# Low-Cost Neurofeedback Game for ADHD Treatment

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### ABSTRACT
This paper describes the development of a digital game for ADHD treatment through neurofeedback from a portable neuroheadset. The purpose of the game is to improve the player's ability to concentrate and be relaxed at the same time. To achieve this, the player is connected to a portable neuroheadset that reads brain activity, which sends signals to the game. The environment of the game then changes based on the received activity.

### Author Keywords
ADHD, Digital Game, Experimentation, Neurofeedback, Neuroheadset.

### ACM Classification Keywords
D.1.3 Concurrent programming, D.1.5 Object oriented programming, D.2.13 Reusable Software, H.1.2 Human Factors, H.5.2 User Interface, Input Devices and strategies, H.5.5 Signal Processing, K.8.0 Games.

### General Terms
Design, Documentation, Human Factors, Theory.

### INTRODUCTION
Attention deficit hyperactivity disorder (ADHD) is a development disorder which cannot be cured. There are many causes for ADHD, including genetic heritage, mother drinking alcohol or smoking during pregnancy, traumas, toxins, food additives, excessive watching of TV during an early age, and many more. [1, 2, 3]

Common treatment methods include:

- Participation in social activities on which the patient afterwards reflects and anlyzes outbreaks.
- Self-treatment in form of jogging, biking and other physical exercises that relieve stress.
- Medicine in form of pills.

Especially, the pill treatment has become very widely used over the past few years, which is a problem due to the side effects that such pills can cause [4, 5].

Another treatment method which has shown promising results is neurofeedback or Electroencephalogography (EEG) Biofeedback. In this method, sensors are attached to the scalp of the patient, and the electrical activity is monitored to see brain activity in different bands. In case of ADHD, the patient will have an increased activity in theta band and decreased activity in beta band compared to a normal person. During a session, the patient is guided through various mental exercises during which the goal is to increase activity in the beta band and decrease activity in theta band [6,7]. Previous research have additionally also shown that primary difference in brainactivity between ADHD patients and others lies in the forntal lobe and the temporal lobe (see Figure 1) [7,8, 9].

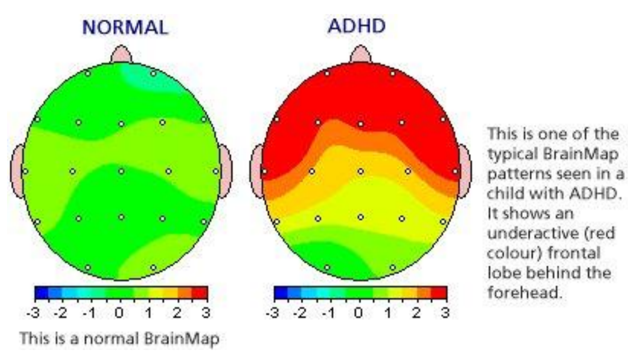


**Figure 1: Comparing EEG of children with and without ADHD**

While the last method is clinically proven to be successful in improving the condition of patients, it requires expensive technology and personel that supervises the training procedure.

This paper experiments with a different approach, where ADHD patients can do unsupervised selftreatment while wearing a low-cost neuroheadset [10].

The development and testing of this project included no communication with real ADHD patients, and the actual implementation of models has to be tested on real cases of ADHD before any conclusive results can be presented.

### SELF-TREATMENT THROUGH GAMING
To design an unsupervised self-treatment method, the patient needs to continuously be informed about his way of thinking in order to improve. A game is well suited for this purpose, as children with ADHD often love playing digital games and games can change gradually based on input.


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The designed game, Space Sheep, has no age restriction and includes no violence. The player controls a sheep in a UFO that flies up into space. On its way up, the sheep has to gather batteries to power its UFO. The player's role is to control the UFO to either left or right side and by only using the mind.

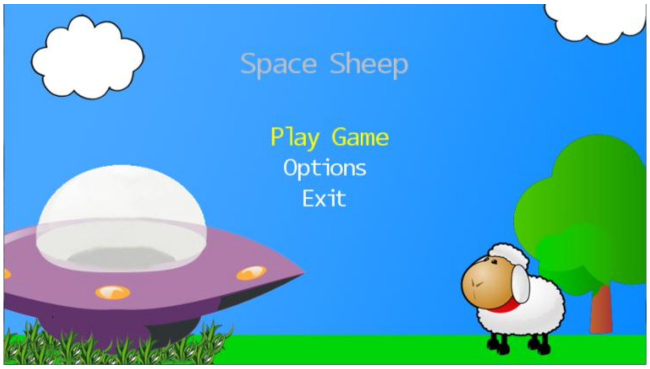


**Figure 2: Main menu of the game**

To be able to control the UFO, the player wears a neuroheadset named EPOC, which is equipped with fourteen sensors for measuring EEG activity.

### Transforming Brain Activity into Movement

To transform the EEG signals from raw data to actual brain activity, and to reduce noise in the signals, software designed for this specific headset is used. The software is a part of an application called "Smartphone Brain Scanner" developed at Technical University of Denmark (DTU) [11].

From the software, information about theta (4-8 Hz), alpha (8-13 Hz) and beta (13-20 Hz) activity in the frontal lobe and the temporal lobe are extracted. The extracted data is transferred through UDP to the game at 8 Hz.

Since the brain scanner application sends readings very fast, it is necessary for the game to make a rolling average over the input received. In the final game a window size of 12 is used for the rolling average.

When the player starts the game, a training screen appears (see Figure 3) for ten seconds during which a baseline for each band in each brain region is found. This is an important step, as the baseline is a point of reference for determining whether activity is improving or becoming worse.

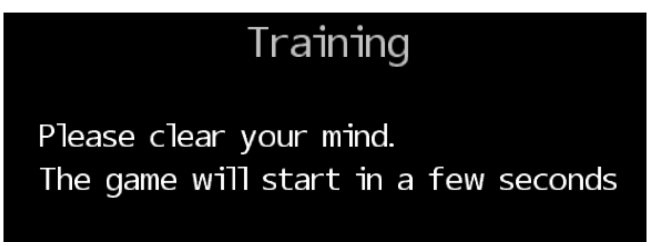


**Figure 3: Determining baselines at start of game**

When the player sees the training screen, a natural response is to pay attention the screen and concentrate on it, as the player expects the game to start any second. Thus the baselines are slightly lowered for beta band after training finishes. This also lowers the difficulty of the game, making it easier to play for an extended amount of time without becoming exhausted.

The direction of the movement is currently only determined by the activity in alpha compared to the baseline in the frontal lobe:

$$(\alpha > baseline_{alpha}) = MOVE_{LEFT}$$
$$(\alpha < baseline_{alpha}) = MOVE_{RIGHT}$$

The speed of the movement is determined by the difference in beta and theta for both frontal lobe and temporal lobe:

$$SPEED = c \sum_{r=1}^{2} w_r(\beta_r - \theta_r)$$

Where c denotes constant for speed, r is the region index (1 = frontal lobe, 2 = temporal lobe), and $w_r$ is the weight of a region. In the current implementation, the frontal lobe is weighted 0.7 while the temporal lobe is 0.3. These numbers are experimental and reflect no previous research.

Figure 4 shows an example of the gameplay, where the user is currently moving towards left, indicating that alpha activity is above its corresponding baseline. Beta and theta activities are not visible in the gameplay.


**Figure 4: Example of gameplay**

### Implementation Overview

The game has been implemented in an object-oriented manner, to ensure that the model of the brain, components of the game, and the game logic itself are separated.

This makes it possible to develop new games or other applications that process information about brain activity without modifying the game. It also allows the game to be disconnected from the neuroheadset, allowing the player to move the character at constant speed using the keyboard.

The full model of the implementation is attached in Appendix A.

If the game is connected to the neuroheadset, additional applications need to be running. The full system consists of following applications:

- **EEG Logger** – Reading raw EEG data
- **Handheld Brain Scanner** – Processing EEG data
- **Space Sheep** – The game itself
- **EEG Activity Logger** – Test application

All communication between these applications runs over different UDP ports and by use of threads to ensure a continuous flow of information and to avoid lag during gameplay. Figure 5 shows the information flow between the different applications.

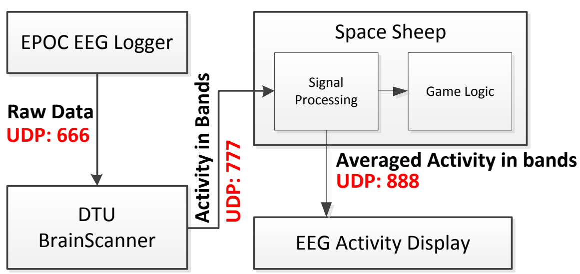


**Figure 5: Flow of information when using neuroheadset in game**

## TESTING

To see whether the game moves as intended, brain activity has to be visualized. The game has extended functionality to send all measurements of brain activity to another implemented application named EEG Activity Display. The application receives and displays all information in real-time.

Figure 6 shows the EEG Activity Display application. Each graph represents a band and contains the current activity as well as the baseline for the given band. The top graph represents theta (green), the middle represents alpha (red) and bottom represents beta (blue). The baselines are shown as continuous constant lines.

The y-axis of the graphs represents μW, being the raw power calculated by the handheld brain scanner application, and the x-axis is the amount of measurements received.

The figure shows a session, where in the beginning of the gameplay, after the training has completed, alpha and beta go slightly up, because the game suddenly starts. As the game proceeds, each time alpha (blue) passes the baseline, the direction of movement switches. Looking at the beta band, the concentration does not change much over time. This is a result of the player focusing heavily switching sides by relaxing and becoming tense.

The final peak in the graphs is caused by the player's decision to exit the game.

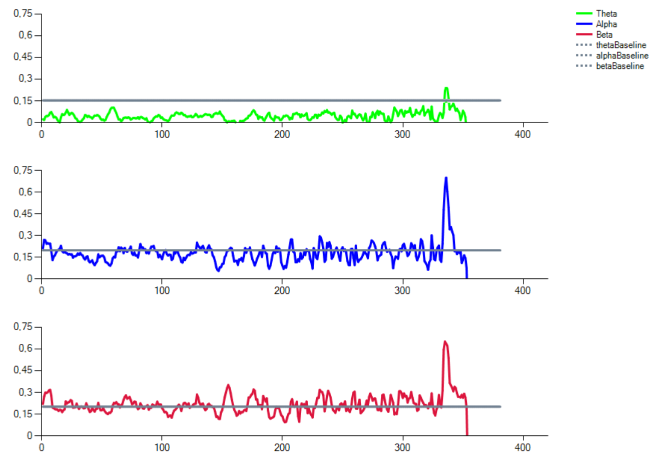


**Figure 6 Visualization of brain activity in frontal lobe with focus on movement**

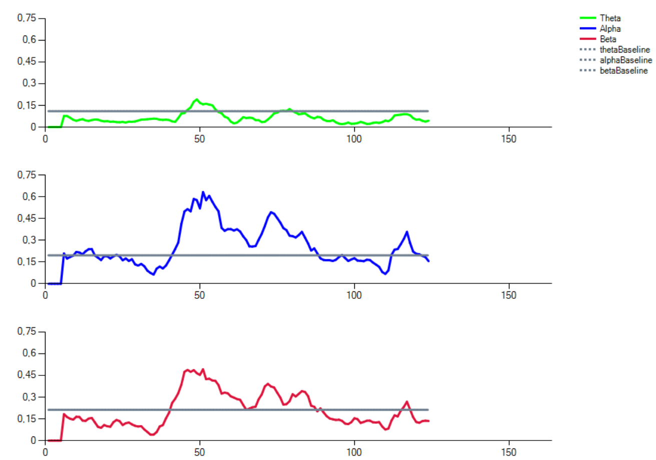


**Figure 7: Visualization of brain activity in frontal lobe with focus on movement speed**

Figure 7 shows another scenario in which the task is to move the UFO as fast as possible. Compared to Figure 6, the activity in both beta and alpha are much higher, showing that the player becomes tense when trying to move the ship.

Once the ship was moved to one side, the player had difficulties relaxing enough to start moving in the other direction before speeding up again.

From both figures over visualization of brain activity, it is visible that alpha and beta follow very similar patterns. This also means that with the current model, it is difficult to move at high velocity towards the right side, because alpha has to be low and beta activity often naturally also decreases.

## FUTURE IMPROVEMENTS

Most basic features are successfully implemented in the game, but there are still features that require improvements before the game can be distributed.

The current implementation does not take activity in temporal lobe into account. This means that while impulses, reasoning and judgment can be improved through playing the game, the emotional responses are ignored.

A difficulty setting is present in the options menu, but it does not change anything in the gameplay. This setting was meant adjust the baseline and the impact of the relationship between beta and theta activity, but was not implemented. The difficulty in the game has to gradually increase over time, to keep the game interesting for the player.

There will be periods of time where the player just needs to fly up, and another indicator of concentration can be implemented to help the player. The screen brightness can be a representation of the beta activity, going from normal brightness when the person is concentrated, to gradually darker brightness when the person is not concentrating.

The came be further improved by adding more different objects into the game, such obstacles or power-ups.

## DISCUSSION

Even though no people with ADHD have played the game and provided feedback on the content, the testing provided sufficient results in detecting things that have to be changed in the final implementation.

Testing shows that if the player wants to move from one side to the other quickly, it is important that alpha does not vary too far from its baseline, else it becomes hard to switch side. This makes the application good for training the player to remain in a certain state of mind, but does not encourage a different way of thinking. Thus, a different model has to be created for controlling movement, in order to increase alpha activity.

In terms of neurofeedback, it is better if the movement of the character is manipulated using traditional input devices such as a controller or keyboard. This allows the player to concentrate without drawbacks from movement restriction.

## CONCLUSION

During the project phase, two applications have been developed one for modeling and visualizing brain activity as and one for controlling objects (the game).

The modeling application is used to visualize and improve understanding of the alpha and beta bands and their usage as possible controlling variables for a game. It has also been shown that it is far from a trivial task to use brainwaves to control the game.

The game itself is a workbench that allows rapid test of the implementation of control system based on the output from the neuroheadset.


## ACKNOLEDGEMENTS

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# Appendix A – Class diagram for Space Sheep: