Low-cost Neurofeedback game for ADHD treatment using a smartphone device

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Abstract. This paper describes the development of a smartphone game that can potentially be used for ADHD treatment. The purpose of the game is to improve the player's ability to concentrate and stay relaxed at the same time. To achieve this, the player is connected to a portable neuroheadset that reads brain activity, and sends EEG signals to the game. The EEG signals are then used to control different parts of the game.

Keywords: ADHD, Context-awareness, EEG, Emotiv EPOC, Games, Experimentation, Mobile Applications, Neurofeedback, Neuroheadset.

1 Introduction

by Abdulla Ali

Attention deficit hyperactivity disorder (ADHD) is a development disorder which is not curable and is increasingly becoming a greater problem. There are many causes for ADHD, including genetic heritage, alcohol or smoking during pregnancy, traumas, toxins, food additives, and many more. [1, 2, 3] Common treatment methods include:

- Participation in social activities on which the patient afterwards reflects and analyzes causes of 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 promising treatment method is neurofeedback or Electroencephalography (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 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 has additionally also

shown that the primary difference in brain activity between ADHD patients and others lies in the frontal lobe and the temporal lobe (see Figure 1) [7,8, 9].

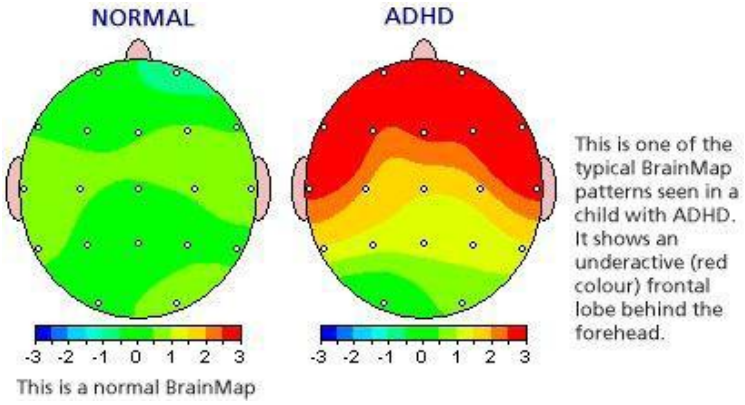

Figure 1: Comparing EEG of children with and without ADHD

While the neurofeedback is clinically proven to be successful in treatment of ADHD, it requires expensive technology and personnel to supervise the training.

1.1 Previous Work

In a previous paper the authors of this paper experimented with development of a game, where ADHD patients can do unsupervised self-treatment while wearing a low-cost neuroheadset [10]. The game was runnable on Xbox360 as well as any machine running a Windows operating system.

One of the conclusions derived from the previous paper, being the main problem, is, that the EEG signals are not utilized in an optimal manner. The game is controlled only through brain activity, which causes the player to get tired quickly [12].

In this paper, only the most necessary parts from the previous paper are summarized. This means that all preprocessing parts of EEG signals are not described in this paper, as no changes are made on these parts.

1.2 New Approach

In this paper, the primary task is to improve the overall user experience of the previously developed game – this includes removing the problem that the user becomes tired quickly.

The game is modified to run on smartphones with Windows Phone 7 (WP7) operating system. WP7 has been chosen as platform because most elements from the original game can be directly reused.

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.

2 Original Game Summary

by Adnan Vilic

The previously designed game, Space Sheep, is playable at all ages and has 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. To be able to control the UFO, the player wears a neuroheadset, EPOC, which is equipped with fourteen sensors for measuring EEG activity.

When the game is launched, a training screen appears (see Fig 1) 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.

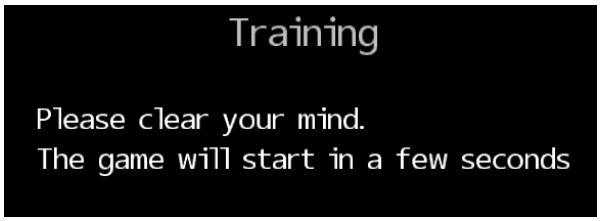

Fig. 1. Determining baselines at start of game

When the player sees the training screen, a natural response is to pay attention to the screen and concentrate on it, as it is expected that the game starts any second. Thus the baselines are slightly lowered after training finishes. This also lowers the difficulty of the game.

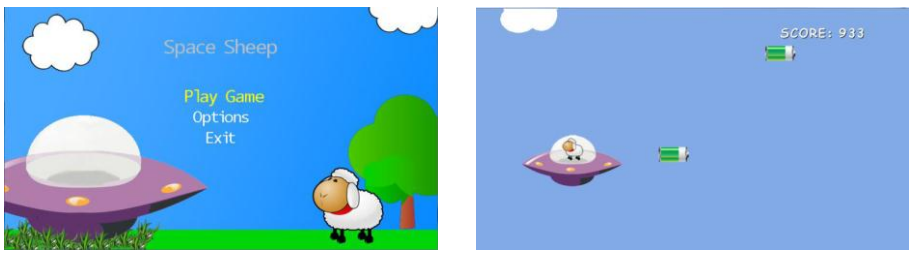

Fig. 2. The main menu is shown on the left. The actual gameplay is shown right, where the sheep is flying up, and has two batteries that it can pick up.

In the original game, the direction of the space ship (left/right) is determined by activity in the alpha wave compared to the baseline in the frontal lobe. The speed of the movement is determined by the difference in beta and theta for the frontal lobe.

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].

3 Space Sheep 2.0

by Adnan Vilic

The new version of Space Sheep preserves the concept of the upward flying sheep that needs to pick up batteries, while adding many new features. Since the game is now running on a smartphone, sensors are used to improve user experience and add more context-awareness. The new Space Sheep features:

- Different movement behavior
- Gameplay based on local weather
- More intractable objects
- Bonus stages for improved mind training
- Optimized memory allocation to fit smartphone requirements

3.1 Designing the prototype

When designing the game, the first decision that needs to be made is whether the game will have a low- or high fidelity prototype. A low-fidelity prototype is usually very limited in functionality and often consists of a paper prototype, while a high-fidelity prototype has many fully functional features, with which the user can interact. Both types of development have their advantages and disadvantages that have been discussed in more detail by Rudd et al. [13].

In this paper, a high-fidelity prototype has been developed because of the ability to explore and test in such prototypes. As an example, in the previous game, the game was controlled with thoughts alone, which seemed like a good idea, but in practice it turned out to be exhausting for the player. This is a design flaw that can only be discovered through testing or expert knowledge.

A great risk with a high-fidelity prototype is that it is very time-consuming to create. If the design is flawed from the beginning, many hours can be wasted on developing a useless prototype. To minimize the risk of developing a bad prototype, the design has been changed several times during development of specific features. The different design ideas are in Appendix A.

3.2 Movement

The first change that has been done is modification on the movement algorithm. Previously, the user would move the sheep only based on EEG activity in the frontal lobe. Depending on how relaxed the user is the sheep would move left or right. The movement speed would depend on how concentrated the user is.

The movement to either left or right is now done using the accelerometer. This means the user no longer needs to switch mentally between being relaxed and not relaxed, and can play the game for an extended period of time without becoming tired. To avoid fast direction switching when the phone is held almost still, the accelerometers' sensitivity is slightly reduced through simple if statements:

$$\begin{aligned} \text{if}(accelerometer.X < 0.015) &= MOVE_{RIGHT} \\ \text{if}(accelerometer.X > 0.015) &= MOVE_{LEFT} \end{aligned} \quad (1)$$

The speed still depends on the concentration of the user. It is determined as the difference between activity in beta, β, and theta, θ, waves multiplied by a constant, c. The constant ensures a fast speed when the user is concentrated.

$$SPEED = c(\beta - \theta) \quad (2)$$

3.3 Weather

An experimental new feature is weather dependent gameplay. The purpose of this feature is to increase context-awareness and thereby provide a slightly different game every time, so it does not become tedious [15]. It may also cause the player to launch the game while bored and simply looking at the weather.

Fig. 3. Local weather is already visible from start. From right to left, the screens represent weather types: sunny, rainy and snowy.

When the game is launched, the current GPS location is found and a request is sent to an online API from WorldWeatherOnline. The API returns information about temperature, wind speed, humidity, description of the weather and a code in XML or JSON format.

The API provides forty-seven different types of weather conditions. Since this application is a prototype, all types have been parsed into three types of weather:

- Sun
- Rain
- Snow

Once the request is retrieved, the background image of the game changes accordingly as seen in Fig 3.

3.4 Obstacles

by Abdulla Ali

Obstacles have been introduced that the player needs to evade. Each weather condition currently has one unique obstacle type which behaves differently (displayed in Fig 4).

Fig. 4. Obstacle types for each type of weather. From left to right, on a sunny day there are bee's falling down, during rain there's lightning and during snow, there are snowflakes.

Brief summary of obstacles:

- Sun: Bee that falls downwards fast (only one can be present at any time)
- Rain: Lightning that splits the screen (only one can be present at any time)
- Snow: Waves of snowflakes that fall slowly (multiple can be present at any time)

3.5 Bonus Stages

For an application to be successful, it has to be unique in some way. The uniqueness in the previous game was that the character was controllable solely based on brain activity. The new features that have been introduced so far do not make much use of the neuroheadset. In order to utilize the neuroheadset even more a new concept of bonus stages has been introduced.

During every gameplay, regardless of weather, portals will appear. When the player interacts with a portal by touching it, a bonus stage will launch. Bonus stages will always appear in the same order, so the player needs to fly higher to explore new content.

By adding a new dimension to the game, it makes it possible to change the gameplay completely. It does not need to revolve about the sheep fetching batteries to get higher. Each bonus stage is unique.

In the prototype, there is currently only one implemented bonus stage (see Fig 5). The sheep needs to shoot a wolf while at the same time avoiding bullets. The sheep is only able to move left and right, and cannot fall during this stage. In the top right corner, instead of the current score, the game now shows a focus meter. Once the focus meter hits one hundred percent, the sheep shoots every 600ms while having full focus. To complete the stage, the wolf has to be shot three times. If the sheep is hit the player returns back to regular gameplay.

Fig. 5. Example of a portal to a bonus stage (left) and the bonus stage itself (right)

To get the focus to one hundred percent and shoot, the user needs to be relaxed (activity in alpha wave). The higher the activity in alpha wave is, the higher the focus. One hundred percent focus is reached once the activity in alpha is thirty percent larger than the baseline for alpha.

3.6 Optimization

By Adnan Vilic

The final improvement that has been focused on is performance optimization. Since the game was originally developed for PCs, memory and CPU usage have not been taken into account. Smartphones are much more limited than regular laptops and PCs' and from the user point of view, it is important that the game does not stutter.

To optimize the performance, first an analysis of the application is done, resulting in the graphs in Fig 6 and Fig 7. The x-axis denotes time in seconds, and colors represent activity in different CPU threads, along with memory consumption. The thread colors represent:

- **Green** represents the User Interface Thread, and shows screen updates and touch inputs. As a general development guideline, this thread should not exceed 50% of CPU usage.
- **Purple** are application threads. These show all activity outside the UI, such as the game loop and timers.
- **Grey** are system threads that deal with the background tasks which are not in the application and yet affect the application.

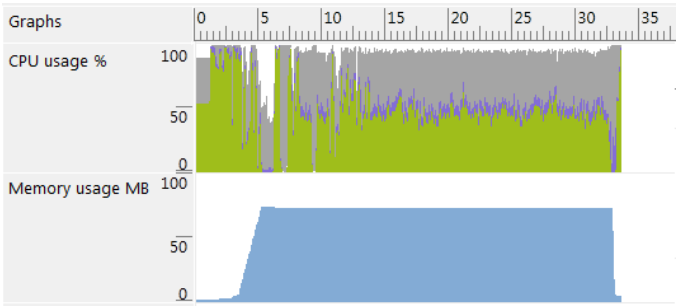

Fig. 6. Overview of CPU and memory usage *before* optimization

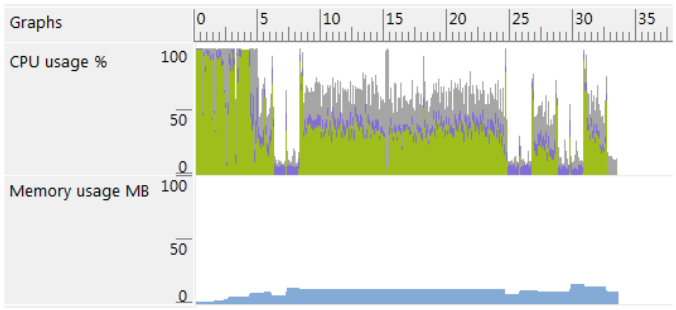

Fig. 7. Overview of CPU and memory usage *after* optimization

The user interface threads mostly stay around 50% as recommended and the usage of application threads are not very used. Together with the system threads however, all CPU usage is almost always about 100%, which often causes stutter. The reason why system threads consume so much of the CPU can be found in the memory usage. WP7 applications may not exceed 90MB of RAM usage, and so the system threads become responsible for handling the memory so that the application can continue to run.

Fig 7 shows the performance analysis of the optimized gameplay over the same amount of time. In the optimized game, the graphics have been resized in advance, so no scaling is performed, and content is only loaded when needed. E.g. every time the user enters a portal, everything except from the score, is removed from the regular game. Finally, the background now consists of only three background images which keep rotating, without giving the impression of repeating gameplay.

It is also important to note that the analysis in Fig 6 only contains the features of flying up, moving to the side and gathering batteries, while Fig 7 shows the same features as well as all new features described in this section.

4 Discussion

by Abdulla Ali

As in the previous paper, it was not possible to get any real ADHD patients to play the game and provide feedback. Even with ADHD patients, it would require thorough testing to conclude whether the game has any impact. Nevertheless, it is still possible for the developers to get a feeling of general differences in gameplay.

The game is now playable for an extended amount of time as intended, because the user does not constantly need to switch between being relaxed and tense. This poses a new problem though, because the gameplay difficulty does not change. In bonus maps, this doesn't have a negative impact because the user will be inside each bonus map for a much shorter period of time. This issue can be resolved by gradually adding more weather as the game progresses, and increasing the flying speed over time.

In a paper over self-tracking Gary Wolf [14] talks about how people monitor all sorts of activities and numbers for sharing, comparing and understanding aspects of their lives. A feature inspired by this paper, but not implemented due to time restrictions, is tracking of brain activity over time. Self-tracking can be implemented in the game as a separate menu item, in which the player can see charts over longest periods of focus, average activity in different bands, highest baselines etc.

5 Conclusion

The overall goals that have been set for this project have successfully been met. The game has been ported to a smartphone device, and the user experience has been improved by adding more features and context-awareness into the game.

The normal gameplay is controlled using the accelerometer and neuro-input in form of amount of concentration. Furthermore, new levels have been added where the user controls the gameplay with neuro-input in form of relaxation.
Multiple other improvements consist of location awareness and weather information.

The project phase has also given an insight to some considerations that need to be addressed when transforming a desktop application into a smartphone application. Especially the reduced computing power and the reduced amount of memory pose challenge. Improved memory management skills which have been acquired during this course period have been useful for solving this task.

Interesting thought:

As for the game, it is now also playable for an extended period of time (since the user does not get tired), which also poses a threat to the difficulty of the game. The difficulty of the gameplay does not increase over time and thus the game might become boring.

6 References

1. Causes of ADHD. http://www.myadhd.com/causesofadhd.html.
2. Attention Deficit Hyperactivity Disorder (ADHD) - Cause. WebMD http://www.webmd.com/add-adhd/tc/attention-deficit-hyperactivity-disorder-adhd-cause.
3. Forbruget af medicin til ADHD stiger voldsomt. MetroXpress. (2010). http://www.metroxpress.dk/nyheder/forbruget-af-medicin-til-adhd-stiger-voldsomt/pTejjm!23_1242-89/.
4. Very Difficult ADHD: Temporal Lobe ADHD. ADHD Information Library. http://newideas.net/adhd/different-types-adhd/temporal-lobes.
5. Brain Scanning. Sydney Developmental Clinic. 2005. http://www.sydneydevelopmentalclinic.com.au/brain_scanning.htm.
6. Emotiv. http://www.emotiv.com/.
7. 15.000 voksne får nu ADHD-medicin.TV2, 2010. http://nyhederne.tv2.dk/article.php/id-45516268:15000-voksne-f%C3%A5r-nu-adhdmedicin.html.
8. Rabiner, Dr. David. Neurofeedback/ Quantitative EEG for ADHD diagnosis. 2008. http://www.sharpbrains.com/blog/2008/11/23/neurofeedback-quantitative-eeg-for-adhd-diagnosis/.

9. Nauert, Rick. PsychCentral. 2007. http://psychcentral.com/news/2007/09/06/childhood-television-watching-correlated-to-later-attention-problems/1238.html.
10. Leavitt, Lydia. Brain scanner app lets you show off your smarts on-the-go. 2011. http://www.engadget.com/2011/09/16/brain-scanner-app-lets-you-show-off-your-smarts-on-the-go/.
11. Gevensleben, Holger. Is neurofeedback an efficacious treatment for. Journal of Child Psychology and Psychiatry. 2009, Vol. 50, 7.
12. Adnan Vilic, Low-Cost Neurofeedback Game for ADHD Treatment, http://www.setzner.com/wp-content/uploads/2012/03/s052240_ADHDtreatment.pdf
13. Jim Rudd, Ken Stern, Scott Isensee, Low- vs. High-Fidelity prototyping debate.
14. Gary Wolf, Know Thyself: Tracking every facet of life, from Sleep to Mood to Pain 24/7/365
15. Yvonne Rogers, Moving on from Weiser's Vision of Calm computing: Engaging UbiComp Experiences.

7 Appendix A

Throughout the design and development phases, several other designs have been considered for the game, which have been left out from the main part of the report, to avoid confusing the reader with what is part of the actual implementation and what are only considerations.

7.1 Weather

The initial idea with the weather was that small lightning's and snowflakes would come out of the clouds during rain and snow.

In case the ship is hit by snowflakes, it freezes to ice and starts falling. While the sheep is falling, the player needs to concentrate and relax, to heat up the ship. This idea was discarded because the player would most likely get excited or stressed when something happens to the ship, and it will be difficult to calm down fast.

After discarding this idea, portals to bonus stages have been introduced because the neuroheadset is, as in the original game, not used optimally.

Fig. 8. Sheep freezes after touching snow

7.2 Health

Another discarded idea is health indicators for the wolf and the sheep. The feature extends the gameplay by not ending the game if the sheep gets hit by an obstacle. Two options have been discussed for health indicators; one is a health meter which decreases with a certain percentage each time the character is hit, and another showing damage on the character.

Visualizing the damage on a character is preferred, since health loss is meant as a discrete variable. The health idea was removed for the sheep, as it was decided to be a superfluous feature. Due to time restrictions, it was not possible to visualize damage on the wolf.

Fig. 9. Example on health loss