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USING BRAINWAVES AS A CONTROLLER IN GAMES

– how games can use Senzeband

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USING BRAINWAVES AS A CONTROLLER IN GAMES

– HOW GAMES CAN USE SENZEBAND

Senzeband is a neuroband, an electroencephalogram (EEG) measuring device which measures different kinds of brainwaves. With these measured values, Senzeband can be used for many kinds of applications, for example, as a controller for games, which has been the basis of this study.

This thesis examines how the different values can be used as a controller in games. The main objectives were: (a) to find out what the best practice is when using a brainwave measurement device as a controller in games; and (b) to acquire an understanding of user experience when using brainwaves as a game controller. For this purpose two different games were used: a memory card game and the Paavo Nurmi Games running game. For the first game, the objective was to study if it is possible to use different brainwaves as a controller in games and for the second game, the objective was to investigate the possibilities for an entertainment-oriented game and the entertainment value, the "fun factor", in such a game. The memory card game was developed by the researcher for the purpose of this study, while the Paavo Nurmi running game is a game which was developed in Turku Game Lab for Microsoft Kinect and was adapted for use in this study. This game was modified to use a brainwave measurement device, more precisely the controller method was changed from camera-based to Senzeband-based.

This study made use of development journaling as a discussion aid for explaining the best practices for programming with brainwave measurement controllers. The study also observed gameplay during and interviewed several users after playing the Paavo Nurmi game to determine what their experience with brainwave controllers was like.

The result of this study was that it is possible to use Senzeband as a controller, but it is difficult to use all the possible measurements and, therefore, the recommendation is to use only the beta wave readings for game control. The study also shows that brainwave controllers provide a fun factor and can also be used in a game that is developed for entertainment purposes.

KEYWORDS:

brainwaves, EEG, entertainment, entertainment industry, game sector

CONTENTS

FIGURES

LIST OF ABBREVIATIONS (OR) SYMBOLS

Abbreviation	Explanation of abbreviation (Source)
ADHD/ADD	Attention deficit hyperactivity disorder (ADHD) and attention deficit disorder (ADD) are types of deficits in ability to concentrate and process information.

(https://www.healthline.com/health/adhd#add-vs-adhd)

BCI	Brain Computer Interface. Sometimes called a neural-control interface (NCI), mind-machine interface (MMI), direct neural interface (DNI), or brain–machine interface (BMI), is a direct communication pathway between an enhanced or wired brain and an external device.

(https://en.wikipedia.org/wiki/Brain%E2%80%93computer_interface)

EEG	An electroencephalogram (EEG) is a test used to evaluate the electrical activity in the brain. (https://www.healthline.com/health/eeg)
PNG Games	Paavo Nurmi Games game collection. A series of games developed in Turku Game Lab
SDK	A software development kit (SDK or devkit) is typically a set of software development tools that allows the creation of applications for a certain software package.

(https://en.wikipedia.org/wiki/Software_development_kit)

UI	User Interface (UI). Simplified: UI is how things **look.**

(https://medium.freecodecamp.org/whats-the-difference-between-ux-and-ui-design-2ca8d107de14)

VR	Virtual reality (VR) is an interactive computer-generated experience taking place within a simulated environment. (https://en.wikipedia.org/wiki/Virtual_reality)

1 INTRODUCTION AND THEORETICAL FRAMEWORK

Physical and mental states are closely related in a person’s well-being. If a person is not using their brain, this results in deterioration of the mental capabilities of this person in the same way the physical state deteriorates if one is not exercising physically. (Tucker-Drob, Salthouse 2008). For instance, it has been studied that elderly people need mental as well as physical training to maintain their physical and mental state of their body while growing older. For example,there has been studies investigating Microsoft Kinect in exergames as a means of to prevent elderly people from falls by training their physical condition (Garcia, Navarro et al. 2012). One answer to this challenge of the deterioration of the mental abilities is to train the brain through doing cognitive exercises that trains the brain to work at maximum level. New devices that measure EEG waves have been coming to the global market during the past few years. This thesis researches the possibilities in theory and in practice with devices that read EEG waves to train brain activity. This will be achieved by selecting one device to be researched more closely and by attempting to create an application that will train the brain activity of the player.

Senzeband, selected from devices that read EEG data is developed and manufactured by a company in Singapore, Neeuro. The reason for selecting Senzeband was that it is a simple solution to a complex problem of reading brain waves. The device looks simple and it is easy to use, compared to other similar devices. One of the main reasons for choosing Senzeband is that it does not require calibrating the device for each different user, therefore, making it more accessible than the alternatives. The greatest competitor product, Epoc Emotiv, for example, is more complex (Figure 1) and it requires a longer calibration before it can be used. This study was carried out in Turku Game Lab, which is a joint working environment of University of Turku and Turku University of Applied Sciences, which provides services in game education and development. Turku Game Lab established a working relationship with the developer of Senzeband and has been able to obtain a device to test in-house and have easy access to information on the operation and use of the device directly from the developer. This study also assumes that the cost (or average price tag for the consumer) of the device is a factor for an average user so it is advisable to develop applications for devices that would be more within reach for the consumer. At the time of writing this thesis, the price for the Epoc+ device was more than two times that of the Senzeband.

Figure 51: Visual physical comparison between Senzeband (right) and Emotiv's EPOC++ (left)

Senzeband observes brain activity by measuring brainwaves of five different kind: Delta, Theta, Alpha, Beta, and Gamma. Senzeband SDK also gives developers three kinds of data, which are calculated from the brainwave data: attention, relaxation and mental workload.

1.1 Using brainwaves as a controller

Using brainwaves as a controller is a part of the advanced brain computer interface (BCI) (Schalk, McFarland et al. 2004). Neeuro's business concept has been to use this interface as a brain training platform, in other words, to use Senzeband to train and measure the brain activity. Neeuro intends its product to be used to medically train the brain so that it would stay in optimal condition and is developing applications for that purpose. Senzeband is, in fact, with Memorie Mobile, Neeuro's collection of brain-training programs, a platform for brain-training.The Memorie mobile platform allows one to train different areas of brain and follow one's progress. Senzeband has four forehead sensors, which measure brainwaves independently. (Neeuro 2017)

Emotiv has taken a different approach to the advanced brain computer interface. The Company's device Epoc+ is more targeted for gamer's and game developers. It has more sensors than Senzeband and 14 mobile channels. Emotiv also has a shop for applications, but with very few games. Although games are scarce on the Emotiv store, there is Unity3D support for Emotiv's products that can be purchased from the shop.

Measuring brainwaves has traditionally been performed usually for medical purposes by means of highly sophisticated technologies and machinery. During the past few years there has been discussion to use brainwaves in more than it was thought originally when these devices were developed. For instance, in the early 2000 the focus on the research of BCI shifted from measuring brainwaves to producing solutions for people with motion disabilities. Many people~~,~~ who require augmentative communication technology~~,~~ because of possibly diminished muscle control can use BCI based brainwave scanners (Gao,Xu et al. 2003; Schalk, McFarland et al. 2004). During the past decade, the market has seen the introduction of devices for purposes that go beyond medical application. Especially interesting~~,~~ has been the use of brainwave scanners as an entertainment game device. The research of BCI has naturally continued with solutions to enhance the quality of life for those with disabilities, but there has also been focused work on the use of BCI in games and as a controller in other applications (Chen,Shi 2015). At present though, using EEG as a controller in games is still a fairly new research field and for the Senzeband device, the main use of EEG is for brain-training with the Memorie Mobile (Figure 2) A~~a~~ndroid application.

The Neeuro company has developed games of a particular type kind, which the player can play to train their brain activity. Some games measure brain activity during problem-solving, but some do use Senzeband as a controller. For example, the helicopter game uses the player’s attention to control the movement of the helicopter (Neeuro 2017). Emotiv and some other developers, such as Mindwave, are using their devices as a controller, but their products have not yet come to greater success. In the field of entertainment games, the research is even more in the early stage and no published evidence about the Neeuro helicopter app’s brain training effectiveness could be found at the time of the writing of this thesis. Moreover, research in the past two years is more concerned (and rightly so) with experiments on the technical possibilities and measuring the validity of using brain waves as a game controller. No work could be found up to the time of writing this thesis that explicitly researches player experience with BCI controllers.

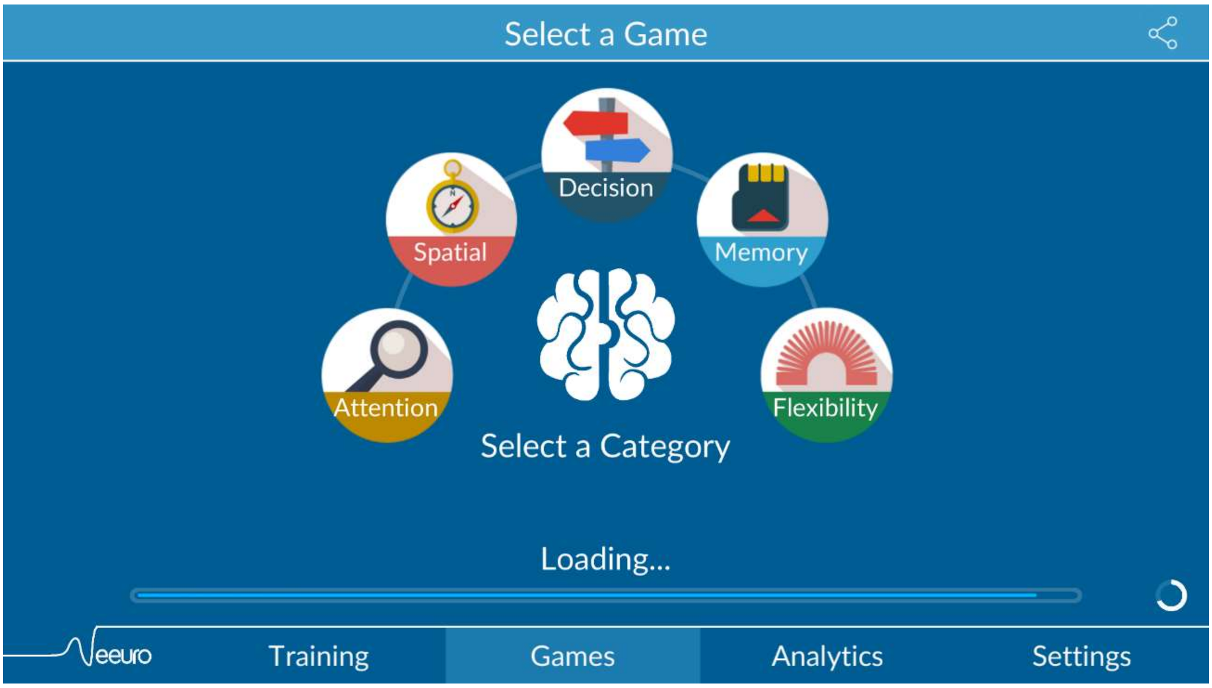

Figure 62: Memorie Mobile’s UI of different game categories

1.2 How measuring brainwaves works

Devices that use EEG work by measuring the electrical activity of the brain and this brain activity can be differentiated to brainwaves of different kinds. Senzeband measures low frequency signals on the forehead, which are picked up by four individual sensors, giving four individual channels of brain signals. The brain signals are within the ranges of 0.5 to 100 Hz with amplitudes in the region of microvolts. As mentioned earlier, Senzeband differentiates between five kinds of brainwaves.

The five brainwaves that Senzeband measures are as follows.

1) Alpha waves are in the range of 8 to 13 Hz and when they are in a active state the person is relaxed.

2) Beta waves are in the range of 13 to 30 Hz and an active state represents the user’s attention.

3) Delta waves (0.5 to 3 Hz) are slow waves that suspend external awareness and are the source of empathy.

4) Gamma waves (38 to 42 Hz) are the fastest and densest of all brainwaves that were previously thought to be just “brain noise”, but nowadays gamma waves are considered as relating to expanded consciousness and spiritual emergence.

4)Theta waves (3 to 8 Hz) are fairly slow waves, similar to delta waves, and are dominant when the person is asleep or exercising deep meditation. (Brainworks)

Besides these five raw values, the SDK also provides processed values. These calculated values represent attention, relaxation and mental workload. From these, the attention and the relaxation values were tested and used in the development of two games for Senzeband, the memory card game and Paavo Nurmi running game for Senzeband. In later SDKs, which were obtained during developing these games, the mental workload processed value is not available anymore. Attention is considered a state of readiness, such as when one is focused on some assignment or one is attentive. The first hypothesis, when trying to create a game that uses Senzeband as a controller, was that attention and the high activity in beta waves mean the same subject Relaxation is somewhat the opposite of attention. One is relaxed when one is not focused on an assignment, meaning that one’s mind is in a resting state. Thus, the relaxation value was assumed to be the same as a high state of alpha wave activity.

2 PROBLEM STATEMENT

The situation is at the present time as described earlier: Senzeband is focused on monitoring brain activity during brain training games, while EPOC+ is more focused to use brainwaves as a controller in entertainment games. That is, the company Emotiv is not so much focused on mental training and its possibilities. If these two different approaches could be somehow joined together, it could become more interesting for the average user to use the EEG-based devices. The target audience with this kind of combination would be larger than the target audience of the sum of the individual approaches. This development could eventually lead to the EEG measuring devices' increased popularity, so that it would become a desire for an average computer gamer to own that kind of device. Although somewhat ahead on the entry-to-market curve, similar development is going on, for example, with virtual reality headsets.

This thesis studies the possibilities of combining brain games with games that are directed for entertainment purposes. This could lead to the large scale utilization of the EEG controllers for the games in the future. The device could become one gaming platform, as VR devices are nowadays. As with early VR research, in order for producers to make business sense to produce large quantities of BCIs, it must be determined if players will actually enjoy playing games with a BCI as controller. Since no direct research could be found that answers this question, this thesis sets out to scratch the surface of player sentiment toward BCI as a game controller.

Another problem that game developers face when developing games for BCI is that they tend to be lost in trying to understand EEG theory even so much that they give up shortly after starting, or never even start at all. Senzeband and Neeuro have made some work toward removing the need to understand EEG theory and the usual game development tasks. Senzeband provides an SDK with access to real-time processed values (attention, relaxation and mental workload) that are easy to understand, as well as raw brainwave data (alpha, beta, delta and theta activity). However, due to their complexity, this study chose to not consider gamma waves at all. Now one is faced with the question whether developers should rather work with the processed values or the raw data.

3 AIM AND OBJECTIVES OF THE STUDY

The aim of this thesis is to determine the practical implications and end-user perceptions of using the Neeuro Senzeband as a game controller. The aim is to build applications to show whether Senzeband is a suitable controller, both from a development and user perspective, for brain training gaming. This thesis does not cover the testing of brain training's effectiveness, which could maybe be a topic for another thesis. In order to meet the aim of the thesis, the following objectives were put in place:

- To study which brainwave data are the most suitable to be used to control a game. Are the calculated values for relaxation, attention and mental workload easier to develop with than the alpha, beta, delta and theta raw value activity and which of these sets of values provide the most precise outcome?
- To study user reception of controlling games with a brain controller interface. Do players enjoy using the Senzeband as a game controller?

4 METHOD

First it had to be determined what kind of data is needed when using Senzeband as a video game controller and how to use this data in developing games for Senzeband. This was done by developing a game for Senzeband and experimenting with different kind of values, both raw and calculated, and experimenting with different brainwave values. For this purpose, a memory card game for Senzeband was created. The memory card game was designed is such a way that it was possible to compare two raw value activities against two calculated values. The author used a technique called development journaling to keep track of his experiences in developing with the raw values and then with the calculated values. Although the research result of this activity relies quite heavily on the experience of the author, brainwave specialists were also consulted about best practices in developing games for Senzeband.

User sentiment was tested with user-oriented research by means of observation during gameplay and interviewing players once they had completed a gaming session with the Senzeband BCI. To study the presence of a “fun factor” of BCI control, the Paavo Nurmi Games running game was adapted for Senzeband. Paavo Nurmi Games is a collection of sport games which were developed in Turku Game Lab for the Microsoft Kinect platform, simulating real life sport competition. One of these sport games, the running game, was selected to test the main assumptions and questions of this thesis. Paavo Nurmi Games Senzeband game was tested for enjoyment with the author of this thesis and five other test subjects. The Kinect version of the running game could be played in single- or two-player mode and the author attempted to replicate this in the BCI version.

The test subjects were taken from several backgrounds; (a) experienced gamers from Turku Game Lab were used because they were more familiar with what makes games fun; (b) individuals with (one diagnosed and the other suspected) some form of attention deficit disorder (ADD) to confirm the reliability of the BCI (i.e. the author expected these individuals to display a lower performance with the BCI than the healthy test subjects) and suitability for all kinds of individuals; and (c) non-(regular) gamers to check how easily BCI could be understood by new players.

During each game, the test subjects were observed to gather any evidence about the “fun factor” and interviewed after the game how they liked playing. Both games, the card game and the Paavo Nurmi running Senzeband game were tested with similar experimental setup. The main difference was that the running game was tested in two-player mode (as originally designed).

The contribution of this study is to make a base for further study on the user experience of BCI as a game controller and provide some practical guidelines for game developers, who would like to develop games that use Senzeband as a controller. This can lead, as mentioned earlier, to more Senzeband games and recognition of Senzeband as a real gaming platform.

5 WORK DESCRIPTION

5.1 Development process for the memory card game

The first assignment was to study the possibilities and restrictions of Senzeband by creating a game that uses Senzeband as a controller. The task was to program a memory game with Unity3D game engine. Figures 3 and 4 show the Android interface for the memory card game. The researcher used Android because the Senzeband SDK, at the time of development, was only available for Android. After the Android version development, the purpose was to transfer the Android project to the platform of PC as soon as the PC version of the SDK was obtained from the developer. The idea of the game was to find a corresponding pair of cards by turning them over one-at-a-time. The scoring system was based on how many pairs player found. Initially one would have eight cards, which would be faced down. First one turns one card over and trys to find a pair for it by turning a second card. If cards constitute a pair they remain faced up. If not, they will be returned to their original faced down positions. The game continues until all cards are faced up, so one would see all the pictures in the cards, which means the player has won the game.

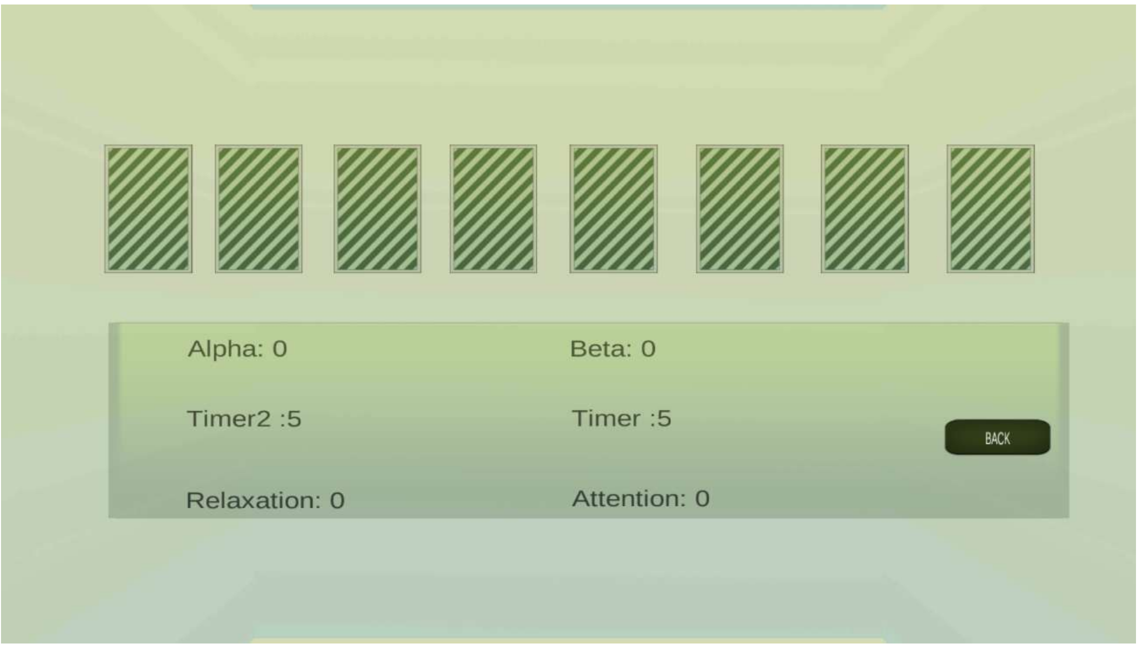

Figure 73: Early stage UI of the Android memory card game

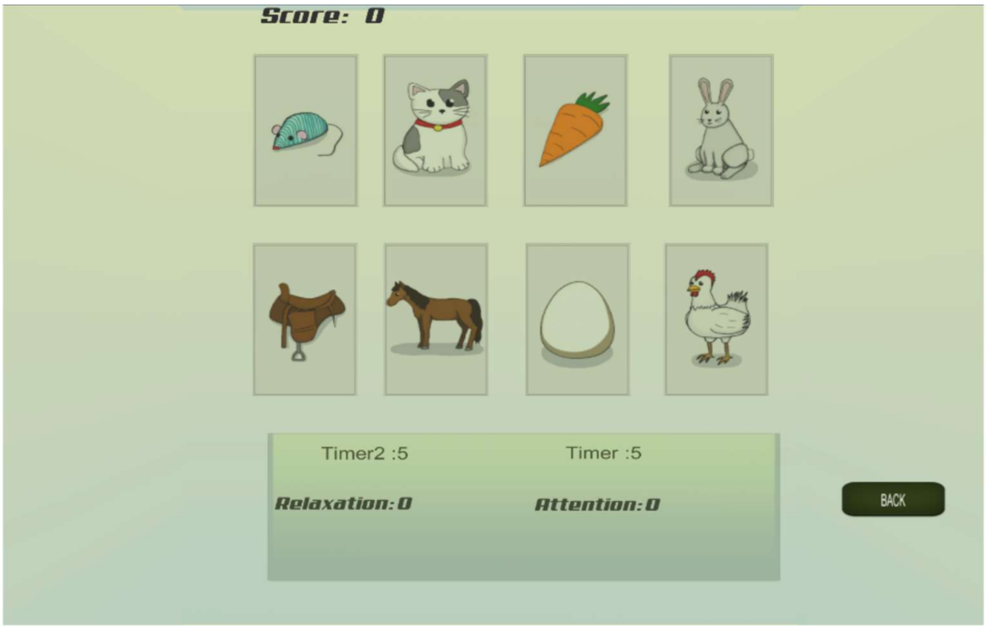

Figure 84: Later version of the memory card UI with all cards turned

At first, the author researched and tested different brainwaves. It became clear that only two of the available brainwaves should be used, for the main reason that it wouldn't be possible in the scope of this study to study the brainwaves more closely. Also the nature of the brainwaves influenced this decision, delta waves and theta waves correspond to empathy (or external awareness) and sleep (or deep meditation) respectively. Neither of these have an easily recognized connection with games and gameplay. Also, different brainwaves overlap each other and in order to get clear results, brainwaves that appear to be opposite in nature were more interesting for closer inspection. It was decided to use alpha and beta waves as they represent perceptibly opposite ends of human brain activity. Relaxation (alpha waves) and concentration (beta waves) were thought to be obvious brain activities that take place when gaming and good activity spectrums for brain exercising. Even while this decision was made, there was still a definite element of overlap between the two sets of waves. It seemed that even if the brainwaves in question were the opposite brainwaves of each other, they sometimes changed regardless of each other. If brainwaves are to be used more extensively in game development, it should be researched how a BCI, one is developing for, handles different kind of brainwaves.

In this study phase, two kinds of brainwaves were used. Beta waves represent user attention or concentration and alpha waves represent the user's relaxation level. From Senzeband's SDK, that controls the connection to the end device with Senzeband, the developer can receive different values. These values include both values for different brain waves (raw values) and values for concentration and relaxation (calculated values) levels. One has access to these values in the code of the SDK through a file called *useEEG.cs*, which contains values both for raw values and calculated values. There is an existing array in the SDK that one must access to obtain these values.

Initially, during the process of experimenting with different brainwaves, the raw values for all brainwaves that one can get from SDK were used. After the initial phase, beta and alpha waves were chosen for closer inspection and used as a basis for this thesis for the reasons explained earlier. After this, it had to be decided also whether to use raw value or calculated values. At first, the calculated values (relaxation and attention) were tested and used in the memory card game. To get a more dependable result, the author also tested with raw values (alpha and beta values). The range for both these values was from 0 to 1, 0 meaning no concentration or relaxation and 1 means a high state of concentration or relaxation. The challenge with these values however, was that they can change from 0 to maximum in a very short time period. The solution to this problem will be explained later in this thesis.

For the turning of the first card, Senzeband's attention value was used. For turning the second card (of the potential pair), the relaxation value was used. In order to turn a card the user had to mentally control the brain wave activity beyond a certain threshold value – the threshold value was a number on the 0 to 1 scale of the SDK representations of the various brain activities (in this case alpha and beta). Threshold value was used as a trigger for the event of turning a card – if the brain activity went beyond the threshold value, a card would turn over. The alpha and beta threshold values were determined through trial and error. The values were initially set to 0.4 and then lowered because it seemed that at that level it was really hard to turn cards. The testing process to determine the threshold value was repeated several times and resulted in setting the relaxation threshold to 0.2 and the concentration threshold to 0.25. The scope of this thesis does not include investigating whether these values are significant in brain training. The values were chosen to ensure that players would have a fair chance to experience using a BIC as game controller. In other words, the threshold values presented enough of a challenge to not generate a state of boredom, but were also not so challenging that they caused anxiety or frustration among players. The memory game was played as follows: if the user wanted to turn the first card, one had to try and concentrate their brain to such an extent that the beta readings went higher than the threshold. The player then had to perform the opposite for turning the second card. That is, elevate their relaxation levels so that the alpha waves went beyond its respective threshold value. The rest followed the usual memory card game rules. Figure 5 shows the UI of Senzeband's control panel and indicates the measurements that can be obtained.

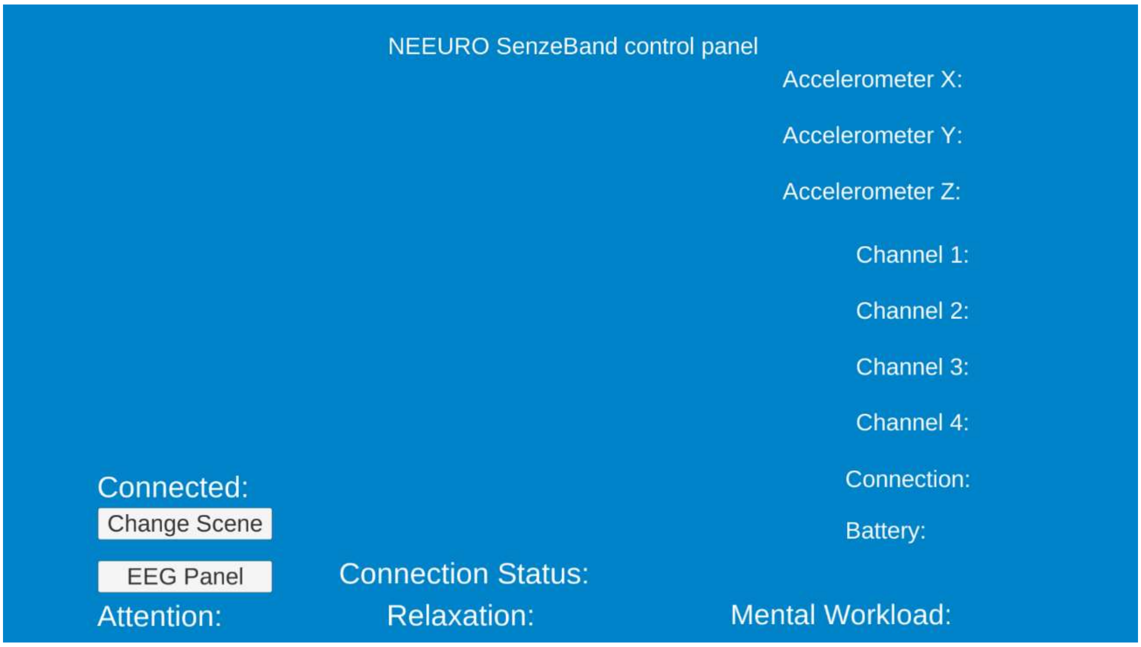

Figure 5: UI of the Senzeband control panel

Initially the game mechanics were conceived so that first one has to concentrate and maintain their attention level for a period of time which was determined to be five seconds. The mechanics of the timer were included in the following series of actions: (a) one would select the card that one wants to turn; (b) the five-second timer would start once one has obtained a concentrated state beyond the threshold value; (c) after five seconds, the game would measure player's concentration level again. If your concentration level was still beyond the threshold value, the card would turn over. Basically, the game measures whether able to maintain a concentrated state for a certain period of time – five seconds in this case. Turning over a single card, using concentration levels went fairly well and now the task was to see if relaxation levels could also be incorporated in a similar fashion. Figure 6 shows the Unity state machine for turning cards.

For turning the second card, two five-second timers were used. The first timer "listens" to the attention and the second timer "listens" to the state of relaxation of user's mind. Once the first card has been successfully turned over, the user is able to select the second card for turning over. Once the card is selected, the second timer activates immediately. After five seconds, the game checks the player's relaxation state. If the relaxation state is beyond the threshold value at this point in time, the second card turns over. If the cards are a corresponding pair they remain turned over and the player can continue to try and find the next pair according to the usual rules of memory card games.

In summary, the game checks to see if the player is first able to maintain a certain level of concentration for five seconds (turn the first card) and then switch to a predetermined level of relaxation within another five seconds (turn the second card). This 10-second game loop is repeated until all matching pairs are found, thus creating a cyclical attention-relaxation brain training pattern for the player.

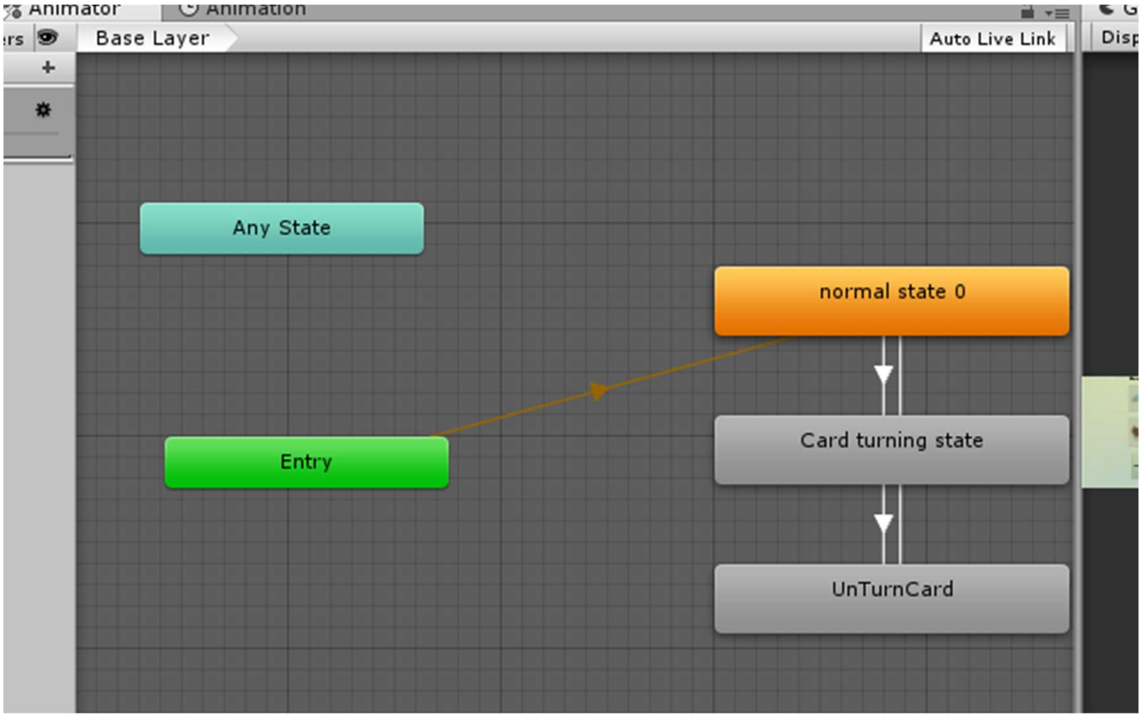

Figure 6: Unity's animator state machine showing the card-turning states

During the development process it became obvious that the brainwave states were somewhat erratic. The values changed very quickly from zero to complete relaxation or concentration. The author had to find out if the reason was in the user's concentration or relaxation abilities, in the device itself or in the SDK. Other coding also had to be taken into account because depending on the timing of the measurement, it could distort the values. After some further experimentation, without a suitable answer to the problem, the author opted to use some kind of mean of the values for concentration and relaxation.

An algorithm (Figure 7) was written that calculated mean attention and mean relaxation values in a timeframe of about 2.5 seconds. The algorithm measures values every 0.25 seconds and calculates the arithmetic mean of these values. The goal of this algorithm is to decrease the erratic behavior of these values, making the measuring of these values more stable. These values were then used during the rest of the development process because it seemed that they worked best—the problem was considered solved.

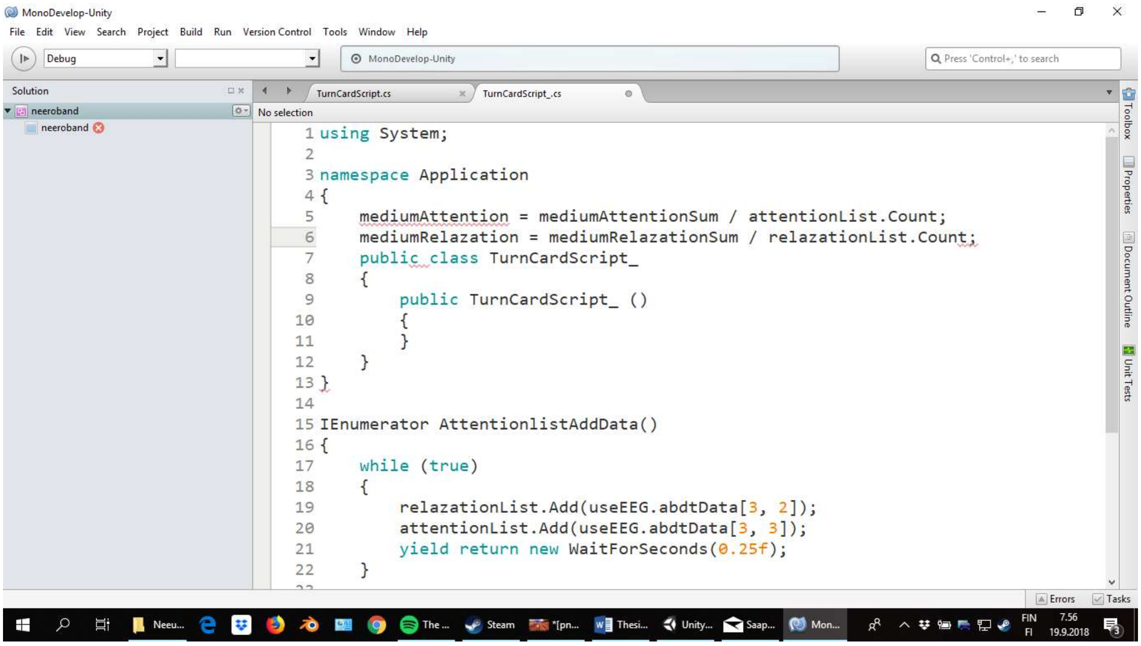

Figure 7: Code snippet of algorithm that calculates average brain wave readings

In order not to break the player's concentration-relaxation cycle, the cards needed to be turned over smoothly, but without losing the realism of playing an actual memory game. For this animation of turning the cards, Unity's animation tools were used. Although it is fairly basic, one can make animations quickly and this allowed the author to test various turning permutations. After some expert evaluation of different animation cycles, it was decided to use a 180-degree card rotation in 1 second (Figure 8).

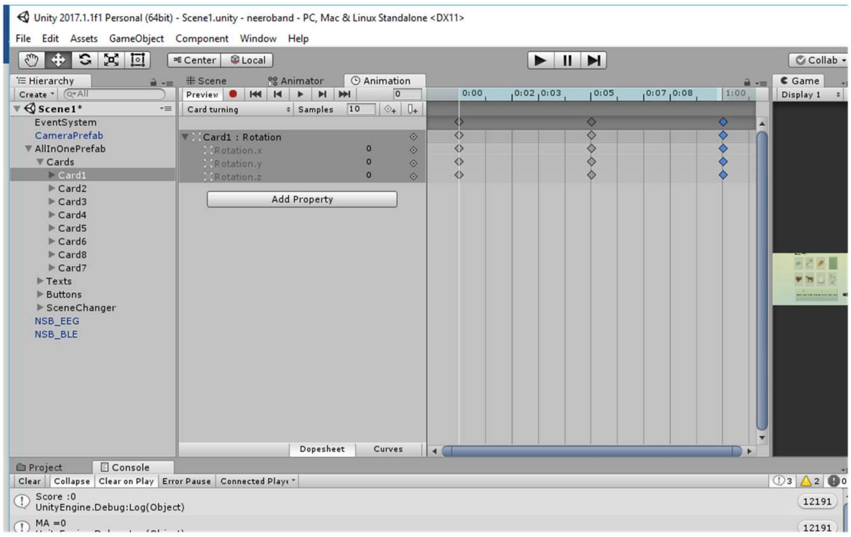

Figure 8: Unity animation tool showing the card-turning animation cycle

5.2 Developing the Paavo Nurmi Games Senzeband game

After learning about how to use Senzeband raw and calculated values with the Android memory game, the next step was to determine if players enjoyed playing with BCI controllers. At this phase in the research, Neeuro made the PC SDK for Senzeband available. This meant that the author could use an existing game and modify the controls in such a way that it would “listen” to the Senzeband brain wave scanner as input device. The choice to use an existing game and modify it, allowed the author more time to investigate the user experience with a BCI controller.

The author chose to use a two-player game so that the possibility of using multiple Senzeband sensors simultaneously could also be investigated. This was not the primary focus of the study and was therefore not explored extensively. The author opted for the Paavo Nurmi Games suite, developed at Turku Game Lab, and made use of the running game for this experiment. The Paavo Nurmi running game was made for the Xbox and this meant that the author had to convert the controller from Kinect-based motion detection to Senzeband. The primary mechanic in the running game was that the player would physically run on the spot. The Kinect camera would track the player’s movements and project these onto the on-screen character. The faster the physical running became, the faster the on-screen character would run. The Kinect camera used the player’s knee movements as an input for running speed. The camera was able to pick up two players at the same time, enabling them to run against each other over a virtual distance of 100m. The game could also be played in single-player mode, where the player character would run alone along the 100m track and the completion time would appear on a leader board.

The idea was to only change the controller for the game, without changing the main goal of winning a 100m sprint. Through the memory card game experiments, it was decided to use concentration to a control the character in the game. If user’s concentration was at a low level, the character would walk in the game and as the player’s concentration increased, the on-screen character would start to run faster. The player’s goal would be to obtain a high level of concentration from the start and maintain it, in order to get as fast a time as possible for the 100m sprint. Unfortunately, the author soon learned that there were some major technical difficulties, due to Bluetooth connection limitations (connection speed and data transfer rates), in implementing multiple Senzeband controllers at the same time. As stated earlier, the simultaneous use of multiple Senzeband controllers was not the focus of this study. Hence, the author did not spend a significant amount of time to try and resolve the problem. This meant that players could not “concentrate against each other” at the same time. To continue pursuing the multi-player option, the author created a so called hot-seat mode whereby first one player would run a 100m and then the second player would do the same—the times would be compared after both players completed their runs. In this fashion, players were still able to compete, but in a turn-based manner.

The first development goal was to change the controller method to support Senzeband. At first it seemed a fast and straightforward task, but in the process it became evident that it was harder and a more time-consuming task than initially estimated. The game was developed only for Kinect and the mechanics were executed with only that controller in mind. At that stage it was clear it would require a lot of work and time to modify the code so the game would accept Senzeband as a controller. After some examination, it was decided to remove all code that was linked to Kinect and then replace it with new code from Senzeband’s SDK. There were some version compatibility problems because the Senzeband SDK, at first, only supported an older Unity version than what the Paavo Nurmi game suite was developed with. An updated version of the SDK, obtained from Neeuro, resolved this issue.

The first steps of development, therefore, involved removing existing Kinect code and all code related to simultaneous two-player gameplay. The strategy was to first implement a one-player version only and later work on the competitive hot seat mode.

Based on the earlier tests with Senzeband in the memory card game, it was decided to control the character in the game with only one value, concentration. This was selected for several reasons:

a) In the card game, it was quite difficult for the player to change from a concentrated (or alert) state to a relaxed state;
b) A relaxed state implies that the player may close their eyes and this would mean missing some of the potentially fun gameplay;
c) Higher concentration has a high psychological fidelity connection (easier for the user to understand) to on-screen faster running speed—relaxing to run faster does not make sense;

The calculated mean value of beta waves, which was already being used in the card game, was used as the concentration value. According to informal desktop tests and the own experience of the author, these average values work well in the development process of a game which uses Senzeband as a controller.

The second goal was to study the reactions towards using a game that was not originally developed with Senzeband in mind, but was modified for the use of Senzeband to control the game. Turku Game Lab developed a running game, which was part of a sport game suite, called Paavo Nurmi Games for PC. The game's original idea was to use a Kinect camera to track the movement of the player and when the player ran in front of the camera, the player's character ran also in the game screen (Figure 9). The game's main application was to use it as an exergame (exertion game). As the player runs faster in real life, the character runs faster in the game. This game is playable in one- or two-player mode and the author modified it to work using Senzeband as a controller. As mentioned earlier, the simultaneous two-player mode was not possible with Senzeband. The compromise was to make a hot-seat mechanic whereby the first player gets three chances to get a best possible time in the 100 meter sprint. Then it is player two's turn, who then tries to beat player one's best time. When this player switch happens, player two gets the Senzeband from the player one and then makes three attempts to beat player one's best 100m time. Simultaneous two player mode with two Senzebands and a split screen could be a good idea for future tests—given that the Bluetooth limitations are alleviated.

Figure 9: The on-screen character waiting for camera input to start running

After the game was modified to accept Senzeband as the controller, the code taken from the memory card game that listens to the concentration values from the Senzeband SDK, was stable and worked well. The next step was to develop a new menu system for the Paavo Nurmi Games running game so that the Senzeband is introduced properly to the players. The system was created in such way that the Senzeband SDK (used for conneting the Senzeband to the PC) was one scene and the main game was another scene in a Unity project. The menu system was also programmed to be a scene. The menu scene served two purposes. Firstly, it allowed players some standard user interface navigation, such as starting a game, going back to the SDK screen, exiting the game and to reset in the middle of a two-player game. The second menu purpose was to make sure that the game really measures concentration, familiarise the player with the Senzeband controller and to "warm the player up". This was done through a visual concentration meter, which moves according to the player's concentration levels (figure 10). In this menu scene, players had to reach a certain level of concentration to start the game. When the concentration value reached a predetermined threshold value, the game began. For testing purposes, this process could be bypassed by pressing the F key. Sufficient tutorial text was added to the screen to inform the player about the connection between their concentration and the on-screen character's running speed and about what they are supposed to do in the game. In order to determine th ethreshold value for the menu scene, five users were asked to perform conscious maximum concentration exertions while the Senzeband recorded their efforts. An average of all maximums was taken and set as the proposed maximum. The threshold value (for warming the player up) was set to 75% of the proposed maximum concentration value. The proposed maximum is by no means scientifically reliable and the 75% threshold is arbitrary. These numbers purely function as a suitable and humanly attainable cencentration level for familiarising players with the Senzeband controller.

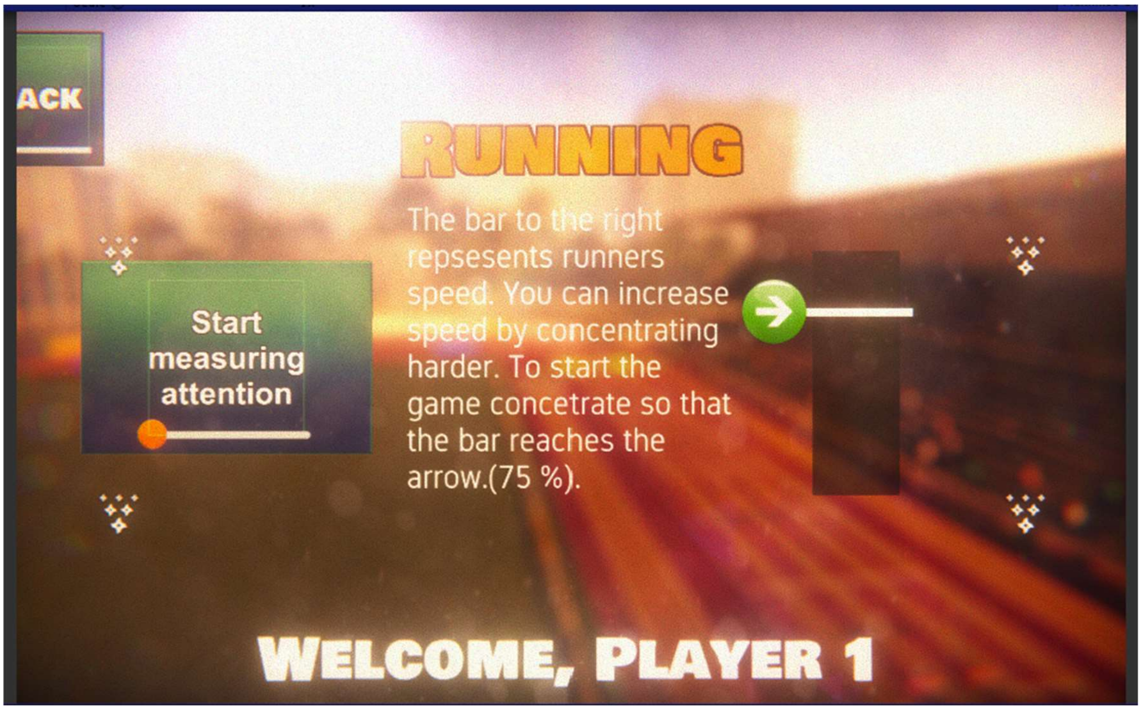

Figure 10: The menu screen to familiarise players witht the Senzeband controller.

One of the bigger chalenges during the development of both the Android and PC versions of the game, was the build-test cycle. In the process of developing the Android memory card game, over 70 builds were done because everytime the author wanted to try if something was working, the entire game had to be built and run on an Android device. The reason for this was that, at the time of developing the game, the SDK didn't support the PC version. It would have been much easier if Senzeband had worked directly in Unity. Even though it was time-consuming and challenging to build the Android version of the game, the development was more troublesome in the PC environment. The PC version of the SDK didn’t genuinely support Unity and building applications for PC happened through Microsoft Visual Studio, by building the application with the build settings in Unity. The build settings had to be chosen to be a windows store app, which is changed in a newer version of Unity to a universal windows version. Therefore, the build process (Figure 11) is more difficult and more time-consuming, than it would be if it could be built directly to PC standalone application from Unity. After the application was built with Unity into a Visual Studio *.sln* file, it had to be built with Visual Studio to make the application a desktop application—an *.exe* file that runs in Windows system with some specific settings in Unity and Visual studio so the application works properly.

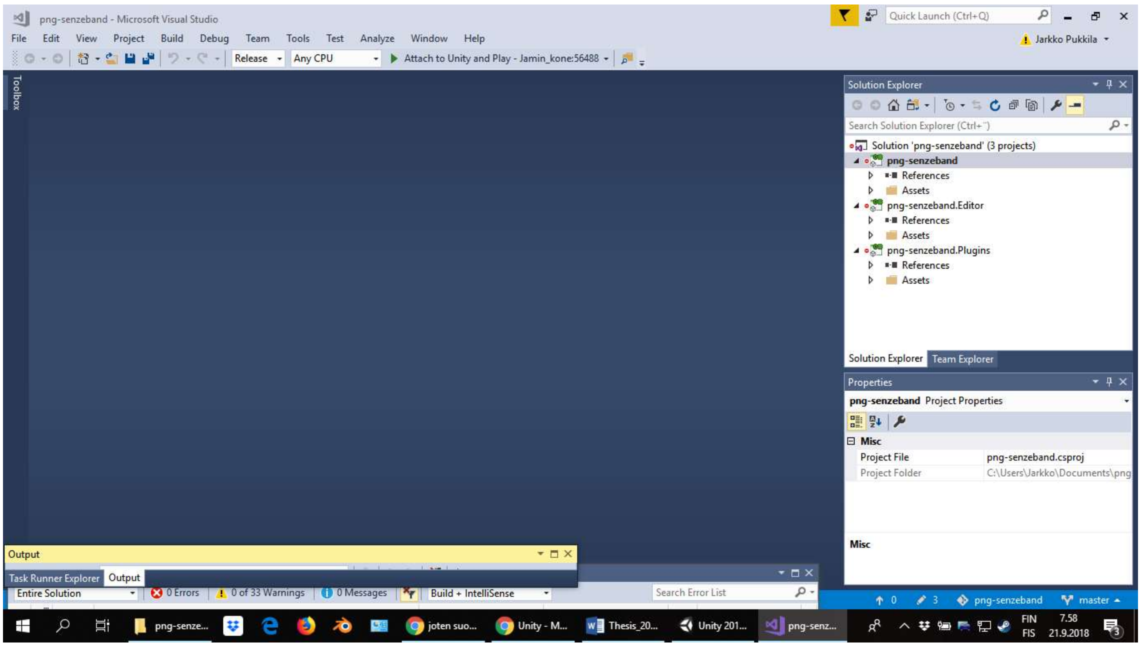

Figure 11: A Visual Studio window from which Senzeband controlled games are built

6 RESULTS AND EVALUATION

This section has two main parts, where the first relates to the author's experiences in programming to use the Senzeband as a game controller and the pitfalls that were encountered. The first part also briefly describes the merits of using either the raw brain activity values or the calculated brain state measurements. The second part outlines the user experience findings in using a BCI as game controller.

6.1 Results from the memory card game

Initially the main focus was to study the possibilities of using a device designed to measure brainwaves as a game controller. It became evident that it is possible, in the case of Senzeband, to develop a game for this type of controller. As stated earlier, the memory game was developed before the development release of Senzeband's Windows SDK. Android development was quite slow because the application had to be rebuilt every time a new element of the game had to be tested. At this stage it felt advisable to develop Senzeband's SDK so that it would work directly in Unity to make the development process for games that support Senzeband as a controller easier and faster.

The second observation during the card game development process was the restrictions of the Bluetooth connection. It became clear that the speed of the connection wouldn't support the simultaneous use of even two Senzebands. For this reason, it was decided that the two player game in the PNG running game for Senzeband would not be plausible and the author rather opted for the two players would use a single Senzeband in a turn-based fashion (hotseat mode). Additionally, during the testing it was revealed that Senzeband did not connect to some computers with older Bluetooth chips. At the time of this writing, Neeuro was aware and working toward a solution for this problem.

A main goal during the study was to experiment with different brainwave values and make a game that utilizes as many of them as possible. The programming of the card game started with the creation of the logic to turn cards with one's concentration. First it was needed to research and evaluate how to get the concentration and relaxation values from the Senzeband setup utility program. After this was decided, the next assignment was to research and select what values would be best as concentration and relaxation thresholds to turn the card. The testing process for determining the best values iteratively selected a value, built the game and tested whether the chosen value made the game boring or frustrating. After several testing efforts by the author, the threshold value was stabilized to 0.3 for concentration. User testing however, showed that this value remained quite difficult to obtain and maintain, so in the demo version of the game, the value 0.25 was used to make it easier to turn the first card. The author followed the same test process (as with the concentration value) for relaxation and determined a threshold of 0.2.The result was that it is possible to use two kind of brain waves in a game within reason, but it was hard for the player to change the way they think during the gameplay. It was really difficult to shift the thinking pattern from a concentration state of mind to a different pattern, relaxed state during a short time in one game. it was also pretty complicated for the player to follow, when to concentrate and when to relax. For this reason it was decided that the PNG running game would utilize only one state of mind, namely concentration.

As part of this study phase, the author also worked with both raw alpha and beta waves for discerning the player's brain activities as well as the calculated concentration and relaxation states. Both were workable, but while the raw values were more precise measurements, their eratic behaviour of jumping between the minimum and maximum values made that the author had to write an algorithm that took an average of 10 readings every 2.5 seconds to smooth the measurement spikes. The author felt that this undermined the reliability of the device and subsequently decided to rather use the calculated relaxation and concentration brain states as game input.

6.2 Results from Paavo Nurmi running game

The development process was continued with the Paavo Nurmi running game based on the results from the memory card game. As mentioned before the concentration (attention) value was decided to be the main controller in this game. Once again, the development process showed that it is relatively easy to use Senzeband as a game controller. The greater programming challenge however, was to convert the program from Kinect controlled to Senzeband controlled.

The other objective about the entertainment use of Senzeband was also fulfilled. The author observed and interviewed several test subjects to determine whether they enjoyed playing an entertainment oriented game wit a BCI controller. What was not studied or revealed in the process of this thesis was the accuracy of the device. This was not an objective for this study but it could be an interesting topic for future research.

For testing the game's entertainment value, and especially the "fun factor" of the using of Senzeband as a controller in this game some user testing was conducted. There were five test subjects, of which two had some form of ADD and the others were a mix of experienced and novice gamers. The author used a note-taking technique while observing the test subjects as they played the PNG running game with the Senzeband controller. One of the test subjects with distraction disorder could not concentrate fully while playing the game, which hampered their enjoyment to the point of annoyance. Although not tested in this thesis, it did give some indication about the reliability of the device. To fully complete its entertainment value for all kinds of people the game may have to be modified for different target groups. Test subjects who did not have ADD or ADHD enjoyed the game fully.

Further observation of the other test subjects showed that they had fun when playing the PNG running game. Almost all test subjects were in a happy state of mind when playing the game, which can be deducted from their behavior. They smiled a lot and some even laughed a bit when something happened in the game. For most people it was also important to test their "concentration abilities" against their friends. They were very curious about how they compete with other people's times in the running game. When using the two-player hotseat mode, this competion was an even greater catalyst toward having fun. After playing the game, people reported that it was a fun game and some even proposed a few technical changes. People were very curious about the technology and afterwards some noticed that their attitude towards this kind of technology was wrong. The preconceptions that were restored included the belief that brain scanning devices could reveal their thoughts, or that these devices were just some sales gimmick. In addition to observing the players during gameplay, the author also conducted personal interviews with each of the participants.

Questions for the test subjects were:

1. How did you like playing the game?
    - As a single player game and as a two -player game against your friend?
2. Were there any problems when playing the game?
3. In your own opinion, were you able to fully concentrate while playing the game?
4. What would you change in the game? (technical changes)

The headline summary of the answers are given below (with the tester types given in parentheses):

1. I liked playing the game especially in two-player mode it was really fun to compete – (experienced gamers and inexperienced gamers).
   It was hard to concentrate to the game, I lost my concentration several times and that is shown in the final result (time). It was however fun to play the game – (person with distraction disorder).
   One person with distraction order was almost angry or at least really annoyed, because he couldn’t concentrate to the game fully.
2. No problems for experienced gamers, but inexperinced gamers needed more advice how to use the device and how to play the game. People with distraction disorder thought it was too hard to concentrate through the game.
3. I could concentrate fully – (experinced and inexperienced gamers).
   I couldn’t concentrate – (people with distraction disorder).
4. I would make it easier – (people with distraction disorder).
   It would be cool to try the game in simultaneous two-player mode – (experienced gamer).
   I would need more advice or a tutorial if I would play at home with my own computer – (inexperienced gamer).

7 DISCUSSION AND CONCLUSION

Experimenting with new technologies requires a development environment where little time and effort between development and testing is required. As mentioned earlier, the Android development was quite slow because the application had to be rebuilt and reinstalled for testing any programming change. Working on the PNG running game was more efficient because the Windows SDK for Senzeband was available at that time. It is also paramount that games should be designed for BCI controllers from the start because converting a game from one controller to another is time-consuming and fraught with potential errors. In the case of PNG running game, the Kinect to Senzeband conversion was particularly difficult because the camera-based controller was integrated into the whole game, making it difficult to find, remove, and replace all code relating to character control.

Further programmatic conclusions came from the Senzeband measurements themselves. The author found that it was better to work with the already calculated concentration and relaxation states, rather than the raw alpha and beta values, simply because the raw values were too eratic and required additional smoothing that may put the reliability of the measurement into question. In addition, it was also found that players (the author included) had great difficulty to consciously switch between a relaxed and concentrated brain state. Although it does stand to reason that continually alternating between relaxed and concentrated brain states makes for effective brain training, the difficulty in doing this might detract from potential entertainment value. The author, therefore, used only the concentration measurement when conducting the user experience part of the thesis.

Playing a game with Senzeband as a controller was fun for players without any attention deficit disorders. This made it evident that games should be modified to different user groups and maybe it could possibly be used as a therapy tool for special groups. This is, however, another topic for study and it would have to be scientifically evaluated. This could be conducted with appropriate flow or scaffolding techniques. The interviews also revealed that a proper tutorial for the game would be useful for inexperienced gamers.

According to the examination and study during the writing of this thesis and developing two games, it is possible to use Senzeband as a game controller. Eventually, this opens several possibilities for the future of development of entertainment and also other oriented games, for example, brain training games. The results in this study were encouraging even when only one brain state was used as a controller. The study of game development for brain measuring devices is still in its infancy, but Senzeband has certainly been shown in this thesis to have made some significant initial strides toward potentially becoming a new gaming platform.

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