Biomedical Signal Processing and Control 43 (2018) 117–129

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Neurofeedback training protocols based on spectral EEG feature subset and channel selection for performance enhancement of novice visual artists

Nasrin Shourie [a,*], Mohammad Firoozabadi [b], Kambiz Badie [c]

[a] Department of Biomedical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran
[c] Research Institute for ICT, Tehran, Iran

ARTICLE INFO

Article history:
Received 3 July 2017
Received in revised form
29 December 2017
Accepted 24 February 2018

Keywords:
Neurofeedback
Artist
Genetic algorithm
Visual perception
Mental imagery

ABSTRACT

No extensive research has been designed to study neurofeedback training protocol to improve performance of novice visual artists although many neurofeedback protocols have been designed to enhance the performance of novices in the other domains. In this article, differences between multichannel EEG signals of visual artists and non-artists are investigated during visual perception and mental imagery of some paintings using PSD (power spectral density) analysis to propose some neurofeedback training protocols for performance enhancement of novice visual artists. In this approach, the relative power values of the EEG signals are calculated in the traditional frequency subbands (delta, theta, alpha, beta and gamma). Genetic algorithm is used to select effective discriminative features and their related appropriate channels. Fitness function of the genetic algorithm is defined based on Davies-Bouldin index and statistical Mann-Whitney *U* test. Therefore, the relative low beta enhancement in Fp1 and F7 is proposed as the neurofeedback training protocol for visual perception performance improvement of novice artists. The relative low beta increase in Fp1 is also proposed as the neurofeedback training protocol for enhancing mental imagery performance of the novices. Since, the brain frontal region is closer to the sources of ocular artifacts as compared to the other brain regions, two neurofeedback training protocols are also proposed in the other brain regions (parietal, central, temporal and occipital). The alpha/theta decrease in T6 and the relative low beta enhancement in T5 are also proposed for visual perception and mental imagery performance improvements of the novices, respectively. It is also recommended that the proposed neurofedback training protocol for mental imagery performance enhancement is verified to the relative low beta increase and the alpha decrease in T5 to ensure the proposed protocol provides the necessary spectral changes in the novices.

1. Introduction

Analyzing the EEG signals of expert artists and athletes has shown that the brain activity patterns are affected by education and extensive experience. It means that experts exhibit a pattern of cortical activity distinguished from that seen in non-experts or novices [1].

For example, Volke et al. have found that chess experts exhibit higher EEG synchronization particularly in delta frequency band as compared to novices while solving chess problems [2]. It has been found that left-hemisphere alpha wave activity significantly increases during the preparatory aiming period of expert marksmen [3]. Salazar et al. have reported a similar result between the best and the worst shots of professional archers [4]. It has also been demonstrated that expert marksmen exhibit significantly more alpha wave activity in left temporal, parietal, and occipital regions as compared to novices [5]. Deeny et al. showed that EEG coherence decreases for professional marksmen as compared to novices during aiming period [6]. Crews et al. demonstrated that an increase in right-hemisphere alpha wave activity is related to decreased errors for expert golfers [7]. It has also been reported that Karate experts show an overall increase in alpha wave activity while breaking wooden boards [8]. Orgs et al. examined the EEG signals of expert dancers and non-dancers in terms of beta power and ERD in beta frequency band. They observed that low beta power values

* Corresponding author.
E-mail addresses: shourie.n@srbiau.ac.ir (N. Shourie), pourmir@modares.ac.ir (M. Firoozabadi), k_badie@itrc.ac.ir (K. Badie).

https://doi.org/10.1016/j.bspc.2018.02.017
1746-8094/

significantly decrease for dancers while watching dance movements. But, no significant decreased beta activity has been found for non-dancers during the time they were involved in watching dance movements [9]. Fink et al. have also found that expert dancers exhibit more right-hemispheric alpha synchronization as compared to novices during mental imagery of an improvisational dance [10]. Petsche et al. have reported that musicians and non-musicians are different in the levels of EEG coherence. Moreover, it has been shown that beta wave activity plays a major role in the music processing [11,12]. Wagner has found that alpha wave activity is more common in musicians as compared to non-musicians while passively listening to music [13,14]. Bhattacharya et al. have investigated differences between musicians and non-musicians in EEG phase synchrony while listening to music in five standard frequency bands: delta, theta, alpha, beta, and gamma. A higher significant increased phase synchrony in gamma frequency band has been observed over distributed cortical areas for musicians as compared to non-musicians while listening to music [15]. Pang et al. have found that artistic expertise is correlated negatively with the amplitude of the ERP responses to visual stimuli [16]. Functional Magnetic Resonance Imaging (fMRI) scans showed that blood flow increased in right-posterior parietal region of the brain for a portrait artist and a non-artist when they were asked to draw a series of faces. However, the level of activation was found lower for the artist as compared to the non-artist. In addition, the expert visual artist exhibited higher brain activity in the right frontal area of the brain as compared to non-artist, indicating that a visual artist uses higher order cognitive functions when viewing and drawing a face [17]. In another study, it has been demonstrated that visual artists exhibit significantly higher delta synchronization and alpha band desynchronization as compared to non-artists when they were asked to mentally compose a drawing [18]. It has also been reported that EEG phase synchrony is significantly higher for visual artists in beta and gamma frequency bands as compared to non-artists while viewing a painting [19]. Visual artists showed a significant increased phase synchrony in delta frequency band during mental imagery. Karkare et al. also classified the two groups by scaling exponents and a neural network-based classifier with an average classification accuracy of 81.6% [20]. Shourie et al. investigated differences between visual artists and non-artists in scaling exponents. They have observed that the two groups are distinguishable at rest by scaling exponents; however, a decrease in average classification accuracy is found for classifying the two groups when performing the same cognitive tasks [21]. In another study, differences between the two groups were investigated in alpha power. It has been demonstrated that relative alpha power values are significantly less for visual artists during visual perception and mental imagery [22]. In addition, it has been shown that the two groups are distinguishable using wavelet and cepstrum coefficients [23,24]. Moreover, it has been reported that approximate entropy is significantly higher for artists as compared to non-artists during the performances of the two cognitive tasks [25].

Analysis of the EEG signals of experts during the performances of some expertise-related tasks provides a reasonable rationale for the use of neurofeedback to mimic such patterns in novices to enhance their performance. Neurofeedback is a non-invasive conditioning technique whereby individuals can learn to voluntarily modify their brain activity [1]. Previous research has shown the effectiveness of neurofeedback training on enhancing the performance of novices, and various training protocols have been suggested in this regard [1,26,27]. For example, Landers et al. have shown that alpha enhancement in left-temporal region provides improvement in archery performance [28]. Rostami et al. have investigated the effect of SMR (13–15 Hz) enhancement at C3, alpha/theta (8–12 Hz/4–8 Hz) at Pz, and high beta (20–30 Hz) inhibition in a group of rifle shooters. Trained participants showed improved shooting performance [29]. Ros et al. reported that SMR/theta neurofeedback training led to improvements in surgical technique and reducing total surgery time [30]. Egner et al. examined the effect of SMR rhythm (12–15 Hz) enhancement at C4, low beta (15–18 Hz) at C3, and theta/alpha (5–8 Hz/8–11 Hz) at Pz in a group of music students. They found a positive correlation between success on the theta/alpha enhancement and improved musical performance [31,32]. The effectiveness of theta/alpha (4.5–7.7 Hz/8.5–11 Hz) enhancement at Pz on improvement of novice dancers has also been shown [33]. Performance improvements provided by alpha/theta training have also been reported for novice singers [34–37].

No extensive research has been designed to study neurofeedback training protocol to improve performance of novice visual artists although many neurofeedback protocols have been designed to enhance the performance of novices in the other domains. To fill this void in the existing research, the aim of this study is to design neurofeedback training protocols to improve performance of novice visual artists. The performance enhancement protocols are usually based on an assessment of the spectral features of EEG signals recorded while experts and novices/non-experts carry out expertise related tasks. Two essential questions have to be answered for designing a neurofeedback protocol: Which features provide the best discriminability between the two groups among the extracted features? Which EEG channels are the best sites for placing EEG recording electrodes? Therefore, multichannel EEG signals recorded from two groups- visual artists and non-artists- during visual perception and mental imagery of some paintings are used to design the neurofeedback protocols. Relative EEG power values in the five standard frequency bands (delta, theta, alpha, beta, and gamma) are calculated for the EEG signals. Finally, the best discriminative EEG feature, and its related electrode site are determined using genetic algorithm for each of the conditions, separately. Accordingly, two appropriate neurofeedback training protocols related to the two cognitive tasks are designed.

2. The proposed approach

2.1. Constituting necessary data set

In this study, EEG signals related to the research of Bhattacharya et al. are investigated [19,20]. The EEG signals were recorded from twenty female participants (ten professional visual artists, mean age 44.3 and ten non-artists, mean age 37.5) using 19 electrodes with reference to the averaged signals of both earlobes. The electrodes were placed according to the international 10–20 electrode placement system (Fig. 1) and the electrode impedance was kept below 8 kΩ for all electrodes. The sampling frequency was set to 128 Hz and A/D precision was 12 bit.

Visual artists had an MA (Master of Arts) degree from Vienna Academy of Fine Arts, whereas non-artists had no specific training or interest in visual arts. All participants had no history of psychiatric or neurological disorders. Participants had to perform four tasks of visual perception and four tasks of mental visualization. In the visual perception task, they had to view the slides of paintings projected onto a white wall for 2 min. In the mental imagery task, participants were asked to mentally imagine the painting shown just under 2 min. This procedure was repeated with four paintings (painting 1: Bean-Festival by Jordaens, painting 2: an etching by Rembrandt, painting 3: an abstract painting by Kandinsky and painting 4: a portrait by Holbein), which vary widely in style, shapes, details, themes, use of colors, etc. Each task was performed after a period of rest (1 min) and distraction period of reading a newspaper text of neutral content (Fig. 2) [19,20].

A 6th order Butterworth band-pass digital filter was used to filter the EEG signals between 0.3 Hz and 45 Hz. In addition, the EEG