Peak Alpha Based Neurofeedback Training within Survival Shooter Game

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Abstract. Neurofeedback has been proven to be a useful tool in games, music or video applications for both treating various disorders and disabilities, as well as potentially enhancing cognitive functions of healthy individuals. However, most neurofeedback protocols are tedious to use and the usefulness of the results is difficult to validate. In this paper we present a framework that allows connecting various types of neurofeedback protocols inside a computer game in a way that the user can gain full benefits of the neurofeedback based training by simply playing a game. The paper outlines the full potential of cognitive training and it's effectiveness when implemented in an entertaining scenario.

Keywords: neurofeedback training · shooter game · alpha and theta training.

1 Introduction

While the neural mechanisms involved neurofeedback training(NFT) are still unexplained [4], the benefits of the technique have been proven both in clinical situations where neurofeedback has been successfully used to treat disorders such as epilepsy [25], learning disabilities [7], ADHD [2, 3, 18], and autism spectrum disorders [15].

Neurofeedback has also shown potential to be a useful tool for healthy individuals to reach their peak potential [22], as well as to improve and evaluate working memory and memory performance for stroke patients [10,13] or attentional processes such as sustaining, orienting and executive attention [9]. Neurofeedback has even been used to help meditation by virtual reality and neurofeedback training while measuring the level of concentration and relaxation [14].

One particular approach with reasonable effectiveness has been taken into consideration individualization of theta/beta ratio (TBR) for ADHD children that are characterized with decreased individual alpha peak frequency (iAPF), alpha bandwidth and alpha amplitude suppression magnitude. In this individualized context there were identified various (adjusted) alpha activity metrics with close relationship with ADHD symptoms [3].

Currently, one approach for coping with ADHD symptoms or other medical situations by using NFT is by developing EEG driven games. Unfortunately, some clinical studies had the goal to entertain children rather than apply and evaluate a learning procedure [2]. From this perspective, development of NFT driven games with clearly defined goal and mechanisms for evaluating learning outcomes represents a challenge that needs researcher's attention. Recently, various dynamic difficulty adjustment strategies have been proposed by [24] triggered by EEG in multi-player games. Still, training and validation remain the key critical issues for EEG driven games.

As main application domain of NFT [19] we outline clinical applications for treatment of ADHD, anxiety, depression and many other dysfunctions highlighting the advantages and limitations of proposed therapies in terms of the effectiveness of treatment of such neurofeedback software. Still, latest research do not provide conclusive results in terms of efficiency of NFT.

The goal of this paper is to build a data analysis pipeline within a NFT tool that is designed as in interactive game. The tool may integrate various cognitive training methods and approaches in order to achieve positive results on various patients: healthy people, people that have suffered chronic strokes or people with Attention Deficit/Hyperactivity Disorder (ADHD).

The chosen method for NFT is peak alpha and alpha/theta ratio because these two bands are more prone to manipulation while manipulation of beta band amplitudes are independent from specified training in visual attention processing scenarios [11]. A general limitation of the NFT is the lack of generalization due to individual differences and demands for various people and applications (i.e., medical, games, etc.) [22]. The proposed approach aims to training for general peak alpha threshold values that may be further used on any game player.

2 Related Work

Various NTF protocols have been widely used for a wide range of practical problems such as: recovery of memory, improving working memory, improving the sustained attention and orientation, improving the level of concentration and relaxation, treatment of ADHD or improving cognitive and affective gains. Among the most used NFT protocols there are: SMR (Sensory Motor Rythm), TBR (theta/beta ratio), upper-alpha, high alpha, peak alpha frequency, gamma, theta and many other [9].

Among many available NFT protocols the alpha training (enhancement and suppression) has been investigated by [8] in order to improve motor skills. Their study showed that alpha suppression may be more effective in the consolidation of motor memory. Another example of individual alpha frequency training was performed by [17] in the context of treatment of adolescent anorexia nervosa.

Another example of NFT aimed to increase the individual upper alpha power in the parieto-occipital area of the scalp has been reported by [6] in their attempt to investigate if working memory performance may can be improved for patients with major depressive disorder. The experimental results in performed studies showed a positive correlation between the improvement in processing speed and the increase of alpha power and thus the effectiveness of the proposed protocol. Specifically, EEG peak alpha frequency (PAF) has been shown to correlate positively with cognitive performance and to correlate negatively with age after childhood [1]. The same interrelation has been found between sensorimotor abilities, cognitive performance and individual alpha peak frequency (iAPF) in [20].

Biofeedback has been combined with (computer) games in various ways. In a comprehensive study Kuikkaniemi et al. studied how biofeedback would enhance the game experience both when the players were aware of the feedback as well as when the game adapted implicitly without players knowing it [16].

Various BCI techniques have been used for creating neuroadaptive games: Pineda et al. proposed a system where player could navigate in a 3D game by controlling their sensorimotor mu-rhythm [23]. Larol et al. utilized Steady State Visual Evoked Potentials (SSVEP) for controlling a game character: the system would show checkerboards flashing at different frequencies and, by observing the user's visual cortex the BCI system could detect which of the checkerboards the user was concentrating and use this information as control signal. Muller et al. used a game like training to help users learn use imaginary movesensorimotor [21].

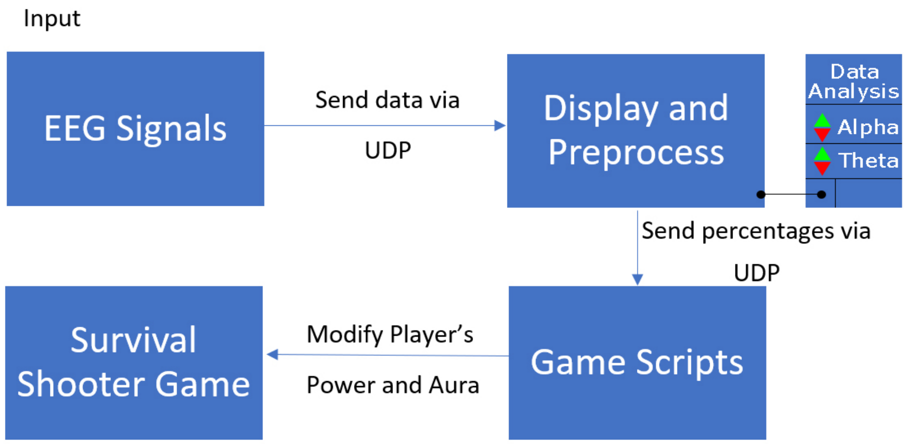
3 Proposed Approach for the NFT

The NFT is based on a data analysis pipeline that is presented in figure 1. It consists of several modules that are designed to process the raw input (i.e., EEG signals) and finally update the GUI of survivor shooter game.

The module responsible for receiving the raw EEG signals from Nautilus headset is based on Matlab and Simulink scripts that obtain the analog signals.From available signals we save only the alpha and theta signals for later use. This module is also responsible for sending via UDP two different packets, one for alpha signal and one for theta signal. Once the signals are logged they are further available for display and process by other modules within the data analysis pipeline.

Once the data is available in *.csv* format it is ready to be processed and displayed. All processing is performed in a custom desktop application (i.e., the game) that uses *qt* framework along with other external libraries such as *qcustomplot* for displaying the dynamic signal graph and *qtcsv* for writing data in a *.csv* file for later processing. The game provides two modes (i.e., high alpha and alpha/theta ration) corresponding to the logged signals through UDP ports. The signals are interpreted such that the byte array received from Simulink is transformed to a decimal number while storing the global smallest and largest values withing current running session. The module further computes the percentage of newly received signal value from the current global smallest and largest values and saves it into a *.csv* file and forwards it to Unity to update the GUI accordingly.

Fig. 1. Data Analysis Pipeline



The data analysis module for the survival shooter game has been designed to accept two game modes available data from the headset: alpha and alpha/theta.

In ***Alpha mode*** mode the data analysis module the alpha band (8-12Hz) and extracted into four 1 Hz bands:

- $Alpha_1$ = 8-9Hz
- $Alpha_2$ = 9-10Hz
- $Alpha_3$ = 10-11Hz
- $Alpha_4$ = 11-12Hz

The goal of peak alpha training is to increase the activity in the upper two alpha bands while decrease it in the lower. Thus, we combined all the four channels into a following formula that gives an overall score on how well the training is going:

$$value = -(alpha_1)^2 - alpha_2 + alpha_3 + alpha_4^2$$

where $alpha_1$ and $alpha_4$

Notice that $alpha_1$ and $alpha_2$ have negative signs, and that the $alpha_1$ and $alpha_4$ are squared to give emphasis on the highest and lowest part of the alpha band.

In ***Alpha/Theta mode*** [5] the data analysis module receives the same input and performs the same transformation, but for computing the final value the following formula is used:

$$value = \frac{alpha_1}{theta_1}$$

where $alpha_1$ and $theta_1$ are the highest alpha and theta signals.

Once the current and precedent values are determined, the percentage may be further computed and forwarded to the game such that the halo lightning intensity and the damage output of the character may be updated.

The value for the ***percentage*** from the currently input is computed taking into account *min*, *MAX* values with the following formula:

$$percentage = \frac{currentValue - min}{MAX - min} * 100$$

Subtract the minimum value from both the current value and the maximum Multiply the smaller value by 100 and then divide the result by the higher value.

If parasite values (i.e., values smaller or larger than a specific threshold value) occur then these values are discarded. When values received values are not parasite but are larger than *MAX* or smaller than *min* then the *MAX* and *min* values are updated and the returned percentage is 100 or 0, respectively.

In-game damage output and halo are updated with the following procedures:

Algorithm 1 updateGunPower

```
if newPercentage ≤ (oldPercentage + sensitivity)  then
    gunPower ← (newPercentage − oldPercentage) / sensitivity
else
    if power ≥ 0)  then
        power ← power − 1
    end if
end if
oldPercentage ← newPercentage
```

Where the variables have the following meaning: **power** is the damage output by the gun (also displayed in game), **sensitivity** is a constant number that can be set in the options of the game whose purpose is to decrease or increase the amount of brain activity variation needed in order to see changes in game, **new percentage / old percentage** hold the last signal received on the UDP channel as well as the current one so that a comparison between them can be made.

Algorithm 2 enableHaloVisualEffect

```
lightIntensity ← power
if lightIntensity ≥ 50  then
    # enable halo
end if
```

4 Sample Usage Scenario

The goal of the player's character is to constantly fight enemies that spawn around the map, survive them and finally get as many points as possible. The GUI displays a health bar such that when an enemy comes close the player's health is decreased. When the player's health reaches 0 the game ends. There are several types of enemies, each with a different health amount. At any moment, the damage the player's gun does is influenced by the power, which acts as a multiplier to the player's damage. The power is positively correlated to the NFT through *alpha* and *theta* signals.

Figure 2 presents the GUI in two sample usage scenarios. The above figure presents the GUI for minimal brain activity while below figure presents the GUI for high brain activity.

Fig. 2. GUI with minimal brain activity of the player

The player mounts the headset and starts the game. Once the game starts it receives the UDP datagrams containing *alpha* and *theta* signals. At this step, the shooter's strength and aura have default values and are not altered by the EEG signals. Once an increase in the *percentage* value is detected the GUI is updated and a larger strength and aura are being displayed. In a similar way, a decrease in the *percentage* value is triggers a decrease in the power of the shooter. The updated of the strength and aura within the GUI are performed every second according with the computed *percentage* value.

Another factor that is taken into account is the intensity of the light. When large values in light intensity take place the aura is enabled. The aura is disabled when the surrounding light has a value under a threshold value of 50 percent. The surrounding light and aura are key elements along shooter's strength in order to provide the player with visual feedback of their current neurofeedback training status and progress.

5 Conclusions

In this paper we described a design for a neurofeedback training game that allows user to gain the benefit of neurofeedback while simply playing a game. The design provides a framework and design principles on how any game could be turned into a potential neurofeedback training application. However, several questions remain that we aim to address in future work. First of all, we need to validate that the free form game neurofeedback training works as well as "dedicated" neurofeedback setup without the potential distractor of the game. Also, we aim to study whether there exist interpersonal differences in the usefulness of different neurofeedback protocols (such as the alpha/theta vs. peak alpha). There are also many other potential training possibilities such as beta and gamma training that has shown potential in enhancing cognitive control [12].

Another practical question is to determine the bare minimum hardware for the training to be feasible: is it necessary to have a high quality laboratory grade EEG device with 64 or even more sensors, or might a commercial grade device with only one or two sensor be capable for providing the same benefits. This has huge economic ramifications as most people are not able to afford a laboratory grade equipment yet there exist several lower quality commercial devices in the market. It is also important to determine how long and how many times the training has to be repeated to gain maximum benefit. Similarly, it is necessary to determine how long the effects last after the feedback training.

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