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Fuzzy adaptive neurofeedback training: An efficient neurofeedback training procedure providing a more accurate progress rate for trainee

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ABSTRACT

In this paper, a new fuzzy adaptive neurofeedback training procedure (FNFT) is proposed, in which a more effective performance in neurofeedback training can be expected. In the proposed FNFT, the threshold is adaptively set considering the cortical activity of the subject. Scoring index (SI) (the number of points increased in subject's score) is set according to the brain activity of the subject and is calculated using a fuzzy rule based system. When training feature surpasses the threshold, the SI points are then added to the points of the subject. This adaptive scoring index leads to having an efficient indicator for the success rate of the subject. In addition, the subject is rewarded with an audio or visual feedback. The sound intensity of the audio feedback and the length and width of the video frame are adjusted in accordance with the SI. Finally, an EEG feature is also considered (brain mental fatigue index) to stop the training as the subject becomes mentally fatigued.

1. Introduction

Neurofeedback is a non-invasive conditioning method, in which individuals can learn to voluntarily regulate their brain activities [1–3]. Athletes, artists and business executives take advantage of neurofeedback to learn how to use the full potential of their brain to reach their superior performance. Neurofeedback is also effective enough to treat the patients with anxiety, depression, epilepsy, etc [3–7].

Neurofeedback training generally consists of recording EEG signals from one or two electrode sites and providing audio or visual feedback for the individuals about their cortical activities [8,9]. Training features are calculated on a moving window that is continuously updated and compared with a threshold. The subject would be rewarded with audio or visual feedback or point increasing when the training feature surpasses the threshold. It must be noted that inappropriate scoring method may confuse subjects when evaluating how successful they were in modifying their brain activity.

Researchers have previously applied various rewarding methods for NFT. One of the most traditional thresholding methods is to have a threshold fixed by a therapist. In this method, the therapist manually sets a fixed threshold for a training session. If the training feature surpasses the threshold, a point would then be added to the score of the subject [10,11]. An open question is how the threshold should be selected. Some therapists set the threshold according to the previous results of the subject and their sensitivity to rewards and punishments [10]. Other therapists determine the threshold according to a schedule upon which the threshold is set to a minimum value in the first session and then is increased during the next sessions. However, a fixed threshold setting would not be adaptive regarding the brain activity of subjects. Therefore, the thresholds should be adaptively modified according to the cortical activity of the subject. In addition, the number of points and the audio or visual feedback should accurately reflect the progress rate of the subject.

Another traditional thresholding method is automatic calculation, done by setting the threshold to the training feature level surpassing 60–85% of the time during the preceding 30 s moving average window [1,8,9,12–18]. When the training feature surpasses the determined threshold, the score would increase by one point and the subject would then be rewarded with an audio or visual feedback. This method is adaptive in nature, and there is no need for the threshold to be manually set by the therapist.

However, this method may confuse the subject and therefore, not provide an appropriate indicator of the success rate. Suppose that it is aimed to train a subject to increase his/her alpha wave activity. For this purpose, the subject starts with a default threshold and then passes the first 30 s window. It is assumed that the new

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threshold is set to 0.3. If alpha power surpasses 0.3 twenty times, 20 points are then added to the points of the subject. It is also assumed that the second 30 s window is passed and the new threshold is set 0.1. If alpha power surpasses 0.1 twenty times, another 20 points are added to the points of the subject.The determined thresholds show that the subject could, in this way, be more successful in the first 30 s window as compared to the second 30 s window, whereas the obtained points and the received audio or visual feedback would be the same for both 30 s windows. Therefore, the subject does not receive a valid progress rate. In addition, while the second determined threshold is less than the first one, it is more probable for the subject to gain more points in the second 30 s window (as compared to the first 30 s window).

The scoring index has been determined regardless of the threshold in most of the previous studies. The subject's score was often increased by one point for each of the threshold values and scoring index was fixed. However, if scoring indexis determined according to the threshold value, the brain activity mirroring of the neurofeedback training efficiency is improved.

Mental fatigue can be caused by mental states such as sleeplessness, depression, stress, or repetitive tasks, leading to reduced performance [19]. Hence, it can influence the performance of subjects during NFT and demoralize them. Gruzelier et al. observed that performance of subjects falls over time during neurofeedback training [20]. However, most of the previous studies have been conducted in the field of neurofeedback regardless of mental fatigue monitoring during the training. Therefore, it is likely that mental fatigue detection during NFT improves its effectiveness. Taking this point into account, we suggest a new modified reward method.

In this article, a fuzzy neurofeedback training procedure (FNFT) is proposed through which the threshold and scoring index is adaptively determined according to the cortical activity of the subject. In this approach, when the training feature surpasses the threshold, the subject's score would increase according to his/her brain activity while the scoring index is calculated using a fuzzy technique. The sound intensity of audio feedback and the dimensions of video frame also vary according to the cortical activity of the individual. In addition, an EEG feature is also considered as the brain mental fatigue index for stopping the training as the subject becomes mentally fatigued.

2. Related works

Lee et al. have examined the effect of increased beta and decreased theta activity in C3 or C4 on the treatment of ADHD children. Participants were rewarded if they could keep beta levels above the threshold 20% of the treatment time, and keep theta levels below the threshold 70% of the time. The threshold was manually adjusted by the therapist depending on the participant's performance [11]. Azarpaikan et al. studied the potential of neurofeedback training (SMR (12–15 Hz) increase and theta (4–7 Hz) decrease) to improve physical balance in Parkinson's patients. In each training session, the level of brainwaves was determined depending on an EEG baseline recorded from CZ. The electrodes for neurofeedback training were placed on O1 and O2. Then, the patients who participated in the study played three video games on the computer screen. When the brain activity changed in an incorrect frequency band, the video game was stopped [21].

Rostami et al. have trained expert rifle shooters using two neurofeedback protocols for improved performance. The first portion of each session consisted of an SMR neurofeedback protocol (SMR increasing (13–15 Hz) and high beta (20–30 Hz) inhabitation) at C3 and C4, and the second portion of each session consisted of an alph/theta neurofeedback protocol at Pz. The participants were rewarded if they could keep SMR activities above the baseline level for 80% (60% for alpha-theta protocol) of the training time (at least for 0.5 s) and decreased high beta activities for 20% of the training time (at least for 0.5 s). Threshold levels were manually adjusted when participants received rewards 90% (at least for 0.5 s) of the training duration [15].

Ghoshooni et al. have examined the effect of SMR (12–15 Hz) neurofeedback training at Oz and Fz to improve cognitive performance. The individual SMR band of each participant was extracted from their recorded EEG baseline. The SMR activity was calculated on a moving average window of 30 s that was updated continuously. The threshold was set manually to the SMR activity surpassing 60% of the time during the window. The participants were rewarded when their SMR activity was over the threshold [16]. Khodakarami et al. have also employed a similar method for training healthy female students to enhance their gamma wave activity [17]. Sajadi et al. also used a similar method for alpha/theta training students with learning disability [18]. Raymond et al. have examined the effect of decreased alpha/theta at Pz in novice dancers. The individual alpha and theta frequency band of each participant was extracted. When the participants' theta power was higher than their alpha power, the sound of crashing waves was heard. Otherwise, a babbling brook sound was heard. An amplitude threshold was also considered for each frequency band. Suprathreshold bursts of theta or alpha were rewarded by a low or high-pitched gong sound, respectively. These thresholds were set manually by a therapist and updated so that theta and alpha amplitudes were over the threshold 60% of the training time [22]. In another study, a similar alpha/theta training procedure was employed to change mood and personality [23]. Gruzelier et al. have also trained novice musicians to increase alpha/theta ratio (alpha: 7–10 Hz and theta: 4–7 Hz). Their subjects listened to auditory feedback related to alpha/theta activities at Pz with their eyes closed. When the subjects' theta was higher than alpha power, a babbling brook sound was heard. Otherwise, sounds of waves gently breaking on the shore were heard. They also considered an amplitude threshold for each frequency band. Suprathreshold bursts of theta or alpha were rewarded by a low or high-pitched gong sound, respectively. These thresholds were set manually and updated such that theta and alpha amplitudes were over the threshold 25–40% and 50–70% of the training time, respectively [24,25].

3. The proposed approach

3.1. The proposed fuzzy NFT procedure

3.1.1. EEG recording interface

A simulation based interface is designed for recording the EEG and neurofeedback training using the FlexCompinfiniti system (Thought Technology Ltd, serial number: A2068, Model: SA7550M, made in Canada). In the designed interface, a monitor is considered for the subject consisting of a video frame, some warning LEDs, and a scoreboard. Another monitor is also considered for therapist to select the training features, video clip, the sound of audio feedback, as well as to adjust the time of training, default threshold, allowed amplitude, and the frequency range of artifacts. The therapist can continuously observe the recorded EEG signals, the variations of the training features, the threshold values, the scoring index values, and the mental fatigue index values. The therapist can also manually stop the training procedure.

The EEG signals are sampled with the sampling rate of 256 Hz, and then filtered using a band-pass digital filter between 0.3 Hz and 45 Hz. Training features are calculated on a 1 s moving window that is updated continuously. If the training feature average is above the threshold, the subject's score are increased. The threshold and the scoring index are automatically updated on a 15 s moving window.