided on the screen below the test stimulus. The circle is in red and to the left, whereas the square is in blue and to the right of the screen as shown in the Fig.2. The color of the stimulus may be red, blue or null and the participant requires making the decision considering only the shape, ignoring the color of the stimulus. It uses three logics: congruent, neutral and incongruent trials, 5 per type making a total of 30 trials. Then a mixed block trial, consisting all six trials run for half as many targets of each type as appeared in the earlier homogeneous blocks. The default response time limit is 3000 m sec.

The participants performed the task on a 19-inch desktop monitor connected to a 64-bit Windows-7® operating system having 2GB RAM, core-i7 CPU @ 3.40 GHz. The screen resolution was at 1280×1024. Headphone and external mouse were also used to maximize the virtual involvement.

2.3. EEG data acquisition and preprocessing

For EEG data acquisition, 32-channel MOBITA wireless data acquisition system (BIOPAC®) that consists of a ConfiCap® and 32-water-based electrodes (Fig. 3) has been used. It transmits the acquired data to another desktop computer (similar specifications) situated 3metres away, via Wi-Fi. Every one second data occupies 1.3kB memory space of the system. The real-time data is stored on that computer by running AcqKnowledge® software which is processed off-line in MATLAB® platform version R2015. The use of non-invasive water electrodes and wireless connection has made