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Moving an on-screen cursor with the Emotiv Insight EEG headset

An evaluation through case studies

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Abstract

Today smartphones are everywhere and they ease the lives of millions of people every day. However there are people who, because of various reasons, are unable to receive the benefits of these devices because they are not able to interact with a smartphone in the intended way; using their hands.

In this thesis we investigate an alternative method for interacting with a smartphone; using a commercially available electroencephalography (EEG) headset. EEG is a technique for measuring and recording brain activity, often through the use of sensors placed along the scalp of the user.

We developed a prototype of a brain-computer interface (BCI) for use with android and the Emotiv Insight commercial EEG headset. The prototype allows the user to control an on-screen cursor in one dimension within an android application using the Emotiv Insight.

We performed three case studies with one participant in each. The participants had no prior experience with EEG headsets or BCIs. We had them train to use the Emotiv Insight with our BCI prototype. After the training was completed they performed a series of tests in order to measure their ability to control an on-screen cursor in one dimension. Finally the participants filled out a questionnaire regarding their subjective experiences of using the Emotiv Insight.

These case studies showed the inadequacies of the Emotiv Insight. All three participants had issues with training and using the headset. These issues are reflected in our tests, where 44 out of 45 attempts at moving the cursor to a specific area resulted in a failure. All participants also reported fatigue and headaches during the case studies. We also concluded that the Emotiv Insight provides a poor user experience because of fatigue in longer sessions and the amount of work needed to train the headset.

Keywords

EEG, Emotiv Insight, BCI

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1. Introduction

Today smartphones are everywhere and they ease the lives of millions of people every day. However there are people who, because of various reasons, are unable to receive the benefits of these devices because they are not able to interact with a smartphone in the intended way; using their hands. Therefore we wanted to investigate an alternative method for interacting with a smartphone; using a commercially available electroencephalography (EEG) headset.

In this chapter we discuss the definitions of EEG, BCI, Emotiv Insight and case studies. This is done in the chapter *Definitions*. After that we present our purpose and scope in the chapters *Purpose* and *Scope* respectively. Later on in the chapter *Alternative hands-free input methods* we present alternative hands-free input methods besides EEG. Finally in the chapter *Related work* we discuss related work and studies, and their experience with using EEG as a control method with both commercial and noncommercial headsets.

1.1 Definitions

1.1.1 Electroencephalography (EEG)

Electroencephalography is a technique for measuring and recording brain activity, often through the use of sensors placed along the scalp of the user. EEG has long been used as a way to record and measure brain activity because of its ease of use, relative low cost and the fact that it is non-invasive method [1].

In recent years, several commercial EEG products have been made available by companies such as Emotiv [2], Neurosky [3] and Muse [4]. These allow developers to create their own applications using EEG technology.

1.1.2 Brain Computer Interface (BCI)

A brain computer interface, or BCI, is any software that provides an interface between a users brain activity and a computer [5].

1.1.3 Emotiv Insight

Emotiv Insight is an EEG headset developed by Emotiv. It comes with a software developer kit that allows developers to more easily create software that utilizes EEG. The headset has 5 EEG sensors and wireless connectivity through Bluetooth Low Energy. It can detect up to four mental commands (i.e. imagining pushing an object) at the same time. The headset can also detect facial expressions (i.e. blink and smile) and performance metrics (i.e. excitement and relaxation). The headset also include accelerometer, gyroscope and magnetometer. In order to get the best performance for each user, a user needs to calibrate the headset to detect their mental commands or facial expressions better. Information regarding this calibration is stored in a profile.

Image 1: Emotiv Insight

1.1.4 Case Study

Orum et al. defines a case study as “an in-depth, multifaceted investigation, using qualitative research methods, of a single social phenomenon” [6]. Case studies have long been used in order to make conclusions regarding a whole, by studying one or multiple cases. A case can be anything from a company, to an event or to a person [6]. In this study we present three cases, available in the *Research Method* chapter.

1.2 Purpose

We will investigate an alternative way to control a smartphone; using EEG read from the user by a commercially available EEG headset, specifically the Emotiv Insight, using mental commands provided by the headset. It is with this piece of hardware that we seek to develop an interface that can control an on-screen cursor in one dimension. The purpose of the prototype is to allow the user to interact with an android smartphone device. We believe that the ability to reliably move an on-screen cursor in one dimension on an android smartphone is a good stepping stone to reaching full control of an android smartphone, using only EEG as an input method.

We have chosen to limit ourselves to one dimensional control as we are under time constraints for this work.

The motivation for this thesis is to explore EEG as a alternative input method as this would help people who lack motor controls to use a smartphone.

In 2013 around 5.4 million people in USA were paralyzed [7], meaning that they might not be able to use smartphone with or without hands-free control methods, depending on their paralysis. By developing a way for them to use a smartphone they are given the ability to perform the tasks that smartphones allows, despite their disabilities. We believe that the best alternative input method to make this possible is EEG as it allows all persons with sufficient brain activity to use smartphones despite physical disabilities.

1.3 Scope

We want to explore the option for hands-free smartphone control by reading EEG data with the help of the Emotiv Insight from the user. This is done to allow the user to control the smartphone without moving his or her head. The Emotiv Insight gives us the options to measure: mental commands, facial expressions, performance metrics, acceleration, orientation, angular velocity and magnetism. But we opted for only using mental commands as this option is the only one that does not require the user to move any muscles.

Due to the time consuming aspects of the task and the fact that we are limited in allotted time for this work, we will limit ourselves to exploring the possibilities and limits of controlling an on-screen cursor in one dimension only; vertically. This will be explored using the Emotiv Insight, a lower end model.

1.4 Alternative hands-free input methods

Besides EEG, there are other input methods available to those that lack the required physical abilities to use traditional input methods. Those input methods are listed in this chapter.

1.4.1 Voice assistant

A voice assistant is a piece of software often found integrated into a smartphone's operating system such as Siri for Apple iPhones [8], Google Assistant for smartphones running android [9] and Bixby for the Samsung Galaxy smartphone models [10]. These voice assistants can achieve many things with the use of voice commands, such as make calls, set timers, get directions and more. However they are still limited compared to using one's hands for input. A user cannot interact with any application that is not supported by the voice assistant software, which excludes interacting with many third-party applications or privately developed applications. There is also the question of personal integrity and privacy, as voice assistants requires hardware to always listen for a spoken keyword. While the authors of these software assure that nothing will be recorded without the software being prompted by the keyword, there have been cases that bring up concerns [11]-[13].

Even if one can see past the limitations of using a voice driven software for smartphone control, it is still a technology that requires the user to be able to speak in a coherent enough way for the software to understand. This can create limitations either for people who have speech impediments or are unable to speak entirely such as stroke- and ALS victims [14, 15].

1.4.2 Head tracking

Head tracking is done by using a smartphones front facing camera to track a point on a user's face, such as his or her nose. An on-screen cursor can then be controlled by detecting movement in that point on the face, similar to how a mouse cursor is moved. One example of this is Sesame Enable [16] for Android smartphones, which allows the user to control an on-screen cursor with head-tracking as described above. Sesame Enable also allows the user to interact with the smartphone by displaying a menu with interaction options when the cursor has been still for a few seconds. This allows full control of the smartphone without the need to use your hands but still requires the user to be able to move his or her's head to use.

1.4.3 Eye-tracking

Eye tracking is done by tracking the user's eyes in order to detect where on the screen the user is currently looking. This can then be translated into an on-screen cursor located at the place the user is looking. One example of this is The Eye Tribe [17] which allows the user to control an on-screen cursor by means of eye tracking. Although this solution requires you to be able to move your eyes and therefore have sufficient muscle control. In The Eye Tribe solution [17] clicks are still made by pressing the screen.

1.5 Related Work

In Appendix 4 we have listed the search portals, search terms and how we chose related work for this study.

1.5.1 EEG-based controllers

Studies have shown that EEG-based controllers can work for a variety of different areas. For example Li et al. had six participants that could control the cursor with an accuracy greater than 80% with two to eight sessions of 2 hours of training per session [18]. This shows that controlling an on-screen cursor can be done with data provided from EEG measurements.

Successful attempts to browse the web has also been made in the field of BCI. Bensch et al. developed Nessi, an open-source plugin for the Mozilla Firefox web browser which enables persons totally lacking motor control to browse the world wide web [19]. Nessi places markers (with different colors that correspond to different brain responses) on selectable items which allows the user to select any link on a website. Nessi also includes an on-screen keyboard and the ability to compose and send emails.

1.5.2 Commercial EEG headset based controllers

As with commercial EEG headsets there has been attempts to use a commercial EEG headset to control a small robot using an Emotiv Epoc EEG headset [20]. However Khan & Laique's attempt was not particularly fruitful as they had two participants spend eleven hours each with training four different mental commands; push, pull, rotate left and rotate right. After these eleven hours the participants were able to perform the specified mental commands with an accuracy of around 25%. The participants also reported feeling nauseous, headaches and fatigue.

Mamani and Yamyachi developed an interface to control a drone using an Emotiv Insight headset [21]. Five test persons were able to perform four mental commands with all test persons having at least 50% success rate (with many test persons scoring higher) when attempting to perform a selected mental command. However, they do not mention how much training these results were prefaced with.

Games have also been made to function with a BCI as the only input method [22]. Hawsawi and Semwal used a NIA Controller, a commercial EEG headset marketed for gaming. They developed versions of two classical games, Space Invaders and Breakout; both of which were successfully played by users with the use of the NIA Controller. There is no mention of training times or how many users this was tested on.

1.5.3 Conclusion of related work

These works regarding commercial EEG headsets [20]-[22] seem to be in conflict with each other regarding ease of use. Khan and Laique [20] report it to be very difficult to get consistent signals with the Emotiv Epoc EEG headset. Even with eleven hours of individual training the results were so lacking that they decided not to include it in their main study. However Mamani and Yamyachi [21] found that five test persons were able to perform the same amount of mental commands with much higher success rate. Hawsawi and Semwal also found positive results with their participants using a commercial EEG headset. However, we are sceptical since the results of Mamani and Yamyachi, Hawsawi and Semwal are not prefaced with any information regarding training time.

Based on these findings our preliminary conclusion is that EEG can be used as a reliable input method with high end EEG equipment, as shown by Li et al. [18]. As with commercial EEG headset there still seems to be ways to go as long training times (with lacking results) and discomfort during use are notable issues. However the work of Mamani and Yamyachi, Hawsawi and Semwal shows that satisfactory results from novice users are achievable with commercial EEG headsets even if they do not disclose their preparation and training.

2. Research Questions

In this chapter we state our research questions and also describe the goal and expected outcome for this study.

Our purpose and scope is that we want to investigate an alternative way to control a smartphone using the Emotiv Insight. We want to control an on-screen cursor in one dimension using mental commands.

The questions we seek to answer with this work are:

RQ. 1 Can you control an on-screen cursor in one dimension, with 2 hours of training, with the Emotiv Insight?

We believe that cursor control in one dimension it is a good start towards complete control of a cursor.

In our own experiments we both were able to get such a control of the on-screen cursor that we were able to move it to a certain part of the screen at the other's request. The training sessions were prefaced with some smaller sessions. These smaller sessions has us mostly tinkering with the headset and learning how to best train it. We used profiles with no previous training data during the training sessions when we both were able to get control of the on-screen cursor.

Our training session that resulted in us being able to control an on-screen cursor in one dimension lasted around an hours time. We reasoned that new users should be able to achieve control in the same time, but with some margin and with the help of our instructions. Therefore the max training time will be set to 2 hours for the participating user.

RQ. 2 What is the perceived user experience of using the Emotiv Insight?

It is important that a controller should be comfortable and easy to use; else it could prevent new users from trying it or from wanting to use it again.

We want to find out how users experience the Emotiv Insight. Based on our own experience with the headset we believe that users will think that it is painful to wear and use for longer session. Seeing as our case study participants will have used the Emotiv Insight for 2 hours we believe that their perception of the user experience is valid.

3. Research method

In this chapter we describe how we gathered data. We describe why we chose case study as our research method, who participated in our case studies and how it was constructed and why.

3.1 Why case study?

Originally we had planned to perform an experiment consisting of 30 persons in order to establish a statistical basis for our findings. This was under the pretence that the Emotiv Insight was easily picked up by any new user and that the user would be able to use it with minutes of setup. As we started using the hardware ourselves and reading the official documentation available, we realised that this was not the way that the Emotiv Insight worked. Therefore, we instead decided to go with case studies. Each case study involved one participant.

A case study is defined by Orum et al. as "an in-depth, multifaceted investigation, using qualitative research methods, of a single social phenomenon" [6]. Case studies have long been used in order to make conclusions regarding a whole, by studying one or multiple cases.

3.2 Our case studies

To explore EEG as an control method we performed case studies with one participant in each case study. During each case study the participant trained the Emotiv Insight using our BCI prototype. However, the participants had a maximum training time of 2 hours. After 2 hours of training, the participants were tested on their control skill of a on-screen cursor in one dimension. Finally they filled out a questionnaire about their experience.

3.2.1 Why Emotiv Insight?

We chose to use the Emotiv brand of EEG headsets because we experienced that they marketed themselves as a tool for developers while other brands seemed to market their headsets as tools for meditation. Emotiv offers two headsets: the Emotiv Epoc+ model, with 14 EEG sensors for measuring and 2 reference sensors. And the Emotiv Insight model, with 5 EEG sensors and 2 reference sensors.

We chose the Insight model because of the price (299 USD plus shipping at the time of our purchase) and because we deemed the hardware sufficient for our needs. For development of our prototype we used the Emotiv Community Software Development Kit, provided by Emotiv, which gave us access to detection of mental commands.

3.2.2 Mental command

The Emotiv Insight can detect mental commands. These mental commands are triggered by the user for example imagining pushing an object. These commands need to be trained so that the headset can detect them for the current user. It is also needed for the user to train how the neutral mental state looks like. This is done so the headset can recognize when the user is not trying to trigger a mental command.

The mental commands that the participants were asked to train were push and pull. The neutral mental state is also trained. Below is a description of these mental commands and neutral state:

- A neutral mental state is produced by the absence of any mental command (in our case, push or pull).
- A push mental command is produced by a user imagining pushing an object with their mind.
- A pull mental command is produced by a user imagining pulling an object with their mind.

3.2.3 The BCI prototype

Our BCI prototype is an Android application that was built in the Java programming language, version 1.8, and uses the Emotiv Community Software Development Kit in order to communicate with the Emotiv Insight. We followed the Emotiv Android application examples [23] and their getting started guide [24] when creating the application.

The reason we choose Java as our programming language was that we are both experienced in the language and is one of the official Android programming languages.

3.2.4 Preparation of our case studies

Before the case studies we evaluated the effectiveness of training and performing mental commands through a series of informal sessions with the prototype that we built. This was done in order to determine what amount of time we would give each case study participant. One of us performed better than the other but we were both able to control two mental commands after 1 hour of training. It was therefore we decided that 2 hours, not counting breaks, would be adequate time for each participant.

3.2.5 Participants of our case studies

We had three persons participating in our case studies as we felt that was the number of case studies that we would have time to perform and process. The people participating in these case studies were be persons between the age of 20-30 years old. We know these persons personally and asked if they would participate in our study. Our only criteria for participants was that they could not have any previous experience with this sort of technology. None of these persons had any specific knowledge of our work and no previous experience with EEG headsets or BCI at the time of the study.

3.2.6 Materials used in our case studies

The materials we used in our case studies and their use is described below:

- **Emotiv Insight**
  Used for measuring brain activity and translating to mental commands which we measure with our prototype.
- **Laptop**
  Used for reading log data produced by prototype during use. Also used by us in order to document the case studies.
- **Samsung Galaxy S6 smartphone**
  Used for running our prototype and by our participants for training mental commands. The smartphone was running Android 7.0 as its operating system.
- **USB A to Micro USB cord**
  Used for connecting the smartphone used during the case studies to the laptop.

Other than the materials listed above, the participant of each case study sat with us in a group room at Blekinge Institute of Technology. This was in order to minimise disruptions during our case studies.

3.2.7 Content of our case studies

The training and test in the case studies was performed on one of our personal smartphone, of the model Samsung Galaxy S6 running android operating system version 7.0. The questionnaire was filled out via Google Forms form platform on our laptop.

The case studies consisted of four steps and was performed in the order that they are listed below with motivation.

3.2.7.1 Informing the participants

We informed the participants of what the purpose of the case study was. We had the case study participants read our instructions (see Appendix 5) and ask questions before they started to train. This was in order for them to understand what they were going to be doing and how to act for best results.

3.2.7.2 Training the Emotiv Insight

In order to use the Emotiv Insight the participants have to calibrate it by training it. Without this step, using the headset would be pointless as it would not be adjusted to the user. The participants individually trained the headset for a maximum of 2 hours. This limit stemmed from us being able to get control with around 1 hour of training, which led us to believe that a new user should be able to achieve control with 2 hours of training.

3.2.7.3 Performing the test

With this step we are measuring the user's ability to actually use the headset to move an on-screen cursor in one dimension, after having calibrated it through a series of stages.

3.2.7.4 Questionnaire

With a questionnaire we are measuring the user's subjective experience from calibrating and using the headset.

3.3 Training the Emotiv Insight

Training mental commands or neutral mental state with the Emotiv Insight is done by first selecting the desired mental command or state and then signaling to the headset that you wish to start training. The user is then to perform the selected mental command. After some time has passed (this takes about 8 seconds) one of the following will happen:

- The Emotiv Insight will respond with a IEE_MentalCommandTrainingFailed if the connection strength to the headset was not sufficient during training.
- The Emotiv Insight will respond with a IEE_MentalCommandTrainingSucceded message code if the connection strength to the headset was sufficient during training.
    - If the above is the case, the user will be asked if he or she felt that the training of the mental command or state went well, meaning that the user felt that he or she was

properly focused during training. If the user answers yes to this question, his or her profile[1] will be updated in accordance with the new training.

- If the user did not feel that the training session went well for some reason, such as he or she was not properly focused, the data collected during training will be discarded.

The entire flow of training is described in [24].

For our case studies the participants trained the neutral mental state and push mental command until they had good control over pushing. When this was achieved they could start training the pull command. This is in accordance with Emotiv's instructions [23] which state that one mental command should be mastered before moving on to training another mental command. The participants needed to be consistent with how they perform commands as changing profile[1] data would result in an inconsistent user profile[1], would make it harder for the headset to detect mental commands.

3.4 Performing the test

After the training time expired the participants used the prototype to move a cursor up and down a screen consisting of three white areas, labeled Area 1-3, and four grey areas; see Image 2 below. When the marker is within a labeled area that area will turn green in order to provide visual feedback to the participant; this is displayed in Image 3 below.

[1] Profile is where all of a users trained data is stored. This data is used for Emotiv Insight to detect mental commands and neutral mental state.

Image 2: The test screen

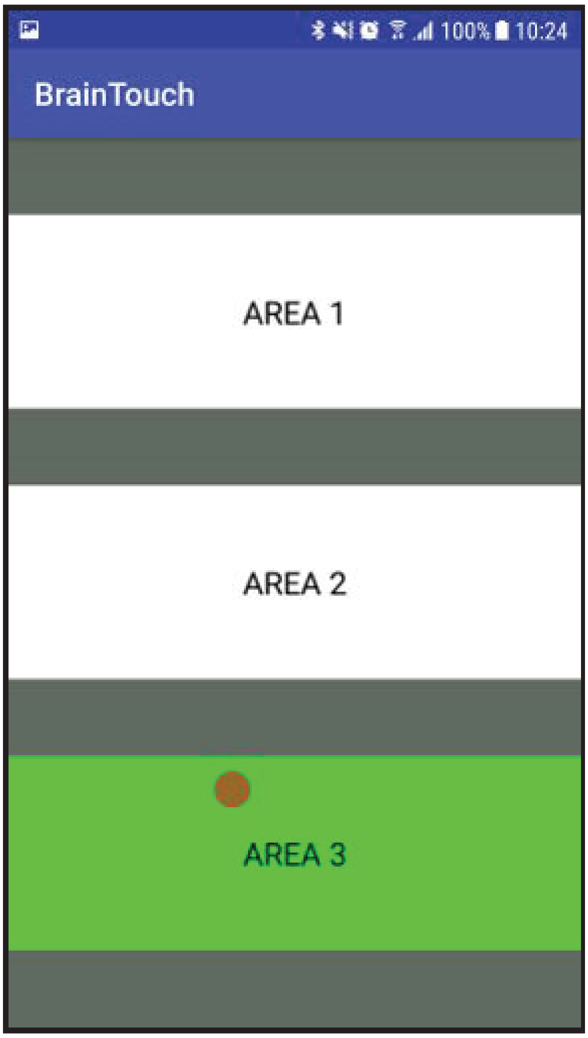

Image 3: The test screen with the marker in Area 3

Our initial theory was that completely novice users would be able to train and consistently perform two mental commands and then control an on-screen cursor in one dimension. For all case studies, as we drew closer to our 2 hour training time limit it was clear that the participant would not be able to sufficiently train two mental commands. As a result we asked the participants to only train the push mental command. In order to compensate for this, the test was reworked to:

- **Stage 1:** Move the cursor to Area 1 in 30 seconds and stay there for 10 seconds.
- **Stage 2:** Move the cursor to Area 2 in 30 seconds and stay there for 10 seconds.
- **Stage 3:** Move the cursor to Area 3 in 30 seconds and stay there for 10 seconds.

With the cursor starting below Area 3 at all stages. This would only require the push mental command to be performed, allowing us to measure the participants control of that mental command. Each stage was performed five times, as intended in the original test. This test also tests the participants ability to move the cursor up in varying distances.

We set a time limit for the attempts of the stages as if a user was unable to show any results in the designated time, they would have likely not show results at all.

In order to allow the participants to perform a stage attempt even after failing a previous stage attempt it is possible to move the location of the cursor by pressing the screen, the cursor will then move to the location that was pressed.

We selected for the participants to hold the cursor on a selected area for 10 seconds in order to test that the user could refrain from producing mental commands when asked. If the user involuntarily produced mental commands this would have indicated that more training was needed in order to properly control the on-screen cursor.

The original test is described in Appendix 6 for reproducibility purposes.

3.5 Questionnaire

After the training and test is completed, the participant was asked to fill out a questionnaire. This was done in order to find out about their subjective experiences during the different stages of the case studies and usage of the Emotiv Insight. The full questionnaire can be found in Appendix 1.

Since the pull mental command was never trained by the participants of our case studies the questions regarding the pull mental command was removed.

4. Analysis and Result

Here we present the findings from our case studies. We will show the results from both the test and the questionnaire which was filled out by each participant. We will then discuss these results along with some of our own observations during the case studies. We finish this chapter by discussing the answers found to our research questions and the observed validity threats to our work. The result from the test are available in Appendix 2. The questionnaire and its' results are available in Appendix 1 and Appendix 3 respectively.

4.1 Presenting the result

4.1.1 Training

Participant A took a total of two breaks. One break starting 50 minutes from start and lasting 5 minutes. After another 31 minutes of training the participant took another break lasting 16 minutes.

Participant B took a total of two breaks. First break started after 40 minutes of training and lasted 8 minutes. The second break occurred after another 39 minutes of training. This break lasted 10 minutes.

Participant C took a total of one break. This break was taken after 35 minutes of training and lasted 10 minutes.

An issue that we faced during participant B and participant Cs training was that the headset ran out of power at times during their training sessions. As a result of this we had to recharge the headset before continuing the training as the headset cannot connect to a user profile while it is being charged (whether this is a defect or not, we do not know). During participant B training session a total of 46 minutes was spent waiting for the headset to recharge and a total of 72 minutes was spent recharging the headset during participant C's training session.

4.1.2 Test

Table header description:

- The column "Stage" is the identifier for which stage the result was for.
- The column "Attempt" is the identifier for which attempt out of five the result was for.
- The column "Success" is if the attempt was a success (represented by a 1) or failure (represented by a 0).
- The column "Note" is a description on what happened during the attempt.

Stage	Attempt	Success	Note
1	1	0	Did not move
1	2	0	Did not move
1	3	0	Moved to area 3

1	4	0	Did not move
1	5	0	Did not move
2	1	0	Moved passed area 2
2	2	0	Moved passed area 2
2	3	0	Moved to area 3
2	4	0	Did not move
2	5	1	Moved to area 2
3	1	0	6 sec in area 3
3	2	0	Did not move
3	3	0	Moved passed area 3
3	4	0	Moved passed area 3
3	5	0	Moved passed area 3

Table 1: Participant A test result.

Participant A failed all attempts at stage 1 and managed to move the cursor slightly one time during the first stage. In stage 2 participant A moved the cursor past the goal in three of the five attempts, was unable to move the cursor in one attempt and successfully completed one attempt. In stage 3, participant A was unable to move the cursor in one attempt, moved past the goal in three attempts and in one attempt, the user was able to move the cursor to the goal but was unable to maintain it within the goal for 10 seconds.

Stage	Attempt	Success	Note
1	1	0	Did not move
1	2	0	Did not move
1	3	0	Did not move
1	4	0	Did not move
1	5	0	Did not move
2	1	0	Did not move
2	2	0	Did not move
2	3	0	Did not move
2	4	0	Did not move
2	5	0	Did not move
3	1	0	Did not move
3	2	0	Did not move
3	3	0	Did not move
3	4	0	Did not move

3	5	0	Did not move

Table 2: Participant B test result.

Participant B was not able to move the cursor at all during the tests, meaning that each stage resulted in failure.

Stage	Attempt	Success	Note
1	1	0	Got to area 2
1	2	0	Got between area 3 and 2
1	3	0	Did not move
1	4	0	Did not move
1	5	0	Did not move
2	1	0	Did not move
2	2	0	Did not move
2	3	0	Did not move
2	4	0	Did not move
2	5	0	Did not move
3	1	0	Did not move
3	2	0	Did not move
3	3	0	Did not move
3	4	0	Did not move
3	5	0	Did not move

Table 3: Participant C test result.

Participant C was able to create some movement during two attempts at stage 1, but not reaching the goal. Participant C was unable to create movement at all other attempts at all other stages. All stages resulted in failure.

4.1.3 Questionnaire

Table header description:

- The column “Question” is the identifier of a question in the list “Questions” below.
- The column “Participant A” is all the answers of participant A.
- The column “Participant B” is all the answers of participant B.
- The column “Participant C” is all the answers of participant C.

Questions:

1. How do you rate your experience in *calibrating* the headset on a scale from 1 - 4, where 1 is effortless and 4 is demanding, when training push.

2. How do you rate your experience in *calibrating* the headset on a scale from 1 - 4, where 1 is effortless and 4 is demanding, when training neutral.
3. How do you rate your experience in *using* the headset as an *input method* on a scale from 1 - 4, where 1 is the effortless and 4 is demanding, when performing push.
4. How do you rate your experience in *using* the headset as an *input method* on a scale from 1 - 4, where 1 is the effortless and 4 is demanding, when performing neutral.
5. How do you rate your experience in *using* the headset as an *input method* on a scale from 1 - 4, where 1 is the effortless and 4 is demanding, when switching between commands.
6. How do you rate your experience in *using* the headset on a scale from 1 - 4, where 1 is the lowest, for the level of comfort.
7. If you found it uncomfortable, why?
8. What is your general opinion of EEG as a control method?

Question	Participant A	Participant B	Participant C
1	4	4	3
2	3	2	4
3	4	4	4
4	2	2	2
5	4	3	2
6	4	4	4
7	Both of the above. Also since it felt like the training didn't work.	Headset was painful to wear for longer sessions	Headset was painful to wear for longer sessions
8	It needs to be less painful and many more hours to learn and train. But when it works it would be excellent for those who can't control a device using hands.	I think it can be very useful for people but it needs to be easier to train. If it is possible to do it easier is something for future work I guess.	uncomfortable and hard to use

Table 4: Answers to the questionnaire.

The questions regarding the training of the mental commands were on a scale of 1 - 4, where 1 is effortless and 4 is demanding. Our conclusion and summarization of the participants answers is as followed:

- Training push was experienced as demanding with ⅔ of the participants answered 4 and the other answering 3.
- Training neutral was experienced differently by all participants with the majority leaning towards demanding. The answers were 2, 3 and 4.

The questions regarding performing mental commands were on a scale of 1 - 4, where 1 is effortless and 4 is demanding. Our conclusion and summarization of the participants answers is as followed:

- Performing push was experienced as demanding, with all the participants answering 4.
- Performing neutral was experienced as more effortless then demanding, with all the participants answering 2.
- Switching between mental commands was experienced differently by all participants with the majority leaning towards demanding, the answers being 2, 3 and 4.

All participants experienced the headset as uncomfortable with all answering 4 on a scale of 1 - 4 where 1 is comfortable and 4 is uncomfortable. Three out of three participants said that they experienced the uncomfortableness stemming from the headset being painful to wear for longer sessions. One participant stated additionally that they experienced the uncomfortableness was due to mental commands being straining to perform and experiencing that the training “did not work”.

The final question of the questionnaire asked the participants to state in their own words what their general opinion of EEG as a control method was after their participation. Their answers are displayed below:

- “It needs to be less painful and many more hours to learn and train. But when it works it would be excellent for those who can't control a device using hands.”
- “I think it can be very useful for people but it needs to be easier to train. If it is possible to do it easier is something for future work I guess.”
- “uncomfortable and hard to use”

4.2 Analysis of the result

4.2.1 Analysis of performing mental commands

Focusing on only training the push mental command, after two hours of training the participants were unable to display any consistent control over the on-screen cursor in the tests. There are several possible explanations for this as presented below.

Performing all the training in a two hour long session with breaks at the participants leisure is not an effective way of training. With shorter sessions side effects reported such as fatigue could potentially be diminished or reduced as participants would have had longer times to recover. It is also possible that the time spent training simply was not enough for a completely new user.

The negative side effects are interfering with the participants ability to focus and ability to train and perform mental commands. As this is a mentally demanding task it is essential that participants are able to focus. The side effects reported, especially headaches, could have substantial impact on the participants ability to focus.

As the test was performed under supervision the participants might have felt stress as a result of needing to perform on the spot. If this was the case, it could have affected the participants ability to focus, which in turn might generate more stress.

The power outages of the headset may be a factor to explain participant B and C's poor results after training. However participant A, the only participant able to pass a stage during the test, was only able to complete a single test, and this was without the interruptions of having to recharge the headset during training. Based on our case studies, it seems likely that the presence of the power outages of the headset would negatively affect the test result for participant B and C since they both showed some control of the push command during training before the power outages. Further testing could be done to reassure that these results are actually due to the power outages and not merely coincidence.

We observed that all the participants were able to show some control of the push command, either within- and/or out of the test. However this control is seemingly lost or greatly reduced after taking breaks and was inconsistent. In the quantitative pilot study by Khan & Laique [20], an Emotiv Epoc EEG headset was trained in sessions. They also had the issues with not performing on the same level as the previous session. This could be because your mental state changes from the one you had while training.

The results from our case studies are in conflict with the results from our own informal training sessions. The reasons for this might be that our prior sessions resulted in a us being more adept at using the headset than we had anticipated. This might in turn mean that giving our case study participants 1 hour more than us was still not enough of a compensation for them being entirely new users. Another reason for this conflict in result might be, as stated earlier in this chapter, that our case study participants had trouble performing on the spot, something that we did not have to take into account during our informal training sessions.

4.2.2 Analysis of user experience of the Emotiv Insight

One thing that all participants noted both during use and during the questionnaire filled out at the end was that they all experienced headaches. Headaches are not something that is associated with the use of EEG, which leads us to believe that the headache comes from the design of the Emotiv Insight. We have observed during our own usage and during our case studies that the headsets "grips" the skull of the user tightly and leaves clear dimples after use. We can support this from our own experience and would describe the headaches that we have experienced during use as moderate to severe. Several times during our own testing of the prototype we had to stop as the headaches experienced made it hard to focus. Sometimes the headaches lasted for the rest of our working day.

The results from our final question in our questionnaire reinforces our participants finding the Emotiv Insight uncomfortable and difficult to use. Although their experiences cannot be used as a basis of judging all EEG headsets or EEG as a whole, they hold true for their experiences with the Emotiv Insight.

4.3 Answers to research questions

Here we list our research questions, followed by our newfound answers to that questions:

RQ. 1 Can you control an on-screen cursor in one dimension, with 2 hours of training, with the Emotiv Insight?

With the two hours provided for training, none of our case study participants were able to control an on-screen cursor in one dimension. We therefore have to conclude that the answer to this research question is no - at least for completely new users. As our own results of being able to perform mental commands within 1 hours of training was prefaced with a series of informal sessions, we cannot include our own results into our answer to this question. This is because our total time spent training with the Emotiv Insight exceeds 2 hours, even though all that time was not spent training a single profile.

RQ. 2 What is the perceived user experience of using the Emotiv Insight?

Based on the reactions and comments from the participants during use of the headset and the answers to the questionnaire, the result from our case studies is clear, that the Emotiv Insight provides a poor user experience. This is, judging by our results, both due to the problems of basic use but most importantly the headaches which make their appearance shortly after a session with the Emotiv Insight is started.

We believe that a negative result from our first research question can provide a worsened user experience. This is since putting hours of time into training the Emotiv Insight and gaining minimal progress can discourage a user from continuing to use the headset.

4.4 Validity Threats

Our opinion is that there does exists possible threats to the validity of this work, they are listed below:

- It is possible that training in a two hour session with occasional breaks does not give enough respite in order to focus and perform well during training and/or the test.
- It is possible that the way that our case study participants trained with the headset was not the most efficient way. It is also possible that the participants had misunderstood how they we supposed to train, even after having read our written instructions.
- As the field of commercial EEG headsets is rather new, we found it hard to find related work. It is possible that we missed, in our search, related work that could have provided further information that we could have used in our work. A full specification of our search terms can be found in Appendix 4.
- As mentioned in this chapter, the best results found during this work was when we trained and used the headset in preparation for the case studies. However, as these training sessions were informal, no documentation of our methods used was written at the time. Therefore we have no exact way of reproducing our training method (which did show the best results) for future reproduction of our work.
- The power outages during participant B's and C's training could have negatively affected the test result.
- For our case studies we only had three participants, all within a certain age group. This gives us a somewhat narrow selection of participants.

5. Conclusion

In this work we developed a prototype BCI (Brain computer interface) for use with smartphones running the Android operating system. The application serves as an interface between the Emotiv Insight and an on-screen cursor. With the application the user is able to calibrate the Emotiv Insight to their individual profile. The user can then control an on-screen cursor in one dimension.

Three case studies were performed with one person for each case study. Each participant had no prior experience of EEG headsets. These case studies where done to determine the user experience of the Emotiv Insight and to determine if two hours of calibration is sufficient to be able to control the on-screen cursor in one dimension. The participants of the case studies trained for two hours, not counting breaks that they took at their discretion. We then tested the participants on their ability to control an on-screen cursor. However the test had to be changed as the case study participants were unable to consistently perform one mental command. The test was modified as to only require the cursor to be moved up. The test was followed up by a questionnaire.

The case study pointed towards that two hours of training is not enough for a completely new user to control a on-screen cursor in one dimension as all participants had issues with gaining control of only one mental command. The results of the case studies also points towards poor user experience as all participants felt training the headset demanding but also experienced headaches which points to the Emotiv Insight being unappealing to use.

6. Future work

It is our opinion that future work to be conducted includes:

6.1 Optimal training methods for commercial EEG headsets

This is to determine such variables during training of commercial EEG headsets as:

- What mind state should a user have during training?
- How much training time is needed for satisfactory training results?
- Do more, shorter training sessions give better training results than few (or one) long training session(s)?
- How do breaks or interruptions during training affect the training of the Emotiv Insight?

6.2 Difference in performance of commercial EEG headsets in different price ranges and brands.

As the hardware we used was not the most expensive commercial EEG headset available, further work could be made in order to ascertain if a more expensive or different model of commercial EEG headset would yield better results under the same circumstances.

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Appendix

APPENDIX 1: Questionnaire

Subjective Experience of using EEG interface

*Obligatorisk

How do you rate your experience in *calibrating* the headset on a scale from 1 - 4, where 1 is effortless and 4 is demanding, in the following areas

1. **Training push** *

   Markera endast en oval.

	1	2	3	4	
Effortless	◯	◯	◯	◯	Demanding

2. **Training neutral** *

   Markera endast en oval.

	1	2	3	4	
Effortless	◯	◯	◯	◯	Demanding

How do you rate your experience in *using* the headset as an *input method* on a scale from 1 - 4, where 1 is the effortless and 4 is demanding, in the following areas

3. **Performing push** *

   Markera endast en oval.

	1	2	3	4	
Effortless	◯	◯	◯	◯	Demanding

4. **Performing neutral** *

   Markera endast en oval.

	1	2	3	4	
Effortless	◯	◯	◯	◯	Demanding

5. **Switching between commands**

   Markera endast en oval.

	1	2	3	4	
Effortless	◯	◯	◯	◯	Demanding

How do you rate your experience in *using* the headset on a scale from 1 - 4, where 1 is the lowest, in the following areas

6. **The level of comfort** *

Markera endast en oval.

	1	2	3	4	
Comfortable	◯	◯	◯	◯	Uncomfortable

7. **If you found it uncomfortable, why?**

Markera endast en oval.

- ◯ Headset was painful to wear for longer sessions
- ◯ Performing mental commands was straining
- ◯ Övrigt: ____________________

8. **What is your general opinion of EEG as a control method?**

____

____

____

____

____

APPENDIX 2: Test results

Table header description

- The column “Stage” is the identifier for which stage the attempt was for.
- The column “”Attempt” is the identifier for which attempt it is for.
- The column “Success” is if the attempt was a success a 1 or failure a 0.
- The column “Note” is just a description on what happened during the attempt.

Participant A test result:

Stage	Attempt	Success	Note
1	1	0	Did not move
1	2	0	Did not move
1	3	0	Moved to area 3
1	4	0	Did not move
1	5	0	Did not move
2	1	0	Moved passed area 2
2	2	0	Moved passed area 2
2	3	0	Moved to area 3
2	4	0	Did not move
2	5	1	Moved to area 2
3	1	0	6 sec in area 3
3	2	0	Did not move
3	3	0	Moved passed area 3
3	4	0	Moved passed area 3
3	5	0	Moved passed area 3

Participant B test result:

Stage	Attempt	Success	Note
1	1	0	Did not move
1	2	0	Did not move
1	3	0	Did not move
1	4	0	Did not move
1	5	0	Did not move
2	1	0	Did not move

2	2	0	Did not move
2	3	0	Did not move
2	4	0	Did not move
2	5	0	Did not move
3	1	0	Did not move
3	2	0	Did not move
3	3	0	Did not move
3	4	0	Did not move
3	5	0	Did not move

Participant C test result:

Stage	Attempt	Success	Note
1	1	0	Got to area 2
1	2	0	Got between area 3 and 2
1	3	0	Did not move
1	4	0	Did not move
1	5	0	Did not move
2	1	0	Did not move
2	2	0	Did not move
2	3	0	Did not move
2	4	0	Did not move
2	5	0	Did not move
3	1	0	Did not move
3	2	0	Did not move
3	3	0	Did not move
3	4	0	Did not move
3	5	0	Did not move

APPENDIX 3: Questionnaire answers

Participant A questionnaire answers:

Question 1	4
Question 2	3
Question 3	4
Question 4	2
Question 5	4
Question 6	4
Question 7	Both of the above. Also since it felt like the training didn't work.
Question 8	It needs to be less painful and many more hours to learn and train. But when it works it would be excellent for those who can't control a device using hands.

Participant B questionnaire answers:

Question 1	4
Question 2	2
Question 3	4
Question 4	2
Question 5	3
Question 6	4
Question 7	Headset was painful to wear for longer sessions
Question 8	I think it can be very useful for people but it needs to be easier to train. If it is possible to do it easier is something for future work I guess.

Participant C questionnaire answers:

Question 1	3
Question 2	4
Question 3	4
Question 4	2
Question 5	2
Question 6	4
Question 7	Headset was painful to wear for longer sessions
Question 8	uncomfortable and hard to use

APPENDIX 4: Study search

Search portals:

- Google scholar
- Diva
- Summon

Search terms:

- EEG headset
- EEG headset control
- electroencephalography + headset
- paralyzed mental
- Paralyzed EEG
- EEG cursor
- Emotiv insight
- An EEG-based brain-computer interface for cursor control
- EEG controller

Choosing the right study

We chose studies that involve EEG or use BCI as a controller.

APPENDIX 5: Instructions for case study participants

Introduction

You will train three different commands for a commercial EEG headset Emotiv Insight. Emotiv Insight uses five sensors to measure EEG waves - electric signals that is produced by the brain.

The three mental commands are PUSH, PULL and NEUTRAL.

- A PUSH command is produced by you imagining pushing an object with your mind.
- A PULL command is produced by you imagining pulling an object with your mind.
- A NEUTRAL command is produced by the absence of PUSH or PULL.

Since all brains are different, Emotiv Insight needs to calibrated for each user - that is the first step in this case study.

After you have calibrated the headset you will be asked to move a pointer on the screen with the help of the trained commands.

Before you start training

- We help you put on the headset so it set up correctly.
- You have a total of two hours to train the EEG headset.
- During these two hours you might feel tired and would like to take a break. It is ok to take breaks, just tell us so we can document your break.
- We can ask you to perform certain commands to see how you are progressing.

How you train

It is important that you master one command before you try to calibrate the next command.

- Take your time in between trainings of commands. Try to achieve a neutral state before you start your next training.
- If you feel that the training did not go well, just press on “no” after the prompt[3] asking if your are satisfied with the training have popped up.
- Training NEUTRAL:
    - Breathe controlled and calmly.
    - Relax and do not attempt to produce any mental command.
- Training PUSH or PULL:
    - Focus at a point or object.
    - Imagine pushing or pulling it.
    - You may use physical movement to help you visualize the command, this is optional.
    - Perform PUSH or PULL during the whole training of a command without interruption. The duration of training a command is about 8 seconds.
- Try not to tense your muscles or make facial expressions while you train a command as this can interfere with the EEG measurements.
- It is important that you are consistent with how you perform an mental command.

Testing the trained commands

When you have trained your commands and feel satisfied with the result is it time to use them to move a cursor on the screen[1,2].

The connection between the commands and the movement of the cursor is as follows:

- **PUSH** - Move the cursor upwards on the screen.
- **PULL** - Move the cursor downwards on the screen.
- **NEUTRAL** - Stop the cursor from moving.

The screen where you will use the cursor consists of three white areas and four gray areas[1], if the cursor is within a white area will make it green instead[2].

You will be instructed six tasks by us that we want you to perform with your trained commands.

Image 1 Test activity

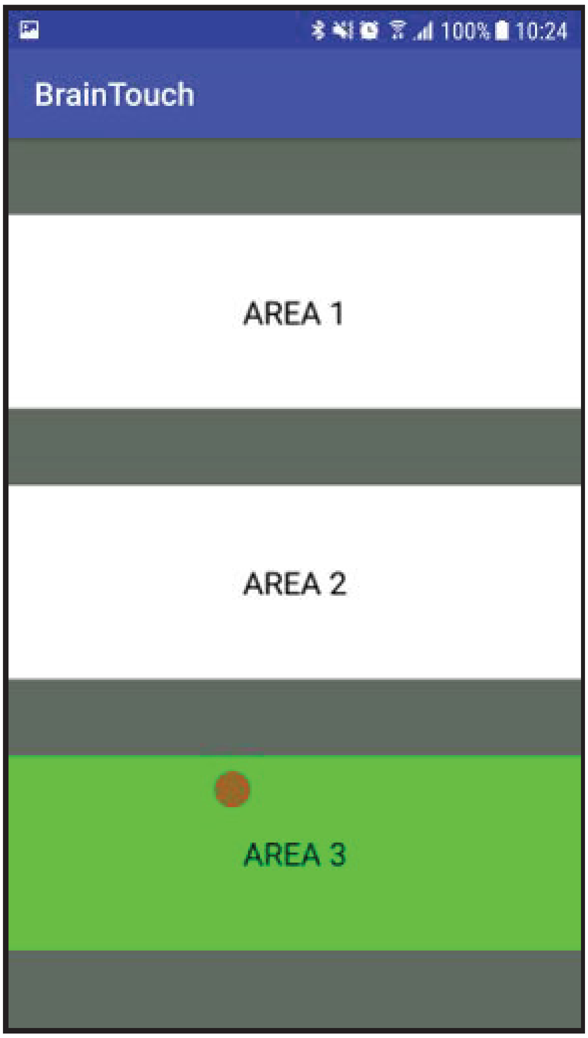

Image 2 Test activity with the marker on area 3

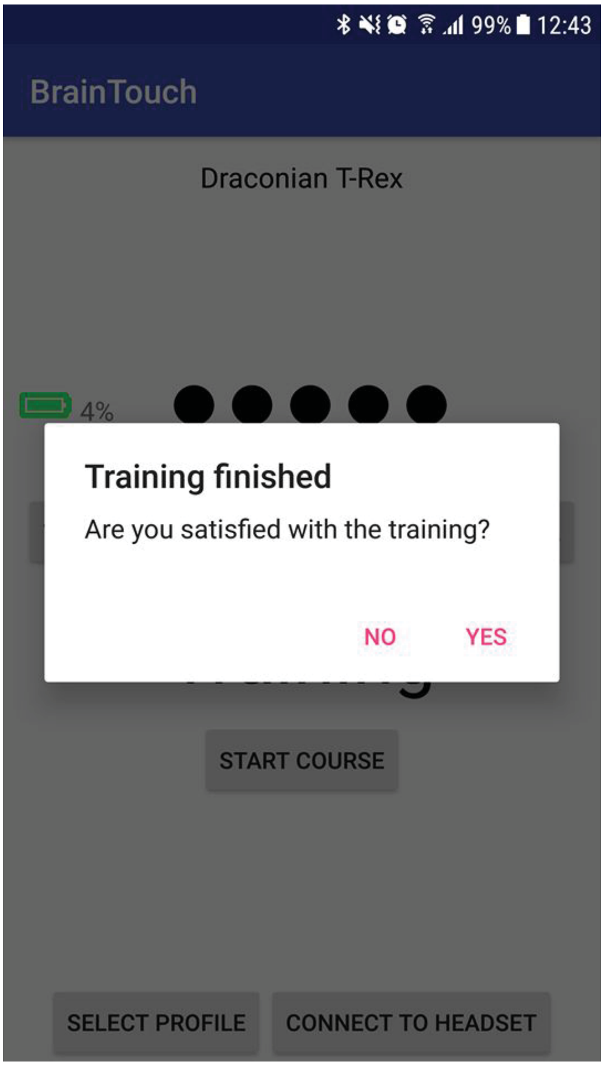

Image 3 Prompt after training a command

APPENDIX 6: Original test

1. Move the cursor to Area 1 within 30 seconds, have the cursor stay there for 10 seconds. If the participant is unable to position the cursor within Area 1 or unable to have the cursor stay in Area 1 for 10 seconds, the outcome of this stage is considered a fail.
2. Move the cursor to Area 2 within 30 seconds, have the cursor stay there for 10 seconds. If the participant is unable to position the cursor within Area 2 or unable to have the cursor stay in Area 2 for 10 seconds, the outcome of this stage is considered a fail.
3. Move the cursor to Area 3 within 30 seconds, have the cursor stay there for 10 seconds. If the participant is unable to position the cursor within Area 3 or unable to have the cursor stay in Area 3 for 10 seconds, the outcome of this stage is considered a fail.
4. Move the cursor to Area 1 within 30 seconds, have the cursor stay there for 10 seconds. If the participant is unable to position the cursor within Area 1 or unable to have the cursor stay in Area 1 for 10 seconds, the outcome of this stage is considered a fail.
5. Move the cursor to Area 3 within 30 seconds, have the cursor stay there for 10 seconds. If the participant is unable to position the cursor within Area 3 or unable to have the cursor stay in Area 3 for 10 seconds, the outcome of this stage is considered a fail.
6. Move the cursor between areas in this order:

   Area 3 ⟶ Area 2 ⟶ Area 3 ⟶ Area 1 ⟶ Area 3

   within 60 seconds. If the participant is unable to move the cursor in this order within 60 seconds the outcome of this stage will be considered a fail.