

MASTER THESIS
In
Universal Design of ICT

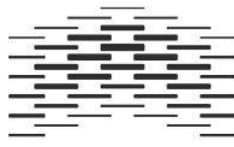
May 2017

**Comparing the efficacy of motor imagery and
visual imagery stimuli with Emotiv EEG.**

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1. Preface

During my years at the Oslo and Akershus University College (HiOA) I became interested in brain-computer interfaces (BCI) and based my bachelor project on electroencephalography (EEG)-based BCI systems. I decided to continue researching BCI systems for my Universal Design master project because I believe BCI to be the final human-computer interface. I want to be one of the people who will make sure that the implementation of the final human-computer interface is Universally Designed from scratch.

This study is in many ways an extension of my bachelor project (Andersen, Andersen, Bauge, Wilhelmsen Holthe, & Thomassen, 2014).

I will therefore briefly explain what the bachelor project achieved and how it ties in with this master project. The bachelor project aimed to create EEGBliss (renamed BlissBrain), an open-source system that would function as a central command centre for controlling multiple computer-programs with the Emotiv EPOC. The bachelor project resulted in functional prototypes of the system GUI and functional prototypes for controlling a computer using visual imagery with Blissymbolics (Blissymbolics Communication International, 2017).

My bachelor group founded a small company and represented both ourselves and HiOA at events such as SpillExpo (Norgesexpo AS, 2017) in 2014/2015 and The Gathering in 2016 (The Gathering, 2017). At these events we exhibited games for Windows, Mac, PlayStation 1 and Nintendo 64 controlled by the Emotiv EPOC using prototypes of BlissBrain.

Our aim was to inspire game developers to implement brain control in their games using Blissymbolics. Source code for the prototypes used to control the PlayStation 1 and Nintendo 64 is available open-source on GitHub (TurboDevs AS, 2017) for developers to use. During these events hundreds of people were playing games using the EPOC with Blissymbolics under our supervision. In 2015, our company (TurboDevs AS) became the assigner of a bachelor project in which a group of students created the BlissBase, a database-solution for Blissymbolics (Magnus William Eriksen, 2017).

1.1 Acknowledgements

I would like to first of all give a huge thanks to all of the test subjects that participated in this study. This report would not have been possible without them.

Many thanks to my supervisor and Associate Professor Tor-Morten Grønli for his support and feedback through the master project and Associate Professor and Head of Studies Tulpesh Patel for helping me with the design of the experiments and feedback.

Thanks also to Associate Professor George Anthony Giannoumis for his feedback and input.

I would like to thank the student organisation HiOA Gaming for their support in organizing the experiments during their events.

I would also like to thank Kari-Mette Andersen and Gunnar Michelsen for their comments on my grammar and such. They are great parents.

Tobias Andersen

26.04.2017.

2. Abstract

The number of consumer grade Electroencephalography (EEG) based brain-computer interfaces (BCI) on the market has increased considerably in recent years. New BCI technologies are emerging every year and the summary of the top BCI projects for the BCI award in 2013 (g.tec, 2017) states that “With so many new groups, ideas, and BCI directions, it can be difficult to identify the most impressive projects and trends. “ (Christoph Guger, 2014, s. 137). The Gartner Hype Cycle has listed “Brain-Computer Interface” at on the rise for the last two years (Chaffey, 2017). Most of these consumer grade devices use affect-detection for identifying emotions such as happy, angry, calm etc. (NeuroSky, 2017; Neurowear, 2017; Robertson, 2017) to improve or control their devices. Some devices also have support for mental commands using motor imagery and visual imagery (Emotiv Inc., 2017; Bobrov, et al., 2011). Former research on commercial grade headsets have mainly focused on general performance compared to the medical grade headsets (Bobrov, et al., 2011; Matthieu Duvinage, 2013) and/or testing performance using motor imagery mental commands (Cornelia Kranczioch, 2014), visual imagery mental commands (Bobrov, et al., 2011) or P300 (Matthieu Duvinage, 2013). Motor imagery, Visual imagery and P300 are all examples for ways to use an EEG based BCI to control a computer. To my knowledge, in this field any official universally designed standard for mental commands is still lacking, and I have not found any papers that compares motor imagery, visual imagery and/or P300 in order to check if either is better suited for universal design. Several companies are in the process of developing products that integrates consumer grade BCI into their products. Research has yet to investigate consumer grade BCI from a user centred design perspective. In this study I compared the real control and perceived control (confirmation bias) between motor and visual imagery with consumer grade headsets manufactured by Emotiv on 21 participants. The aim was to determine if either motor or visual imagery is less susceptible to confirmation bias, where the user think they are in control when they in reality are not. The results could be used to start working on a universally designed standard where motor or visual imagery might be used.

I compared how much control participants reportedly felt they had over a videogame character (score of 1 to 10) while they played using an Emotiv EEG headset to move the

character with motor imagery for 10 rounds and visual imagery for another 10 rounds. Unbeknownst to the test subjects, 5 of the rounds for motor and visual imagery were fake and they were merely watching a round played by someone else. Before the final test with 21 participants I did one pilot test with 6 participants and two pre-tests with 10 participants each to optimize the testing procedure before the final test. After each test I did a T-test on the control scores when in control and not in control for both motor and visual imagery. The T-tests comparing average control scores from the 21 participants in the final test resulted in a P-value of 0.70 for motor imagery and 0.53 for visual imagery. There was no significant difference ($P < 0.05$) between the control scores for when the participants were in control and not in control for both motor and visual imagery. The results from the final test was that 12 of 21 participants (57.1%) reported higher control scores when not in control for motor imagery rounds, and 12 of 21 participants (57.1%) reported higher control scores when not in control for visual imagery rounds. 8 of 21 participants (38%) reported higher control scores when in control for motor imagery rounds, and 8 of 21 participants (38%) reported higher control scores when in control for visual imagery rounds. One participant (4.7%) reported the same control score regardless of being in control or not for both motor and visual imagery. 5 of 21 participants (23.8%) reported higher control scores when in control for both motor and visual. 9 of 21 participants (42.8%) subjects reported higher control scores when not in control for both motor and visual. Three of 21 participants (14.2%) reported higher control scores when in control during motor imagery rounds, but not during visual imagery rounds. Three of 21 participants (14.2%) reported higher control scores when in control during visual imagery rounds, but not during motor imagery rounds. My findings in the final test suggest there is no significant difference between the control scores for when the participants were genuinely in control and when they were not in control. My findings also could not find a difference between motor and visual imagery. Most participants reported control scores that did not correlate with when they were genuinely in control. I was not able to reject my null hypothesis (H_0). More research is needed in order to come closer to a universally designed standard. A universally designed standard for EEG based BCI could benefit from being one where there is a correlation between perceived control and genuine control.

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6. Introduction

6.1 Commercial interest

EEG is an electrophysiological monitoring method to record electrical activity of the brain.

The Emotiv EPOC and Insight headsets used in this study is non-invasive devices for this purpose. Multiple companies already have products that incorporate

Electroencephalography (EEG) (Encyclopædia Britannica, 2017) technology and more companies have announced that they will use EEG or other non-invasive brain-computer interface (BCI) (Christoph Guger, 2014) technologies in future products. I will list some of these who might develop their own standards unless a universally designed standard emerges. In April 2017, Facebook announced that they are working on a non-invasive “typing by brain” technology co-led by Stanford neurosurgeon Jaimie Henderson that aims to achieve 100 words per minute (Strickland, 2017).

In April 2016, Smartstones published a video (Smartstones, 2016) of the upcoming iOS app “Speak :prose” which uses headsets from Emotiv to help people with special needs to communicate using motor imagery with EEG and face muscles (EMG) (Smartstones, 2017).

In February 2016, MindMaze raised \$100 million at a \$1 billion valuation for a combined virtual reality and EEG based headset for stroke victim therapy (Tilley, 2017) that currently only uses emotions to enhance the virtual reality experience (Robertson, 2017).

These companies are presumably making these products without using the same standard and there is no unifying standard yet to speak of.

There is currently no universally designed standard for EEG based BCI. This could lead companies interested in using EEG in their products to make their own standards that are not universally designed. If the academic community is unable to find a universally designed standard for EEG based BCI soon, we might have multiple companies with their own standards that are not universally designed and could exclude people with special needs.

6.2 Working towards a Universal Design standard

This master thesis report is about my findings when comparing the more standardized method of “motor imagery” against the less tested “visual imagery” with the EEG-based Emotiv (Emotiv Inc., 2017) EPOC and Insight BCI.

For visual imagery I decided to use Blissymbolics because it is a well-established ideographic writing system used by people with severe speech and physical impairments (SSPI) for Augmentative and Alternative Communication (AAC). Blissymbolics is also open-source under the Creative Commons Attribution-Share Alike 3.0 Unported License (Creative Commons, 2017).

In the process of designing a universal standard, it will be of paramount importance to first investigate whether any difference exists between motor and visual imagery in relation to genuine and perceived control. This is because both models may be relevant in a universally designed standard. If either motor or visual imagery is less susceptible to “confirmation bias” where the users think they are in control when they are not, then it should be taken into account when deciding on a universally designed standard.

My goal in this project was to learn more about how to create safe and user-friendly BCI systems that is less susceptible to confirmation bias and false positives and/or negatives. The results of my research so far has not found a measurable difference between motor and visual imagery using my current methods, both performed equally well in my tests. More testing is needed in order to determine which of the two is best suited for a universally designed EEG system.

7. Literature review

I will explain in detail the different technologies and concepts that was used in this project and in some cases explain why comparable technologies was not used and the reasons why.

7.1 Background research

My bachelor project (Andersen, Andersen, Bauge, Wilhelmsen Holthe, & Thomassen, 2014) aimed to create EEGBliss (renamed BlissBrain), an open-source system that would function as a central command centre for controlling multiple computer-programs with the Emotiv EPOC. The bachelor project resulted in functional prototypes of the system GUI and functional prototypes for controlling a computer using visual imagery with Blissymbolics (Blissymbolics Communication International, 2017). During the bachelor project we also conducted user-testing on people diagnosed with Tetraplegia and Cerebral Palsy using the prototypes to see if Blissymbolics could be used to answer yes and no questions using the EPOC.

Based on the results from these tests, we concluded that it worked with an accuracy of better than random using the Durbin-Wu-Hausman test with a 0.8 average similarity-score. Our results were presented at the International Conference on Computers Helping People with Special Needs (ICCHP) (ICCHP, 2017) in Paris (2014). The feedback we received at the conference was positive and inspiring. The criticism was mainly about the small sample size. The people we discussed with urged us to research the concept further.

7.2 BCI input systems

A brain-computer interface (BCI) is a device that enables control or communication without movement. BCI devices can detect patterns in the brain-activity of the user which can be linked to commands or messages. The signal sent from the user is decoded using signal processing to identify which command or message the user intends to use and can redirect it to produce an output.

Several methods to achieve this has been explored and the annual BCI awards hosted by g.tec that received a total of 169 submissions in 2013 (Guger, Allison, & Edlinger, 2013), 69 submissions in 2014 (Guger, Müller-Putz, & Allison, 2015) and 63 submissions in 2015 (Guger, Allison, & Ushiba, 2017).

There are several methods that BCI systems can use, such as EEG, fMRI and ECoG, but in the rest of this chapter I will talk about three methods for using an EEG based BCI system: P300, Motor imagery and Visual Imagery.

7.2.1 P300

P300 is a component of an event related potential (ERP) that occurs during decision making. Because it occurs as a reaction to a stimulus and not to the physical attributes of a stimulus, it is considered to be an endogenous potential.

P300 was discovered in 1964 by Robert M. Chapman & Henry R. Bragdon (Robert M. Chapman, 1964) and they found the ERP response to visual stimuli to be different depending on if the stimuli had meaning or not. The experiments they did involved showing participants flashes of light and numbers. The participants watched these stimulations in a sequence one at a time. For every two numbers the participants were asked to tell the researchers if for example the numbers were equal, if one number was larger than the other or which of the two came first in a sequence. The researchers found ERP-responses with a large positive peak around 300 milliseconds after the number stimuli but not the light stimuli. This response was then named the P300 response.

When used with EEG, the P300 signal is detected as a positive deflection in voltage with a latency between the stimulus and response of around 250 to 500 milliseconds (Polich, 2007). The area around the parietal lobe is where the signal is usually the strongest and is commonly used as a metric of cognitive function in decision making by looking at the magnitude, topography, timing and general presence.

The P300 signal can be used in a BCI system as a “P300 speller” where the BCI system looks for the P300 signal while the user looks at a grid of letters and/or numbers and detects when the column and row which the user focuses on lights up.

Medical grade EEG headsets such as the headsets from g.tec can be used in a BCI system for a P300 spelling with more than 10 letters per minute (G.TEC MEDICAL ENGINEERING GMB, 2017). Commercial grade headsets such as the Emotiv EPOC can also be used in a BCI system for P300 spelling (Milsap, 2017), but with slower speeds (around 1 letter per minute) compared to medical grade headsets.

A paper that compared the performance of the Emotiv EPOC with the medical grade ANT acquisition system for P300-based applications concluded that “Although this low-cost headset is able to record EEG data in a satisfying manner, it should only be chosen for non-critical applications such as games, communication systems, etc. For rehabilitation or prosthesis control, this lack of reliability may lead to serious consequences. For research purposes, the medical system should be chosen except if a lot of trials are available or when the signal-to-noise ratio is high. This also suggests that the design of a specific low-cost EEG recording system for critical applications and research is still required.” (Matthieu Duvinage, 2013).

7.2.2 Motor Imagery

Motor imagery is the dynamic state when a person mentally stimulates a given action and mental practise using visuo-motor imagery to improve motor behaviour have been used widely in many different use-cases. To use visuo-motor imagery the user must simulate an action by using imagination without physical movement.

Motor imagery has been used to improve neurological rehabilitation for stroke patients (Page, Levine, Sisto, & Johnston, 2001; Zimmermann-Schlatter, Schuster, Puhan, Siekierka, & Steurer, 2008).

Motor imagery has also been used as a mental practise in combination with physical practise to help people learn a new sport and to help people already proficient in a sport to further enhance their skills (Cornelia Frank, 2014).

When practising a sport, you have both physical and mental practise that generates physical and mental feedback. Mental practise creates a cognitive process which is not easily replicated with physical practise (Cocks, Moulton, Luu, & Cil, 2014).

The same study found that surgeons that do mental practise along with physical practise got the same results as they did using physical practise.

Motor imagery has also been used to communicate with unconscious individuals using fMRI (Gibson Raechelle M., 2014).

Motor imagery has been used in EEG based BCI systems as a control mechanism where the system detects that the user is thinking about a specific action and executes a command that was selected by the user to be executed if that specific action was detected.

One example of EEG based BCI systems that uses motor imagery is the Emotiv EPOC and Emotiv Insight headsets.

In a conference paper called “Feasibility of Using Low-Cost EEG Acquisition Devices for Motor Imagery BCIs” based on a data driven study using Common Spatial Pattern (CSP) and Wavelength Optimal Spatial Filters (WOSF), researchers changed the configuration of the EPOC headset (Soman, Gupta, & Raj, 2013). The researchers wanted to develop a motor imagery based BCI system. Even though the official method for recording mental commands with the Emotiv control panel uses motor imagery, the researchers ended up modifying the EPOC headset hardware for better performance. The modification was changing the placement of two electrodes.

The paper concluded that “Though the original positioning of the electrodes was not found suitable for this paradigm, re-positioning them gave us higher classification accuracy.” The classification accuracy using CSP filtering increased from an average of 63.5% to 70.7% after modifying the EPOC. The classification accuracy using both CSP and WOSF filtering increased from an average of 66.5% to 75.3% after modifying the EPOC.

7.2.3 Visual Imagery

One of the most common examples of visual imagery (also known as mental images) is the mental visualization that occurs when a person is daydreaming or reading a book. According to cognitive scientist and psychologist Steven Pinker we experience our world represented through mental images in our mind which can be compared and associated with others and used to create totally new images. Mental images can be used to create theories about how the world works in likely sequences of mental images in our minds without the direct experience (Pinker, 1999).

Theories on how visual imagery are created in the mind include the dual-code theory by Allan Paivio (Paivio, 1971). Allan theorized that we have two codes for representing information in our brains that are either image codes or verbal codes. The image codes can be a picture of a boat when you are thinking about a boat and the verbal code is when you think of the word boat. Abstract words such as love and hate are easier to think of in verbal codes while more concrete words such as cat and sofa are easier to think of in image codes.

Another theory is the functional-equivalency hypothesis by (Eysenck, 2012).

Eysenck hypothesized that mental images are “internal representations” which works in the same manner as the actual perception of physical objects. Meaning, a picture of a sofa imagined in your mind when the word sofa is read is interpreted in the same manner as when you see a sofa in front of you.

In two different papers which used fMRI, the researchers found that the difference in brain-patterns when a person looks at an image, and imagines that same image is nearly zero (Ishai, Ungerleider, & Haxby, 2000; Ganis, Thompson, & Kosslyn, 2004).

In a data driven study, researchers compared the EEG based Emotiv EPOC headset (Emotiv Inc, 2017) with the EEG based BrainProducts ActiCAP headset (Brain Products GmbH, 2017) headset. The researchers found that both the Emotiv EPOC and BrainProducts ActiCAP could classify the brain-patterns which were formed by imagining pictures based on EEG-pattern recordings (Bobrov, et al., 2011).

It was found through an analysis of the influence of EOG artefacts (from eye movements and eye blinks) that “classification between states is actually based on differences in brain activity measured by EEG, and not on patterns of blinking and movements”. The percentage of correctly recognized states exceeded 33%, with averages for the Emotiv EPOC at 48% and 54% for the ActiCAP.

From these papers it seems that visual imagery can be used as a control mechanism in the same way as motor imagery is used as a control mechanism with the Emotiv EPOC.

7.3 EEG technology:

EEG or Electroencephalography is a method for monitoring electrical activity in the brain by measuring the voltage fluctuations from ionic current within the neurons of the brain (Ernst Niedermeyer, 2004). When neurons communicate, a current occurs.

Most EEG devices are “non-invasive” which means that the electrodes which are used to monitor the activity are placed on the scalp. Invasive electrodes that are operated within the substance of the brain or over the surface of the brain are sometimes used on epilepsy patient to see if the patient can have epilepsy surgery (Epilepsy Foundation, 2017).

EEG is used in several other clinical contexts such as diagnosing sleep disorders, coma, encephalopathies, and brain death where the doctors generally focuses on the spectral content of EEG meaning the type of neural oscillations that are observed. These neural oscillations are commonly just called “brain waves”.

Techniques used in cognitive science, cognitive psychology and psychophysiological research often use Event-related potentials (ERPs) that are averaged EEG responses which is “time-locked” to more complex processing of stimuli such as sensory, cognitive or motor events (Luck, 2005).

EEG was first discovered by Hans Berger in 1942 (Haas, 2003) and has since then been developed on with new methods and devices.

7.3.1 Consumer grade EEG based headsets

7.3.1.1 Emotiv EPOC

The Emotiv EPOC and Emotiv Insight EEG headsets used in this project are both wireless and have the same capabilities for identifying “mental commands” using motor imagery according to Emotiv (Emotiv Inc, 2017).

The Emotiv EPOC has 14 electrodes placed in the positions AF3, AF4, F3, F4, FC5, FC6, F7, F8, T7, T8, P7, P8, O1 and O2 using the standard 10-20 international EEG position system and two CMS/ DRL reference electrodes in the noise cancellation configuration placed on the left and right hemisphere of the head.

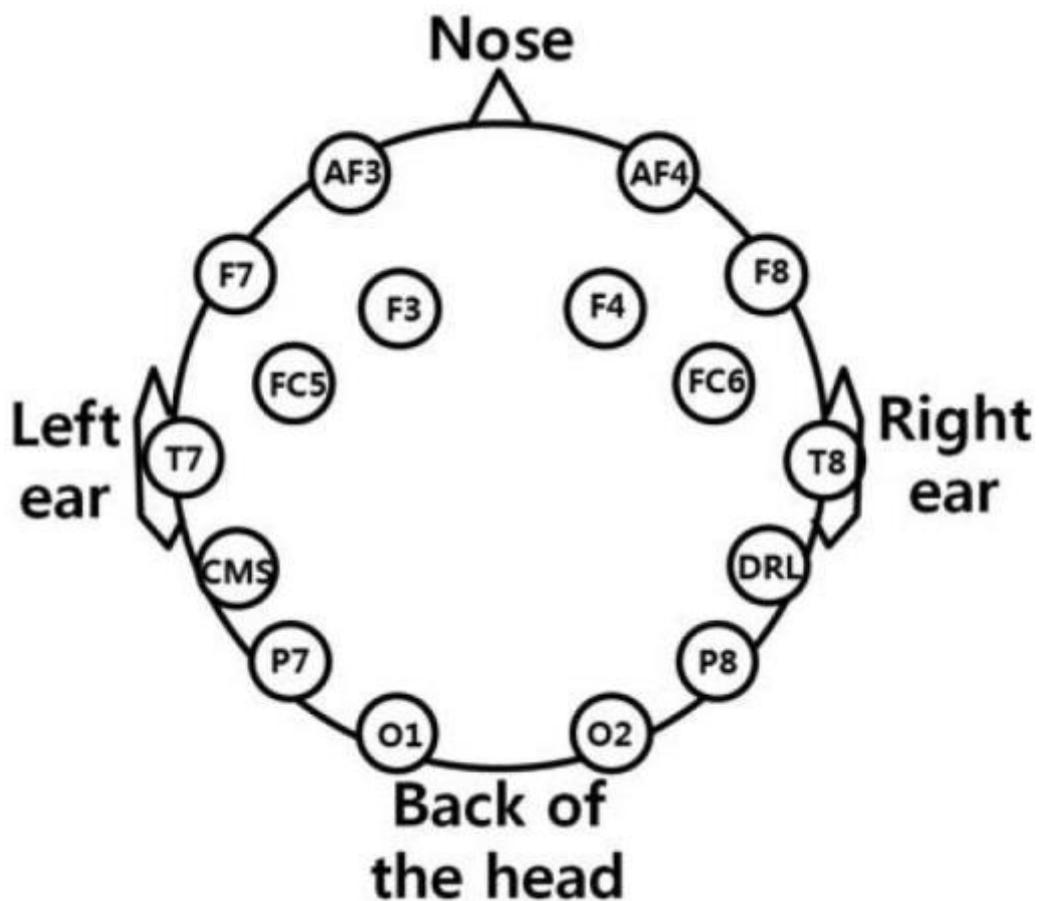


Figure 1 Bang JW, Choi JS, Park KR. (2017, May 14). The positions of 16 electrodes of the Emotiv EPOC headset. [digital image]. Retrieved under (CC BY 3.0) from https://openi.nlm.nih.gov/detailedresult.php?img=PMC3690055_sensors-13-06272f3&req=4

The electrodes need saline solution in order to work, which is less messy to use than conductive gel commonly used in medical grade EEG headsets and takes less time to setup. For communication, you need a proprietary USB Bluetooth 4.1 dongle that allows the headset to send EEG data on the 2.4 GHz band to a computer. The headset records with a sampling frequency of 2048 Hz which is reduced to 128 Hz before sending the data over Bluetooth. There are two versions of the Emotiv EPOC with different firmware where the “research edition” allows real-time raw data access, whereas the regular version does not.



Figure 2 Emotiv Inc. (Photographer). (2017, May 14). Picture of the Emotiv EPOC EEG headset [digital image]. Retrieved from <https://www.emotiv.com/epoc/>

7.3.1.2 Emotiv Insight

The Emotiv Insight has 5 electrodes placed in the positions AF3, AF4, T7, T8 and Pz using the standard 10-20 international EEG position system and two CMS/DRL reference electrodes in the noise cancellation configuration.

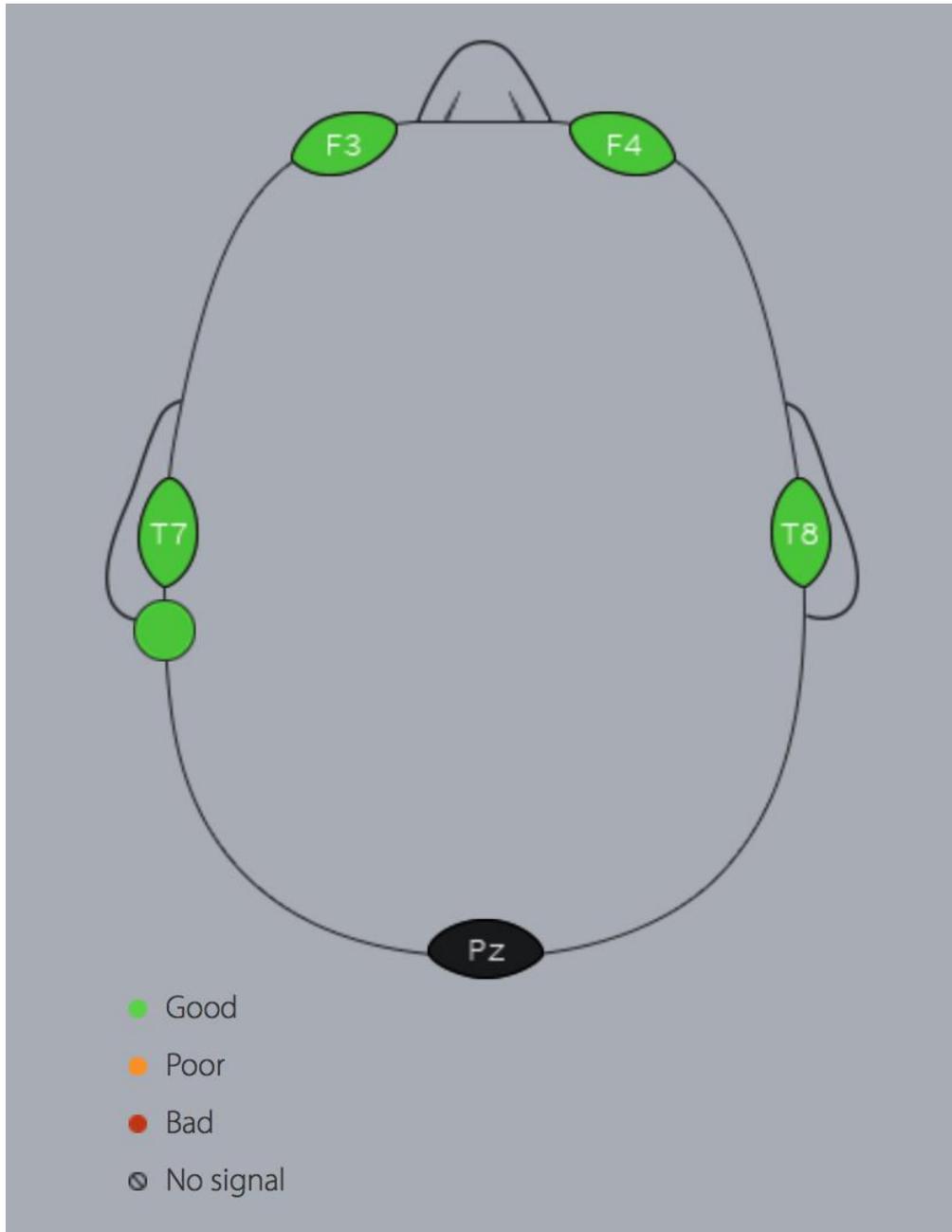


Figure 3 Geek-Mag. (2017, May 14). Screenshot of the positions of the electrodes for the Emotiv Insight headset in the Emotiv Control Panel [digital image]. Retrieved from <http://geek-mag.com/posts/259698/>

The electrodes does not need any saline solution in order to work, because they are made of “long life semi-dry polymer” that makes contact with the scalp using surrounding moisture. This makes it even less messy compared to both the Emotiv EPOC and medical grade EEG headsets that use conductive gel and takes less time to setup. For communication, you need a proprietary USB Bluetooth 4.1 dongle that allows the headset to send EEG data on the 2.4 GHz band to a computer. The headset records with a sampling frequency of 128 Hz that is sent to the computer over Bluetooth.



Figure 4 Emotiv Inc. (Photographer). (2017, May 14). Picture of the Emotiv Insight EEG headset [digital image]. Retrieved from <https://www.emotiv.com/insight/>

7.3.1.3 OpenBCI

OpenBCI is an open-source circuit board made for EEG, Electromyography (EMG) and Electrocardiography (ECG) applications (OpenBCI , 2017). The OpenBCI board can be bought separately and you can print your own 3d-printed headset to use it with (Russomanno, 2017). The electrodes can be placed wherever you want. The Mark III Nova iteration of the 3d-printed headset frame that I looked at when I was deciding which headset to use for my project has the electrodes in the positions Fp1, Fp2, C3, C4, P7, P8, O1 and O2 using the standard 10-20 international EEG position system.

The OpenBCI 8-channel version (OpenBCI, 2017) has been used successfully in a P300 speller system with the electrodes in the positions C3, Cz, C4, P3, Pz, P4, O1, O2 and with custom settings (Frey J. , 2015).

The OpenBCI has also been used to control video games using motor imagery with the electrodes in the positions C3, Cz, C4, FCz, Pz, CPz, O1, O2, C5, FC3, CP3, C1, C2, FC4, CP4, C6 (Frey J. , 2015) by using the free OpenVibe (OpenVibe, 2017) software platform for using BCIs and with custom settings.

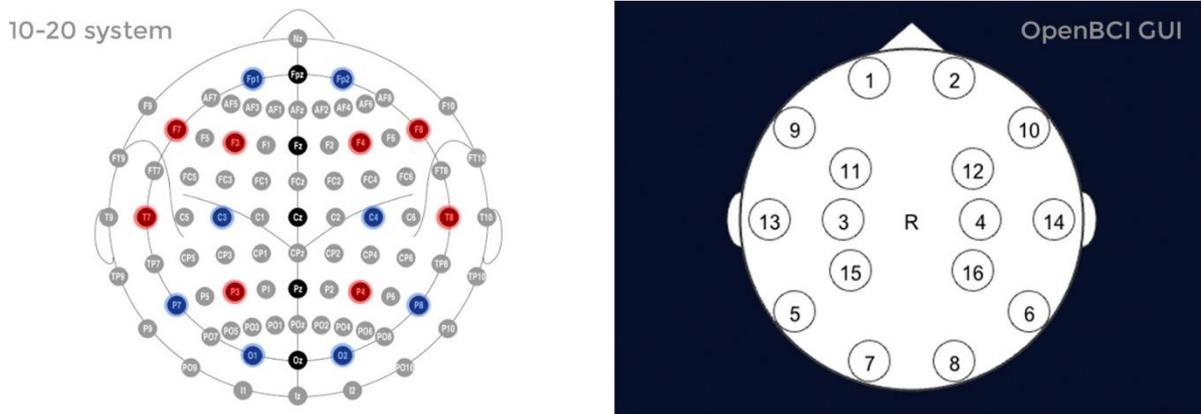
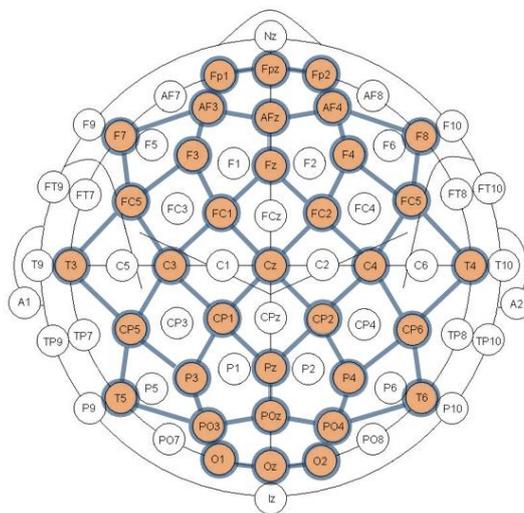


Figure 5 OpenBCI. (Photographer). (2017, May 14). Picture of the positions of the electrodes for the OpenBCI headset [digital image]. Retrieved from https://github.com/OpenBCI/Ultracortex/tree/master/Mark_III_Nova_REVISED

The latest and greatest iteration of the OpenBCI 3d-printed headset frame is the Ultracortex Mark IV (OpenBCI, 2017) that has 35 electrodes in the positions Fp1, Fpz, Fp2, AF2, AFz, AF4, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC5, T3, C4, Cz, C4, T4, CP5, CP1, CP2, CP6, T5, P3, Pz, P4, T6, PO3, POz, PO4, O1, Oz and O2.

In the product description there is a disclaimer saying that the headset is: “not a medical device nor is it intended for medical diagnosis and provided to you "as is” (OpenBCI, 2017).

Ultracortex Mark IV Node Locations (35 total)



Based on the internationally accepted **10-20 System** for electrode placement in the context of EEG research

Figure 6 OpenBCI. (Photographer). (2017, May 14). Picture of the positions of the electrodes for the Ultracortex "Mark IV" EEG Headset [digital image]. Retrieved from <https://shop.openbci.com/products/ultracortex-mark-iv>

The OpenBCI webpage sells several different boards that can be used with their 3d-printed headset frames or that can be used in your own 3d-printed frames.

The 4-channel boards (Ganglion) has a sample rate of 200Hz (OpenBCI, 2017) and uses Bluetooth LE (also known as Bluetooth SMART). You need to buy a Bluetooth CSR 4.0 USB dongle for data transmission to devices that does not support Bluetooth SMART already. The 4-channel board can measure ECG, EMG and EEG.

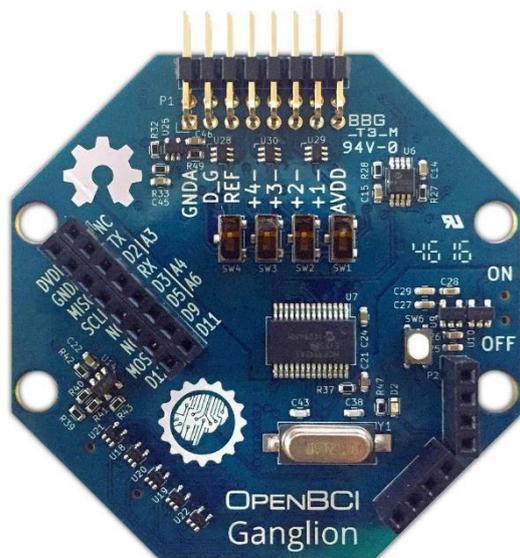


Figure 7 OpenBCI. (Photographer). (2017, May 14). Picture of the Ganglion Board (4-channels) [digital image]. Retrieved from <https://shop.openbci.com/products/pre-order-ganglion-board?variant=13461804483>

The 8-channel boards (Cyton) has higher resolution with more channels compare to the 4-channel boards. It also samples at the higher rate of 250Hz (OpenBCI, 2017).

It is also possible to get a sample rate of up to 16 kHz if you are using the SD-card local storage rather than using wireless transmission or add your own wired USB connection (Strong, 2017). The 8-channel boards comes with a Bluetooth BLE USB dongle included, which allows it to transfer data to a computer, tablet or mobile wirelessly. I has an 8 differential low noise input channels with high gain and a 24-bit channel data resolution. The 8-channel board can measure ECG, EMG and EEG.

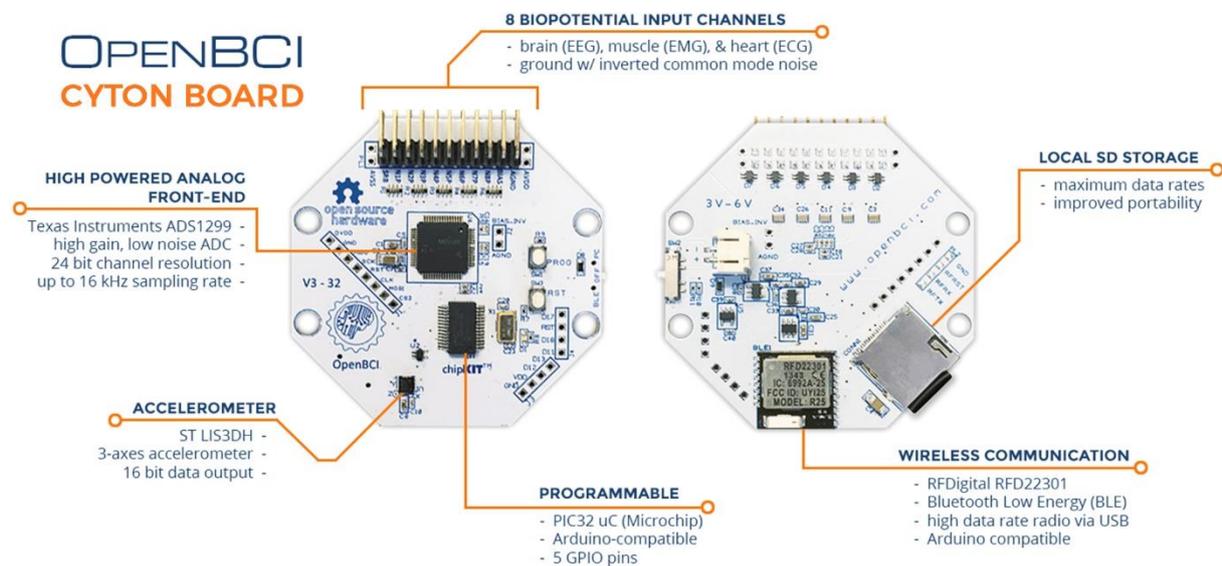


Figure 8 OpenBCI. (Photographer). (2017, May 14). Picture of the Cyton Board (8-channels) [digital image]. Retrieved from <http://openbci.com>

The latest and greatest is the 8-channel board (Cyton) and Daisy combo for 16-channels total (OpenBCI, 2017). The combo samples at 250Hz and comes with a Bluetooth BLE USB dongle included, which allows it to transfer data to a computer, tablet or mobile wirelessly.

I has a total of 16 differential low noise input channels with high gain and a 24-bit channel data resolution split between the two boards. The 16-channel board combo can measure ECG, EMG and EEG.



Figure 9 OpenBCI. (Photographer). (2017, May 14). Picture of the Cyton + Daisy Biosensing Boards (16-Channels) [digital image]. Retrieved from <https://shop.openbci.com/collections/frontpage/products/cyton-daisy-biosensing-boards-16-channel?variant=38959256526>

7.3.1.4 NeuroSky MindSet

The NeuroSky MindWave (NeuroSky, 2017) is a consumer grade EEG headset with one electrode placed in the position FP1 using the standard 10-20 international EEG position system and three reference electrodes around the left ear (A1).

The MindSet uses the patented eSense algorithm (NeuroSky Developer, 2014) to interpret the mental states of attention and meditation of the user. By monitoring the level of power in alpha, beta and theta frequencies the headset can use brain-state values to control computer applications using commands.

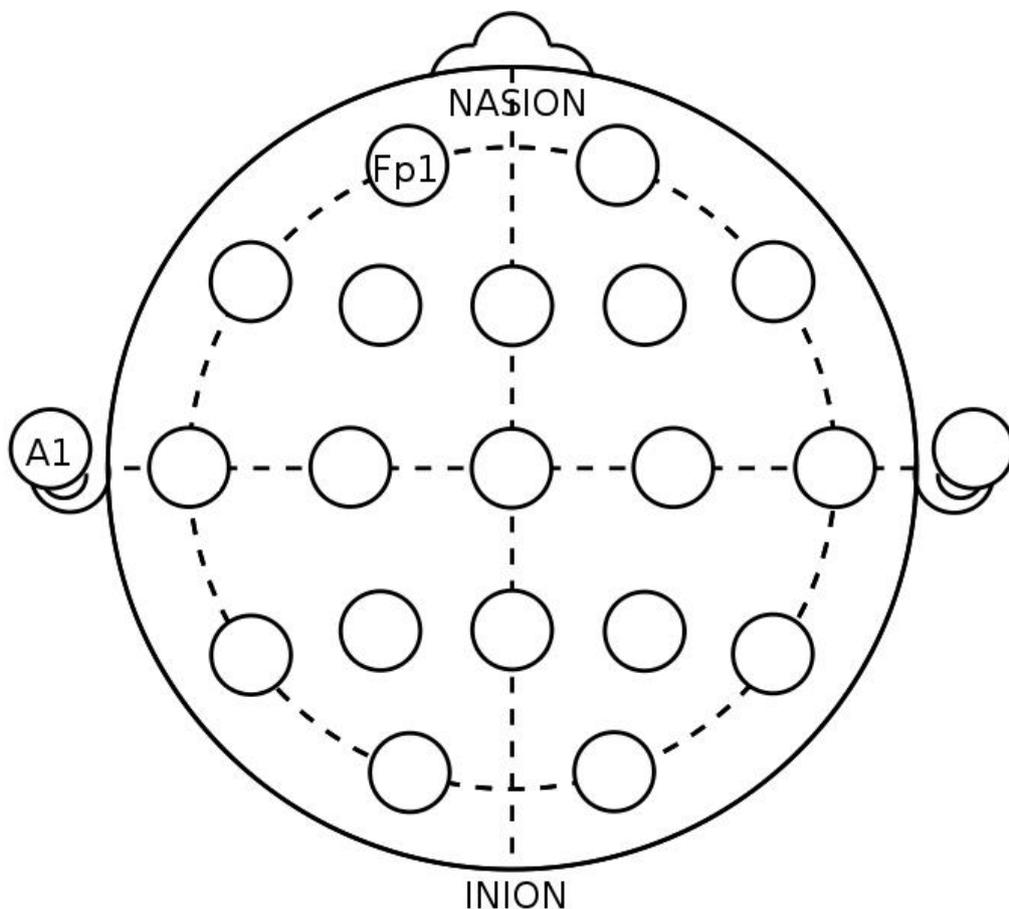


Figure 10 トマツシ24. (2010, May 30). 21 electrodes of International 10-20 system for EEG [digital image]. Retrieved (and edited) from [https://en.wikipedia.org/wiki/10-20_system_\(EEG\)#/media/File:21_electrodes_of_International_10-20_system_for_EEG.svg](https://en.wikipedia.org/wiki/10-20_system_(EEG)#/media/File:21_electrodes_of_International_10-20_system_for_EEG.svg)

The electrodes does not need any saline solution in order to work, because they are dry passive electrodes that makes contact with the scalp using surrounding moisture. The headset uses a Bluetooth to communicate with a computer.

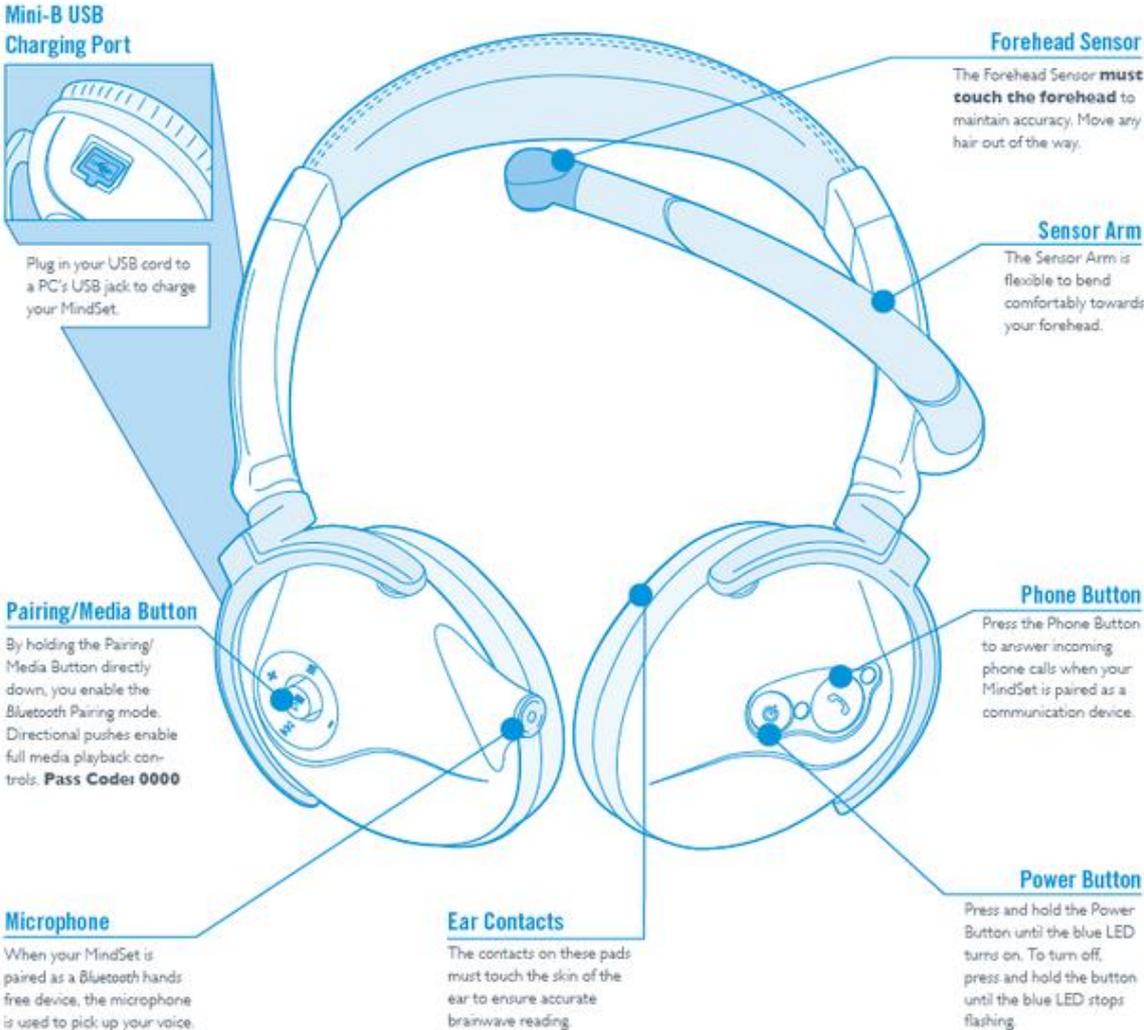


Figure 11 NeuroSky. (Photographer). (2017, May 14). Picture of the NeuroSky MindSet EEG headset [digital image]. Retrieved from <http://support.neurosky.com/kb/mindset/mindset-diagram>

7.3.1.5 NeuroSky MindWave

The NeuroSky MindWave (NeuroSky, 2017) is a consumer grade EEG headset with one electrode placed in the position FP1 using the standard 10-20 international EEG position system and one reference electrode clipped to the left earlobe (A1).

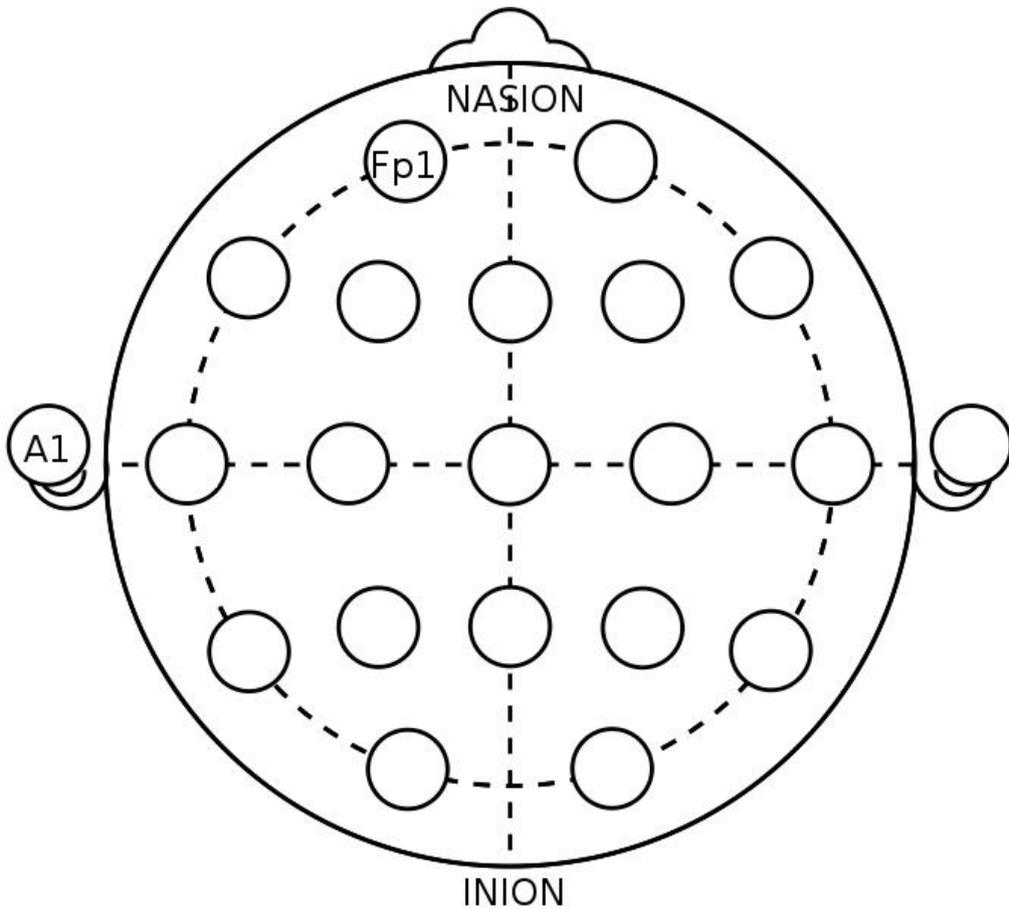


Figure 12 トマツ124. (2010, May 30). Illustration of the NeuroSky MindWave electrode positions [digital image]. Retrieved (and edited) from [https://en.wikipedia.org/wiki/10-20_system_\(EEG\)#/media/File:21_electrodes_of_International_10-20_system_for_EEG.svg](https://en.wikipedia.org/wiki/10-20_system_(EEG)#/media/File:21_electrodes_of_International_10-20_system_for_EEG.svg)

The electrode does not need any saline solution in order to work, because it is a dry passive electrode that makes contact with the scalp using surrounding moisture. The headset uses a 2.4GHz RF link to send EEG data to a computer. The mobile version uses Bluetooth to communicate with Android and iOS devices. The MindWave has a sample rate of 512Hz with a 12bit ADC.

The MindWave uses the patented eSense algorithm (NeuroSky Developer, 2014) to interpret the mental states of attention and meditation of the user. By monitoring the level of power in alpha, beta and theta frequencies the headset can use brain-state values to control computer applications using commands.



Figure 13 NeuroSky. (Photographer). (2017, May 14). Picture of the NeuroSky MindWave Mobile EEG headset [digital image]. Retrieved from <https://store.neurosky.com/pages/mindwave>

7.3.1.6 MyndPlay Brainband / MyndBand

The MyndPlay Brainband, renamed MyndBand, is a consumer grade EEG headset with one electrode placed on the forehead and two reference electrodes on the left ear (MyndPlay, 2017).

The electrode does not need any saline solution in order to work, because it is a dry passive electrode that makes contact with the scalp using surrounding moisture. The headset uses a MyndBand Bluetooth to send EEG data to a computer or android device (iOS devices will be supported in future firmware upgrades). The MyndBand has a sample rate of 512Hz. The MyndBand can detect attention, meditation, mindfulness/Zone and eye blinks.

The MindWave Mobile version and MyndPlay can be bought together in a bundle (MyndPlay, 2017).



Figure 14 MyndPlay. (Photographer). (2017, May 14). Picture of the MyndPlay EEG headset [digital image]. Retrieved from <https://store.myndplay.com/products.php?prod=28>

7.3.1.7 Comparisons of consumer grade EEG headsets

A comparison from 2014 that used both the Emotiv EPOC and NeuroSky MindSet to control a videogame found that the Emotiv EPOC performed better than the NeuroSky MindSet in for adaptation and interaction while the NeuroSky MindSet performed better in terms of satisfaction to the users (Fotis Liarokapis, 2014).

A comparison of the Emotiv EPOC and NeuroSky MindWave from 2016 found that the Emotiv EPOC performed better than the NeuroSky MindWave in eye blinking tasks (Maskeliunas R, 2016).

A review of wireless brain-computer interface systems from 2013 listed the Emotiv EPOC, NeuroSky MindSet and MindWave and the MyndPlay Brainband under the category “Wireless BCI systems for consumer use (Seungchan Lee, 2013).

The current version of the MyndPlay EEG headset called MyndBand calls itself a “research grade” EEG headset, but I was not able to find any papers that compared the MyndPlay EEG headsets to any other EEG headsets (ScienceDirect database and Google Scholar).

The product page for the MyndBand claims it to be “the world first research grade customisable EEG Neurofeedback headset which also integrates directly into VR headsets allowing brainwaves to go beyond the lab and the screen into the real and virtual world.” (MyndPlay, 2017). I have not found any examples of the MyndPlay Brainband or MyndBand used together with a VR headset. In 2015 me and my colleague Robin Ødegård used the Emotiv Insight EEG headset with the Oculus DK2 VR headset (Oculus, 2017) to control the movements of a videogame character (Andersen, Ødegård, & Bauge, YouTube, 2015) and it would be interesting if our experiment pre-dates MyndBand.

I was not able to find any comparisons of the Emotiv and OpenBCI headsets, but I found from examples mentioned earlier that both the Emotiv EPOC and OpenBCI headsets can be used for P300 and motor imagery applications.

The Emotiv EPOC was the only consumer grade headset I could find which had previous research confirming that it can be used for visual imagery applications (Bobrov, et al., 2011), and it was therefore selected to be used in my research.

If I had to pick a headset today, I would consider the OpenBCI 16-channel combo if I could research if the OpenBCI headset can be used for visual imagery applications.

The OpenBCI headsets might perform better than the Emotiv headsets due to the higher sampling rates when used with SD-card/wired USB.

7.4 BCI research:

The latest state of the art summary of BCI research from the annual BCI Award states that “76.1% of all submissions used EEG, which is slightly higher than previous years but still close to the average of 72.1%.” (Guger, Allison, & Ushiba, Brain-Computer Interface Research: A State-of-the-Art Summary 5, 2017, s. 133).

The summary also claims that “real-world applications are approaching” (Guger, Allison, & Ushiba, 2017, s. 134) because of the increase in real-time BCI as opposed to off-line algorithms. Only two of the 63 submissions in 2015 was using off-line algorithms (and neither were nominated).

The summary also states that “Most of the submissions improved the technology by developing new hardware and software, developed new platforms or developed control interfaces for wheelchairs, robots or prosthetic devices including exoskeletons.” (Guger, Allison, & Ushiba, 2017, s. 134)

The type of signal used to control BCI in the 2015 submissions were P300/N200/ERP (28.6%), SSVEP/SSSEP/cVEP (14.3%) and Motor Imagery (36.5%). The summary states that motor imagery based BCIs have consistently accounted for about a third of all submissions the past 6 years.

In a paper called “Flaws in current human training protocols for spontaneous brain-computer interfaces: lessons learned from instructional design” researchers concluded that “As such, we would recommend BCI authors to carefully describe the training protocols they use in their papers, so that the whole BCI design could be fairly understood and assessed.” (Lotte, Larrue, & Mühl, 2013). The same paper also stated that “Most research so far was focused on signal processing, mostly neglecting the human in the loop.”

From the research I have seen so far I agree with Lotte, and I decided to research BCI in user centred design perspective because of this gap.

A paper from 1995 (Marks & Isaac, 1995) which used EEG based BCI devices found strong evidence for the Vividness of Visual Imagery Questionnaire (VVIQ) made by psychologist David F. Marks in 1973 (Marks D. F., 1973). The questionnaire was tested in 1973 by Marks and found that the participants that reported vivid visual imagery was more accurate in the recall than participants that reported poor visual imagery.

In the 1995 paper the researchers found that there is a reliable statistical difference in the patterning of EEG responses for participants that was selected using the VVIQ.

The researchers found differences in particular within the alpha frequency that suggests a consistent different response for the vivid and non-vivid imagers among the participants.

The group “x” interaction condition was statistically significant or close to significant for all of the four tasks. The paper concludes that “these data are a reflection of different levels of regionalized cortical activation in individuals experiencing vivid and non-vivid imagery who are engaged in the process of image generation.” And that more research and analysis is needed.

7.5 Blissymbolics

Blissymbolics, sometimes referred to as Blissymbols or just Bliss, is a semantic graphical language and an ideographic writing system created by Karl Kiesel Bliss in 1949 (Bliss, 1949). The system is built up of hundreds of basic symbols that each represents a concept that can be composed with other basic symbols to represent new concepts. Blissymbolics is one of the largest writing systems globally where the characters don't correspond to spoken language. Blissymbolics is currently used in over 33 countries and translated into 15 languages (Blissymbolics Communication International, 2017).

Blissymbolics has been a standard in the ISO/IEC 2022 character set registry since 1993 and has been approved as an encoded language in the ISO 639-2 and IOS 639-3 standards with the code zbl (Klaus Miesenberger, 2012).

Michael Everson, a primary contributor and editor of the Unicode standard, have proposed to implement Blissymbolics into Unicode (Michael Everson, 2017).

A database over all the official Blissymbols, and their definitions are available on GitHub (Ljunglöf, 2017) under the GNU General Public License v3.0 (Free Software Foundation, Inc., 2017)

Blissymbolics has grammar based on the interpretation of nature by dividing them into matter (material things, energy (actions) and human values (mental evaluations). This is different from other languages where verbs, adjectives and substantives are used.

According to Michael Everson: "Blissymbolics were developed in the middle of the twentieth century by Charles Bliss as a "universal" language that (he hoped) could cut across national boundaries and facilitate international communication and peace" (Everson, 2017).

7.5.1 History of Bliss

During the German invasion of Austria in 1938, Bliss was transferred to the concentration camps of Dachau and Buchenwald because he was Jewish. His German wife Claire found a way to get him released and they ended up as exiles in Shanghai where he had a cousin. During his time as a refugee in the Shanghai Ghetto and later in Sidney from 1942-1949 he became inspired by Chinese characters and created Blissymbols as an international auxiliary language to make it easier for the different linguistic communities to communicate.

Karl initially named his symbols “World Writing” in 1947 but later chose the more international scientific term “Semantography” taken from the Greek “semantics” which means “significant meaning” and “graphein” which means “to write” (Bliss, 1965).

An increase in tourism in the 1960’s increased the demand for a new standard of symbols that could be used for road signs, train stations and airports. Karl renamed his system once again to “Blissymbolics” so that it could not be plagiarized.

During the 1960’s Blissymbolics became a popular method to help disabled people to communicate. A pioneer program was established at the Ontario Crippled Children’s Centre (OCCC) by Shirley McNaughton in 1971 to help children with cerebral palsy to communicate by using augmentative and alternative communication (AAC) with Blissymbolics.



Figure 15 Blissymbolics Communication Institute - Canada (Photographer). (2017, May 15). Picture from the OCCC of a child using Blissymbolics [digital image]. Retrieved from <http://blissymbolics.ca/bcic-history>

Bliss disliked how teachers at OCCC used the system because they used “fancy” terms such as “verbs” and “nouns” when they described what Bliss called “actions” and “things” (Okrent, 2009, ss. 173-4). The OCCC program used Blissymbolics in a practical manner to teach the children how to express themselves in their mother’s tongue. Blissymbolics enabled them to understand the meaning of English words through visual keys.

The published manual for Blissymbolics that Bliss wrote did not have a system for the definition of the symbols, but it had a provisional vocabulary index (Bliss, 1965, ss. 827–67). Shirley McNaughton and her team at OCCC modified the Blissymbolics system so that it could be adapted into a bridge for English (Okrent, 2009, s. 189).

This led to a complaint from Bliss that his symbols were being abused by the OCCC. Bliss granted exclusive world licence for use with disabled children to the “Blissymbolics Communication Foundation” directed by Shirley McNaughton in 1975. In 1977 Bliss claimed that his agreement had been violated and that he had lost control of his symbol system (Stott, 2017). Bliss and McNaughton reached a settlement in 1982 where the OCCC got an exclusive licence to use Blissymbolics while Bliss received \$160,000 which he used to further publicize his Blissymbolics manual (Okrent, 2009, ss. 192–4).

Today the exclusive license is claimed by Blissymbolic Communication International that uses and publishes Blissymbolics for people with language, learning and communication difficulties in over 33 countries and 15 languages (Blissymbolics Communication International, 2017).

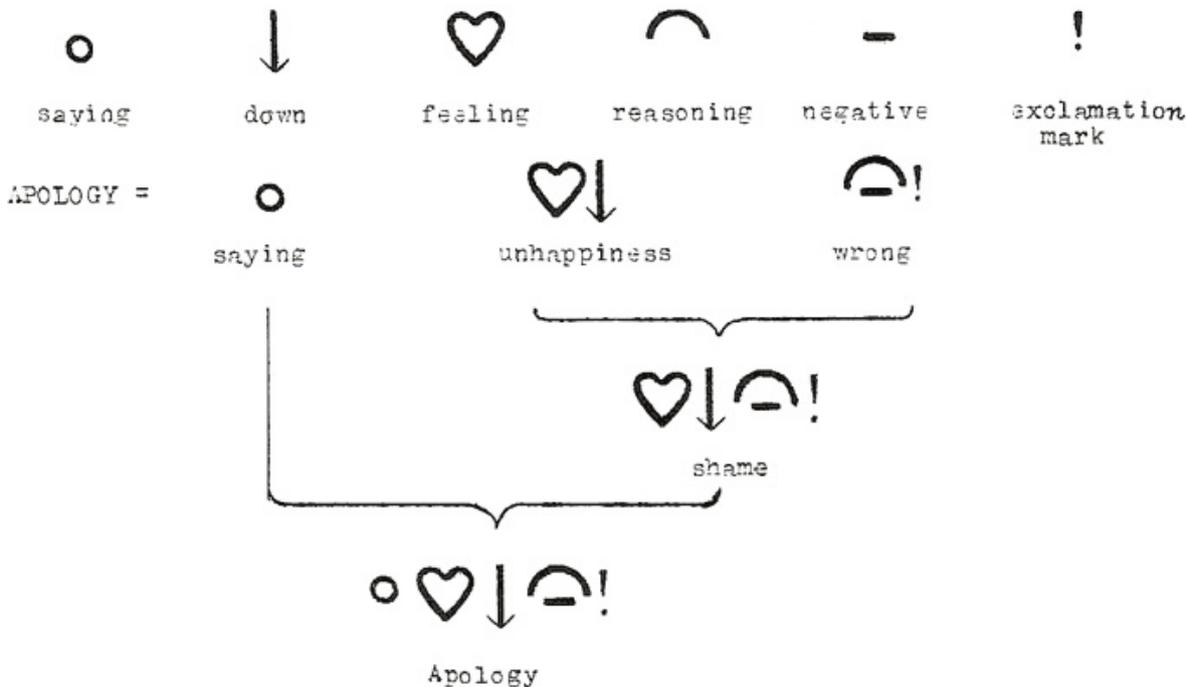


Figure 16 Cheryl Yau (Photographer). (2017, May 15). Picture of the complex word apology written with Blissymbolics [digital image]. Retrieved from <http://idsgn.org/posts/bringing-bliss-to-non-speakers/>

7.6 Other comparable symbol systems

The Dept. of Speech & Hearing Sciences at The University of Washington lists three generative AAC systems in their article named “Selecting a Generative Vocabulary” that is based on symbols (University of Washington, Dept. of Speech & Hearing Sciences, 2017).

One of them is Blissymbolics and the other two are Minspeak/Unity System and Gateway Language & Learning. I will go through these two common alternatives to Blissymbolics.

7.6.1 Minspeak/Unity System

The Unity System version 128 (Luberoff Badman, et al., 2017) has over 2100 root words and with word endings the system can create even more words, along with pre-stored phrases and sentences. Access is often with a 3-symbol code. There is a “Condensed Version” (Prentke Romich Company, 2017) that for the most part uses 2-symbol codes with the drawback of fewer vocabulary items. The Condensed version is still generative with words plus word endings.

The Minspeak symbols are not transparent, which means they have to be taught to the intended user. Words, phrases and word endings are stored and retrieved using a 2 or 3 symbol code. Each symbol has more than one meaning and is used in multiple combinations which reduces the space requirement to fit the symbols on a display.

The Unity system is based on Minspeak symbols and only available to licensed systems (Semantic Compaction Systems, 2017).



Figure 17 Liberator - A Prentke Romich Company (Photographer). (2017, May 15). Screenshot from a device using Minspeak[digital image]. Retrieved from <http://liberator.net.au/language/three-ways-to-represent-language>

7.6.2 Gateway Language & Learning

The Gateway Language & Learning system (Gateway to Language and Learning, 2017) is based on DynaSyms symbols and available for the DynaVox/DynaMyte systems.

The SynaSyms symbol-set has thousands of symbols developed exclusively for DynaVox software (Tobii Dynavox, 2017). About 30% of the vocabulary is single words with 750 root words plus word endings and tense markers which allows the user to make an additional 250 words. The vocabulary is based on vocabulary utilized by other AAC users and aimed at individuals with receptive language at about the fourth year level. The majority of words can be selected with one to three key presses on the device.

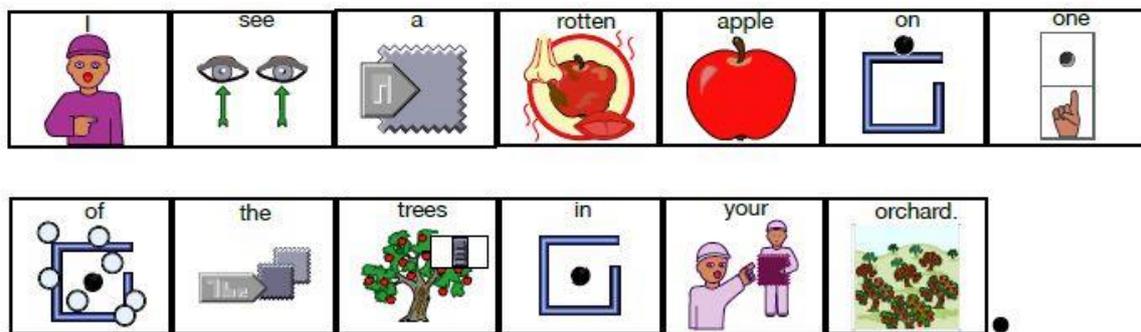


Figure 18 Language Symbols (Photographer). (2017, May 15). Example of a sentence with DynaSyms Symbols[digital image]. Retrieved from <http://languagesymbols.com/dynasyms.html#products>

7.7 Confirmation bias

Confirmation bias is when you favour, search, recall and interpret information which confirms your pre-existing hypotheses or beliefs (Plous, 1993, s. 233).

It is called a semantic error of inductive reasoning and a type of cognitive bias where people display this behaviour when they remember or gather information in a selective way or interpret information in a biased way. Often this effect is the strongest when emotions are involved and people tend to take debatable evidence to reinforce their existing positions.

Confirmation bias can reinforce personal beliefs and maintain them even when confronted by contrary evidence. In some cases you can have what is called the belief polarization phenomenon where different parties disagree on the same evidence that they interpret selectively to reinforce their current beliefs (Fine, 2008). Sometimes different parties can interpret the same information as evidence for their different existing attitudes which in turn can widen the disagreement between them rather than narrowing it down (Lord, Ross, & Lepper, 1979).

7.7.1 Confirmation bias related to my research

One relatively common type of confirmation bias that has been around since the first videogame consoles were released is when someone thinks they are in control of the video game character when they in reality are just watching the game being played.

This phenomenon is often observed where a parent or older sibling is playing a videogame and has given a younger sibling a controller (or something resembling a controller) that isn't connected to the videogame console to play with. The younger sibling thinks they are playing the game because they can see that things are happening on the television.



Figure 19 CoolHandRK. (Photographer). (2016, April 18). 30+ years of research shows, if you give a kid a Nintendo, he will give his little sister an unplugged controller [digital image]. Retrieved from <http://imgur.com/gallery/GtXngGi>

More examples of this phenomenon can be found online, with photographs dating back to the 1990s of children thinking they are playing along (Dorkly, 2014).

A similar phenomenon can be experienced when playing “split screen” video games where the television is divided up into individual windows for each player, and the players can select the same character or variations of the same character.



Figure 20 Dazran303. (Photographer). (2014, June 9). MARIO KART 8 - 3 Player Split-Screen Gameplay [digital image]. Retrieved from <https://www.youtube.com/watch?v=aksEQNQengg>

When the characters are similar, the players sometimes look at the wrong “window” thinking they are looking at the character they are in control of, when in reality they are looking at the character that another player is controlling.

7.8 Research Questions

7.8.1 Research question 1:

Is there a correlation between perceived and real control (confirmation bias) for motor imagery and visual imagery?

7.8.2 Research question 2:

If there is a difference, will the difference be the same for all use cases or are there applications where either motor or visual imagery performs better in relation to confirmation bias?

7.9 Hypothesis

Null hypothesis (H_0):

There is no difference in confirmation bias between motor imagery and visual imagery.

Alternative hypothesis (H_1):

Either motor imagery or visual imagery has less confirmation bias.

7.10 Goals

The main goal of this master project was to determine if there is a significant difference in confirmation bias between motor imagery and visual imagery. The end result should be a set of guidelines for developers who wish to use EEG-based BCI. The guidelines could provide different recommendations for different applications if the difference in confirmation bias depends on the application. The expected outcome of this project was research results that contribute to the improvement of BlissBrain and the development of a universally designed standard for EEG.

8. Methodology

In this chapter I will first present who my participants were, the equipment I used in the tests, the test I used, how the tests were designed to answer the research question and what type of analysis I used on the data collected from the tests. Because I did some changes between the pilot test and pre-test iteration 1, pre-test iteration 2 and the final test, I have described the equipment and test protocol for them individually. I decided to do a couple of pre-tests before the final test to optimize the experiment. If you just want to read about the final test setup you may skip the chapters 8.4 to 8.12.

8.1 Participants and recruitment

I used a Quantitative method and collected data from 47 participants in total by using the convenience sampling method from three “LAN parties” (Johannes Fromme, 2012, ss. 466-469) at graduate school (26 participants) and from the second largest LAN party in the world: The Gathering (The Gathering, 2017) (21 participants). All participants were ostensibly healthy and 18 years old or older (confirmed by asking for identification document such as driver licence).

The three LAN parties at graduate school had around 50 attendees each. I was only able to recruit around 20% of the attendees from each of these LAN parties by asking if people would like to participate over the sound system used for playing music at each of the LAN parties.

The Gathering had around 7.000 attendees (NRK, 2017) and I was only able to recruit around 0.3% of the attendees from The Gathering by asking people walking by the HiOA Gaming booth if they would like to participate. I asked the participants about how regularly they played video games, and all participants reported that they play video games several times a week.

During the bonus test at SpillExpo A few children requested to try Minecraft in virtual reality with the Emotiv Insight, after watching older family members try it. I allowed them to try, but I did not do any testing on them because they were not old enough to give consent. A few test subjects only wanted to try out the Emotiv Insight without the virtual reality headset. The results from these tests has not been included in this report because I did not want to mix results from tests without virtual reality with the rest of the results.

8.1.1 Ethical considerations

The Emotiv EPOC and Emotiv Insight headsets are not classified as medical devices, but have been used by researchers in a variety of applications because of its capabilities (Robert Lievesley, 2011).

All consent forms used in the tests states that the test subject can contact me at any time and have their data removed from the study. My name and contact info is on all the consent forms. See the appendices file for example of consent form.

No personal information was collected in the tests. The test subjects were only identified in the test data with a test-subject number. All data was handled confidentially and when the final report has been completed, the data will be destroyed. It is not possible to identify a test subject by the data collected in the report.

The methods used in this project are the same as I used in my bachelor project and is not deemed necessary for report to the Norwegian Centre for Research Data (NSD), according to correspondence with them last year (Jacobsen, Ingrid, (personal communication), 2016). According to the NSD webpage, if I only use anonymous information in my project, it is not subject to notification (Norsk senter for forskningsdata, 2017).

8.2 Equipment

I used two different EEG headsets from Emotiv in this project with slightly different setups from the pilot test to the final test. I used the same software development kits provided by Emotiv with both EEG headsets. I will go through the setup of the two headsets and software in this chapter, before explaining the experiment procedure and the different setups in the next chapters.

8.2.1 Emotiv EPOC

For the pilot test and pre-test iteration 1 I used the Emotiv EPOC with 14 electrodes placed in the positions AF3, AF4, F3, F4, FC5, FC6, F7, F8, T7, T8, P7, P8, O1 and O2 using the standard 10-20 international EEG positioning system. In addition to these electrodes, I used the two CMS/DRL reference electrodes that is used for noise cancellation located on the left and right hemisphere of the skull. I used saline solution from the local pharmacy to wet the electrodes to improve conduction. I used the proprietary USB Bluetooth 4.1 dongle that came with the headset to transfer data to my computer wirelessly.

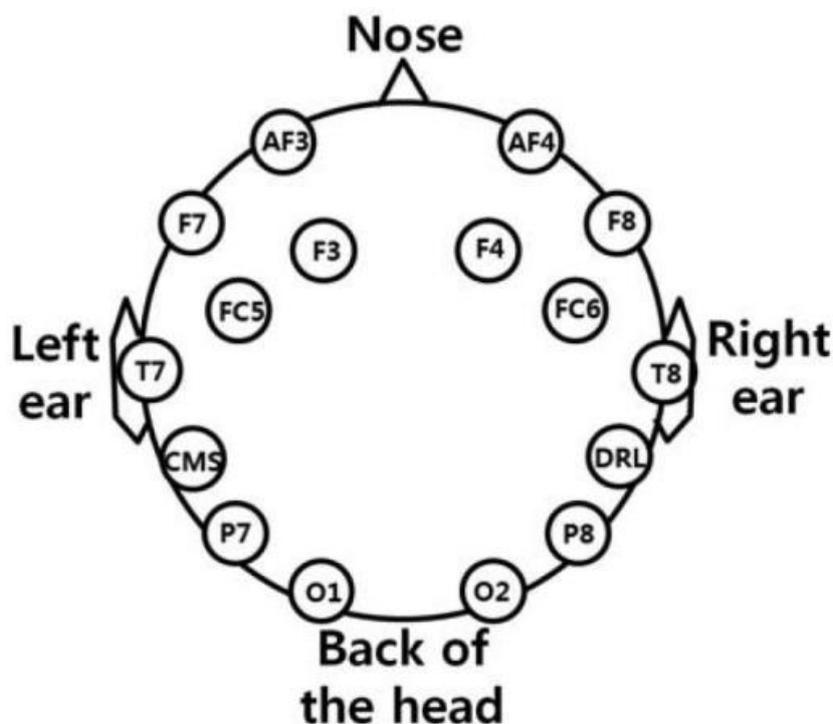


Figure 21 Bang JW, Choi JS, Park KR. (2017, May 14). The positions of 16 electrodes of the Emotiv EPOC headset. [digital image]. Retrieved under (CC BY 3.0) from https://openi.nlm.nih.gov/detailedresult.php?img=PMC3690055_sensors-13-06272f3&req=4

8.2.2 Emotiv Insight

For the pre-test iteration 2, bonus test at SpillExpo and final test I used the Emotiv Insight with 5 electrodes placed in the positions AF3, AF4, T7, T8 and Pz using the standard 10-20 international EEG position system and two CMS/DRL reference electrodes for noise cancellation located on the left hemisphere of the skull. Even though the Emotiv Insight can be used without any conductive gel or saline solution, I used a few drops of saline solution from the local pharmacy to wet the electrodes to improve the conduction and speed up the process. I used the same proprietary USB Bluetooth 4.1 dongle that came with the Emotiv EPOC headset to transfer data to my computer wirelessly.

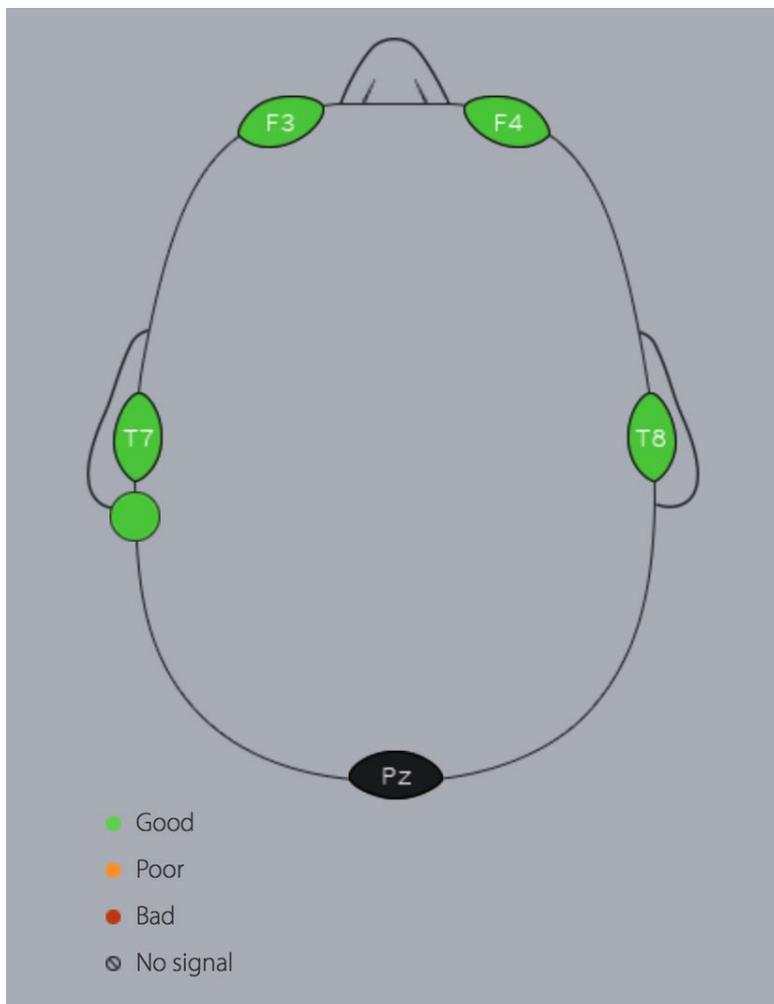


Figure 22 Geek-Mag. (2017, May 14). Screenshot of the positions of the electrodes for the Emotiv Insight headset in the Emotiv Control Panel [digital image]. Retrieved from <http://geek-mag.com/posts/259698/>

8.2.3 Recording software and procedure for motor and visual imagery in all the tests

When testing motor imagery, I recorded 5 samples of “neutral” and 5 samples of “lift” in the Emotiv control panel v2.0.0.21 (Emotiv Inc, 2017) with the “Cognitive suite” using the floating orange 3d cube for visual feedback. The test subjects were instructed to think about the movement of the cube when recording, which would be used when playing the game later.

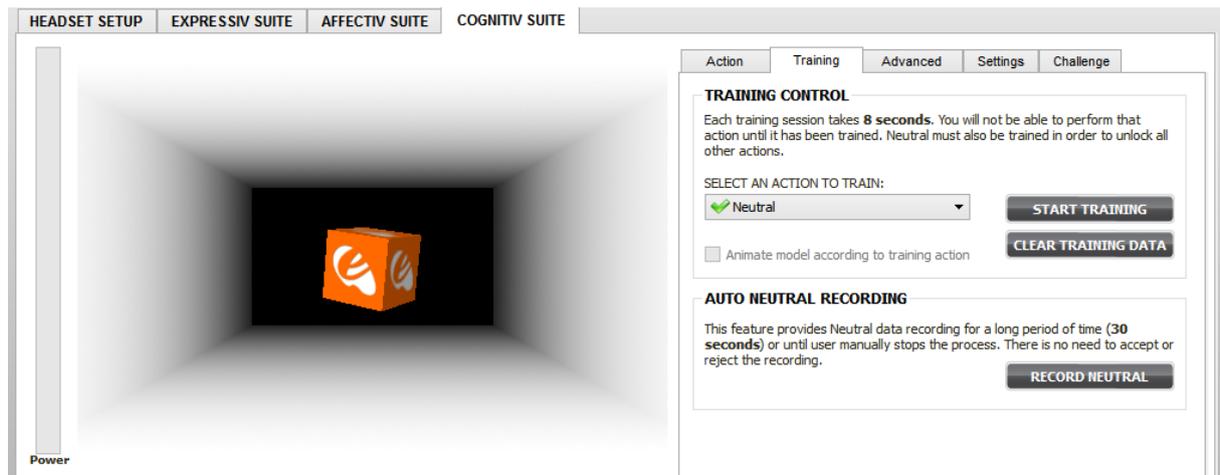


Figure 23 Screenshot from the Emotiv Control Panel.

When testing visual imagery, test subject A and test subject B recorded 5 samples of “neutral” and 5 samples of “lift” in the Emotiv control panel using a full-screen picture of the Blissymbol for “up”. The test subjects were instructed to think about the “up” symbol when recording, which would be used when playing the game later.

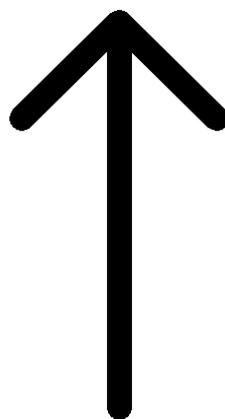


Figure 24 The Blissymbol for "up".

8.3 The experiment procedure

To measure the difference between motor imagery and visual imagery in terms of which of the two that might be more susceptible to confirmation bias, I decided to test if the participants could recognize when they had genuine control of a videogame character.

To do this, I made a variation of the “Wizard of Oz Experiment” (Hanington, 2012, s. 204; Sandnes, 2011, s. 297) where the participants were only in control of the game character half of the time. The participants rated their feeling of control over a videogame character from 1 to 10 while playing the game videogame using only an Emotiv EEG based BCI headset. The videogame I used is the same game I used at SpillExpo in 2014 called “FlappyBrain” (FlappyBrain, 2017).

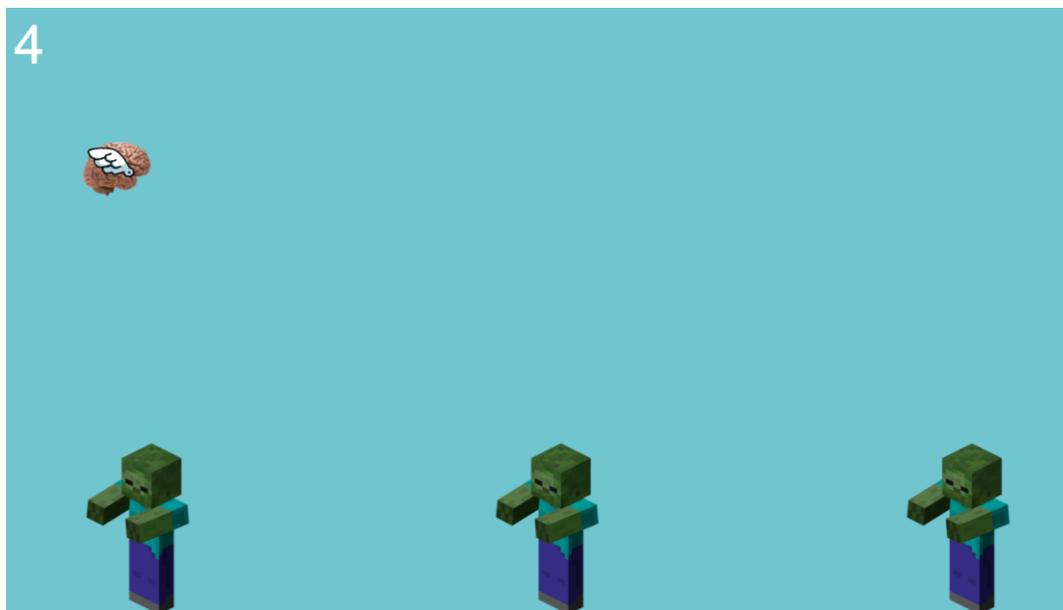


Figure 25 Screenshot from the game "FlappyBrain"

The goal of FlappyBrain is to hold a thought recorded in Emotiv Control Panel (Emotiv Inc, 2017) for as long as possible to keep your game character in the air. If the player fails to hold the thought, the game character will fall to the ground and be eaten by zombies. The game is played by pressing “1” on the keyboard, and can be played using the EPOC with the keyboard emulation tool EmoKey to execute the “1” key on the keyboard if a specific thought recorded in Emotiv Control Panel has been detected. The EmoKey tool is included in the free Emotiv EPOC SDK LITE (v2.0.0.20). The game will give you a score of how many zombies you have flown over.

Each participant played 10 rounds using motor imagery based control and 10 rounds using visual imagery based control. Each participant was given control of the videogame character in half of the motor and half of the visual imagery rounds. In the other half, they watched a round of the videogame as if they were in control. The participants were not informed that they would only be in control of the videogame character half of the time.

By using this method I was able to measure the perceived feeling of control over the videogame character and compare motor and visual imagery to see if either had more participants reporting a high feeling of control when they were just watching a fake round.

I also collected how many obstacles (zombies) points the participants were able to fly over in the videogame when they were not spectating and genuinely in control.

8.4 Equipment setup used in the pilot test and pre-test iteration 1.

I used two Emotiv EPOC headsets and two computers that filled the system requirements for the Emotiv EPOC. The computers also had three video outputs each in order for them to be connected to three monitors simultaneously. I also had a divider between the participants to prevent the test subjects from seeing each other's monitors. The figure below shows how the equipment is configured.

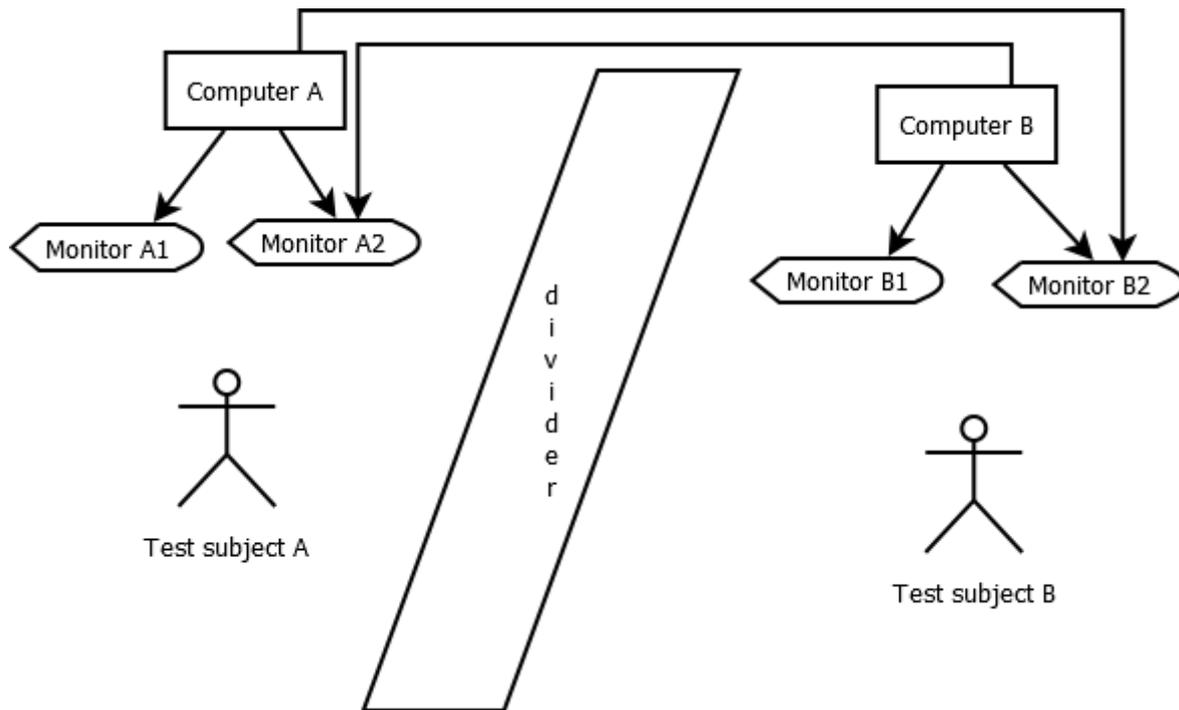


Figure 26 Equipment configuration used in the pilot test and pre-test iteration 1

Monitor A1 and B1 shows the Emotiv control panel, while monitor A2 and B2 are used for displaying symbols and displaying the game which are used in the testing.

8.5 Test protocol used in the pilot test and pre-test iteration 1

Both test subject (Test subject A and Test subject B in Figure 1) were told that they would be testing a brain controlled game I created called “FlappyBrain” and that they were going to play 10 rounds using motor imagery and 10 rounds using visual imagery. In the pre-test iteration 1 I also told them they would be competing in a “duel” after the 20 rounds of motor and visual imagery testing.

8.5.1 Playing and gathering data

Before launching the game, I asked both players to take a short break, close their eyes and relax while the game is prepared. I told them it would help them relax and give them a better chance at winning the duel. While the test subjects had their eyes closed, I changed the Monitor B2 settings to show a mirror of Monitor A2 by altering the source input.

FlappyBrain is now starting on Computer A and shown on both Monitor A2 and Monitor B2. The “Affective suite” which shows emotional responses in the Emotiv control panel is selected and shown on Monitor A1 and Monitor B1. Monitor A1 displayed the control panel on computer A and Monitor B1 displayed the control panel on computer B.

I also asked the participants not to announce what score they got after each round in order to prevent them from disturbing each other. Both players were told before the games starts that after each round they had to put down a number between 1 and 10 to indicate how much control over the game character they felt they had on a scale from 1 to 10.

8.6 Changes in equipment setup and procedure from iteration 1 to iteration 2

I discussed the results from pre-test iteration 1 with my supervisor and the setup was changed from 2 test subjects playing with/against each other, to one test subject playing with/against a video-simulation of the game. This was done in order to give the participants more consistent fake feedback. Five rounds with the same fake game-scores on all test subjects could give me a better comparison between test subjects.

It was also decided that should give all participants earplugs to prevent audible noise from the LAN party to be a factor.

8.7 Equipment setup used in pre-test iteration 2

I decided to go from using two Emotiv EPOC headsets to one Emotiv Insight headset. Both headsets have the same capabilities according to Emotiv (Emotiv Inc, 2017) and uses the same control panel. The hardware in the Emotiv Insight is newer than the Emotiv EPOC and more comfortable to use for the user.

I used one computer that filled the requirements for the Emotiv Insight. The figure below shows how the equipment is configured.

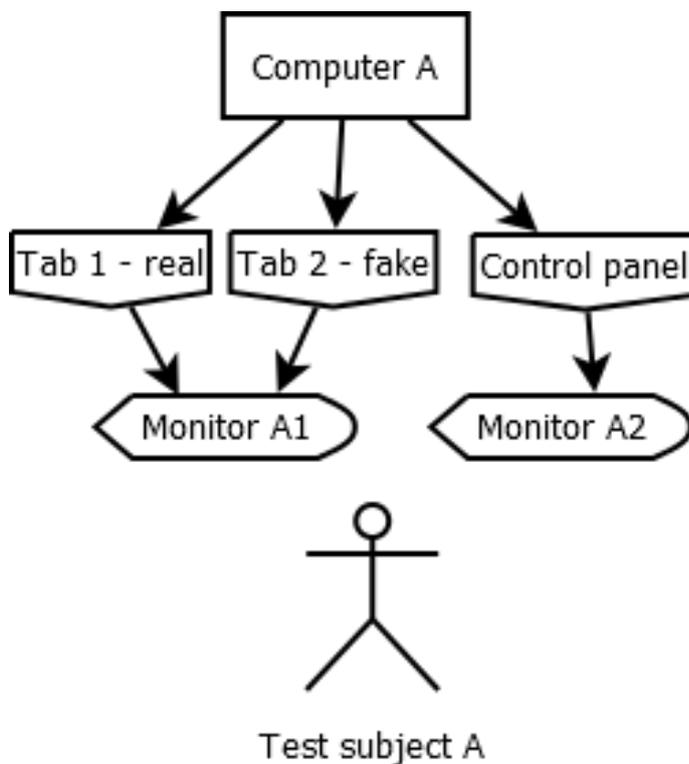


Figure 27 Equipment configuration for the confirmation bias tests in pre-test iteration 2.

Monitor A1 was used for displaying symbols when recording, displaying the game, displaying the fake game with a video player and to display the challenge mode.

Monitor A2 was used for the control panel or to mirror A1 during testing.

8.8 Test protocol used in the pre-test iteration 2

The method for controlling the game FlappyBrain in this test and in previous tests are the same.

The participants (Test Subject A in Figure 5) were told that he or she would be competing in the “Neurogaming” tournament for this LAN party. The participant played “FlappyBrain” using motor imagery in 10 rounds and visual imagery in 10 rounds. After 20 rounds of practice, the test subjects played 3 rounds of “challenge mode” in the Emotiv Control Panel.

The participants were asked to choose either motor imagery or visual imagery for the 3 rounds in “challenge mode”, whichever he or she feels more confident in using after practicing. The test subject with the highest score in “challenge mode” of all the test subjects at the LAN party won a 500 NOK gift card. All participants were genuinely in control during the 3 last rounds of “challenge mode”.

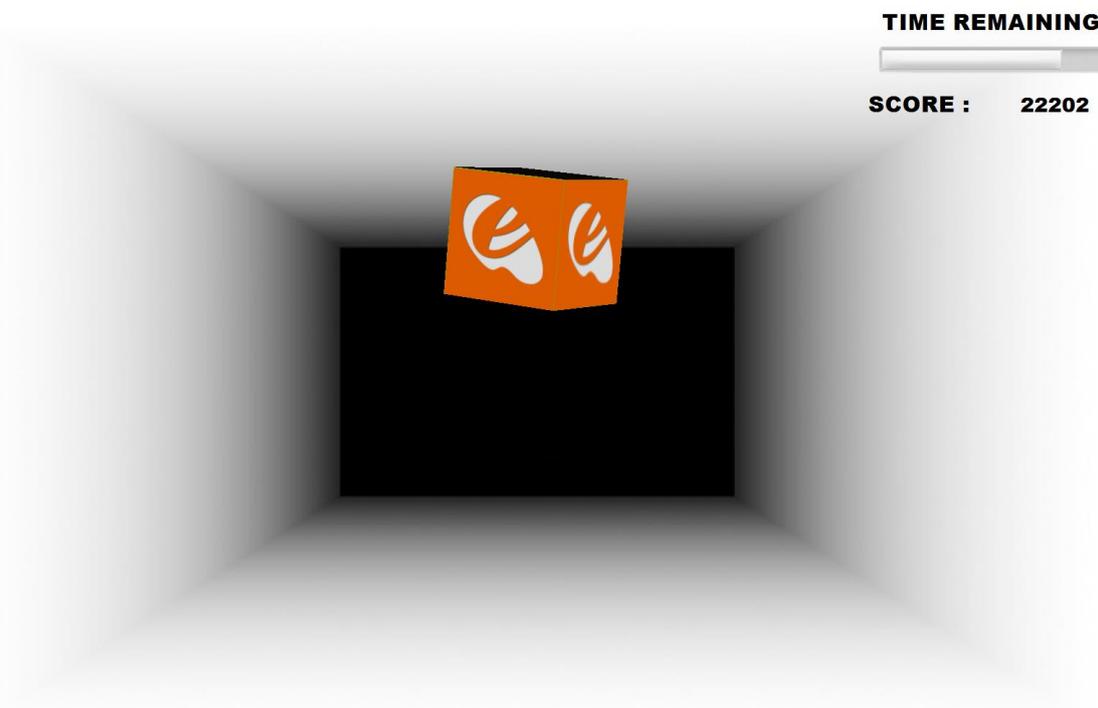


Figure 28 Screenshot from a round of Challenge mode in Emotiv Control Panel

8.8.1 Playing and gathering data:

Before launching the game, I asked the participant to take a short break, close his or her eyes and relax while the game FlappyBrain is prepared.

While the test subject had his or her eyes closed, I “alt-tabbed” (Microsoft, 2017) to either the game FlappyBrain in a web browser in full screen mode (F11 key) or a full screen video of a round of FlappyBrain shown on Monitor A1.

I used the open source media player VLC media player (VideoLAN, 2017) for displaying the fake rounds of FlappyBrain, with “On Screen Display” turned off to hide the media buttons in full screen. This made switching between FlappyBrain in a full screen browser and a full screen video in VLC indistinguishable. I asked the participant to take a short break and close his or her eyes in between each round before switching between the real game and the video.

I had five fake videos in a playlist in VLC so that I could skip to the next one when needed.

The hotkey “N” in VLC Media player was used to go to the next video in the playlist.

The test subjects was given earplugs to prevent disturbances while playing.

The test subjects were told before the games started that after each round they have to give me a number between 1 and 10 to indicate how much control over the game character they felt they had on a scale from 1 to 10.

The test subjects were told to relax with their eyes closed until they feel a tap on the shoulder to signal them that tell them that the next round starts in 10 seconds and that they should open their eyes. 10 seconds I tapped the test subject on the shoulder, I either pressed the “F5” key while in the web-browser with FlappyBrain to start a new or “spacebar” while in VLC Media Player to play a fake round. The test subject played 5 rounds of FlappyBrain and spectated 5 rounds of recorded FlappyBrain footage where the test subject might think he or she is in control of the game.

8.9 Changes in equipment setup and procedure from iteration 2 to bonus test at SpillExpo

After discussing the results from pre-test iteration 2 with my supervisor, a different procedure was made for the bonus test at SpillExpo. This bonus test was arranged at HiOA Gaming's stand at SpillExpo (Norgesexpo AS, 2017) which is the largest gaming expo in Norway. Because the stand was used to promote HiOA as a school and HiOA Gaming as a student organization, I had to use a different game that could compete with the other games at the expo. Nobody would want to play a silly 2d-game (FlappyBrain) if there is any "cooler" games around.

After some brainstorming I decided to use a HTC Vive virtual reality headset (HTC Corporation, 2017) combined with the Emotiv Insight to control the very popular game Minecraft (Mojang AB, 2017) with Vivecraft (Vivecraft, 2017) using brain control while in Virtual reality. This setup would be able to compete with anything at SpillExpo. I made a guide on how to set up this combination on YouTube (TurboDevs AS, 2017), which is the first video on YouTube showing a combination of the HTC Vive and an Emotiv EEG headset.

This bonus test would also be used to see what possible changes I should make before the final test at The Gathering.

8.10 Equipment setup used in the bonus test at SpillExpo

I used a computer that filled the minimum requirements for Emotiv Insight, Minecraft and HTC Vive. The Emotiv EPOC was too large and would not fit under the HTC Vive, so I had to use the Emotiv Insight. The figure on the next page shows how the equipment is configured.

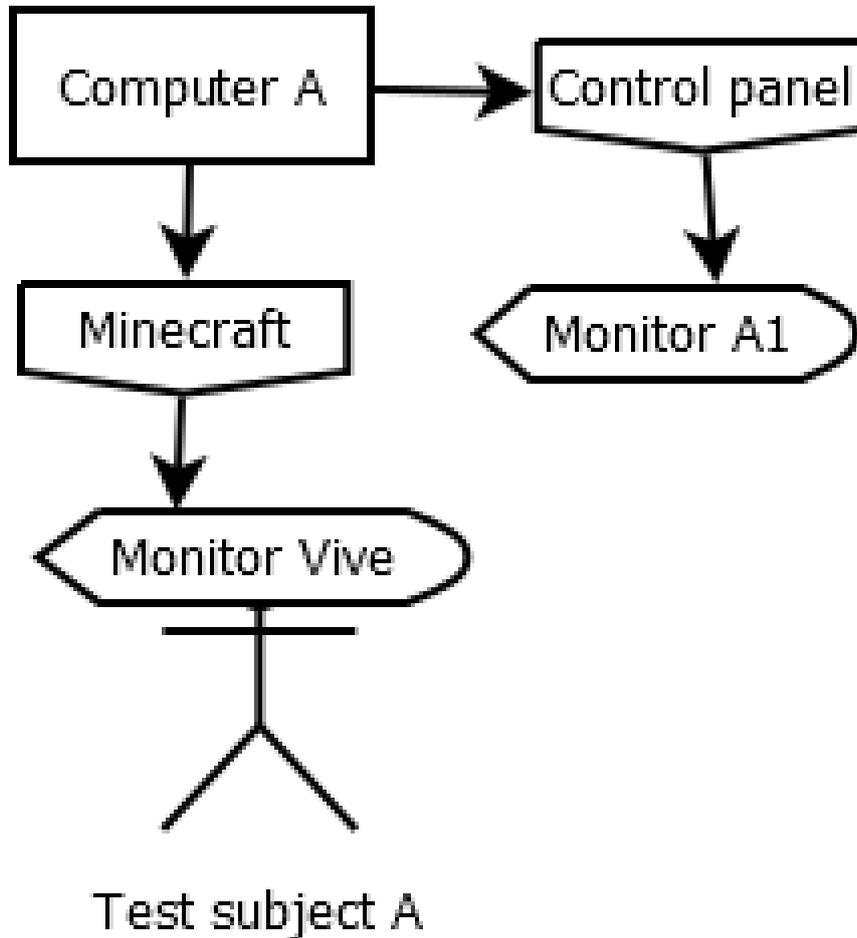


Figure 29 Equipment configuration for the bonus test at SpillExpo.

Monitor A1 shows the Emotiv control panel and is used to display symbols when recording and to mirror Minecraft when playing.

8.11 Test protocol used in the bonus test at SpillExpo:

In this test I decided to not test for confirmation bias because it would take too much time (time constraints). The participants at SpillExpo generally use 5 to 10 minutes on each stand, and even a short test using an Emotiv EEG headset can take more time than participants at SpillExpo wants to use. This is something I learned from experience after presenting games controlled with Emotiv EEG headsets at SpillExpo in 2014 and 2015.

This test was a bonus test where I examined if the participants preferred to play Minecraft in virtual reality using brain control with either motor imagery or visual imagery. The goal of this test was to see if there was a significant difference between choice of motor imagery and visual imagery. SpillExpo 2016 estimated to have 20.000 visitors (NRK, 2017), which gave me a nice pool of randomly selected test subjects who happen to wander by the HiOA Gaming stand.

The test subjects were told that they will be testing brain controlled Minecraft (Mojang AB, 2017) in virtual reality using the HTC Vive VR headset (HTC Corporation, 2017). The game is played as usual but with the flying button (spacebar) is linked to a specific thought recorded in Emotiv Control Panel by using EmoKey (The same tools used in the Pilot test, Pre-test iteration 1 and Pre-test iteration 2).

A video is available on YouTube that shows how you set this up (TurboDevs AS, 2017).

8.11.1 Playing and gathering data:

After the participant were finished with the recordings, I displayed the spectator window for Minecraft that mirrors what is happening inside the HTC Vive on Monitor A1 (Figure 7).

I then asked the test subject to try thinking about “lift” using motor imagery and then visual imagery, to check if the control is working. When it is confirmed that the control is working and the game character in Minecraft is flying (remember to use “creative” game mode in Minecraft to enable flying), I asked the test subject to move to the designated virtual reality play area we had set up at the HiOA Gaming booth.

I then helped the test subject with attaching the virtual reality headset over the Emotiv Insight headset. I then checked that all sensors of the Emotiv Insight were marked with green colour in the EPOC Control Panel to indicate a good signal after the virtual reality headset has been attached. I would reposition the Emotiv Insight if necessary.

When the Emotiv Insight and virtual reality headset has been attached properly, I asked the test subject to first try flying up using motor imagery and afterwards with visual imagery. I switched between motor and visual imagery as the control method three times so that the test subjects could try flying using motor and visual imagery three times. I then asked the test subject if he or she wanted to play Minecraft in virtual reality for 10 minutes using either motor or visual imagery.

8.12 Changes in equipment setup and procedure from iteration 2 and the bonus test to the final test

The method was changed slightly after a discussion with my supervisor after pre-test iteration 2 and the bonus test at SpillExpo. In this test the same general method from pre-test iteration 2 applies, with one change:

Rather than presenting “FlappyBrain” as a game, I presented it as a “calibration tool” that was necessary for the participants to go through before they could play Minecraft with mind control in VR with the HTC Vive (which was also used at the bonus test at SpillExpo).

I had to compete with the many booths at The Gathering and “Mind Controlled Minecraft in VR» was my best bet to get test subjects. Playing FlappyBrain alone as a game and then playing Minecraft would make less sense to the participants than calling FlappyBrain a calibration tool for Minecraft.

8.13 Equipment setup used in the final test

I used a computer that had a video card with enough video outputs for two monitors and a VR headset. The computer filled the minimum requirements for Emotiv Insight (Emotiv Inc., 2017), Minecraft (Mojang AB, 2017) and HTC Vive (HTC Corporation, 2017). The Emotiv EPOC was too large and would not fit under the HTC Vive, so I had to use the Emotiv Insight. The figure below shows how the equipment was configured in the recording and testing part (Figure 8) and the figure on the next page shows how the equipment was configured in the “reward” part with Minecraft (Figure 9).

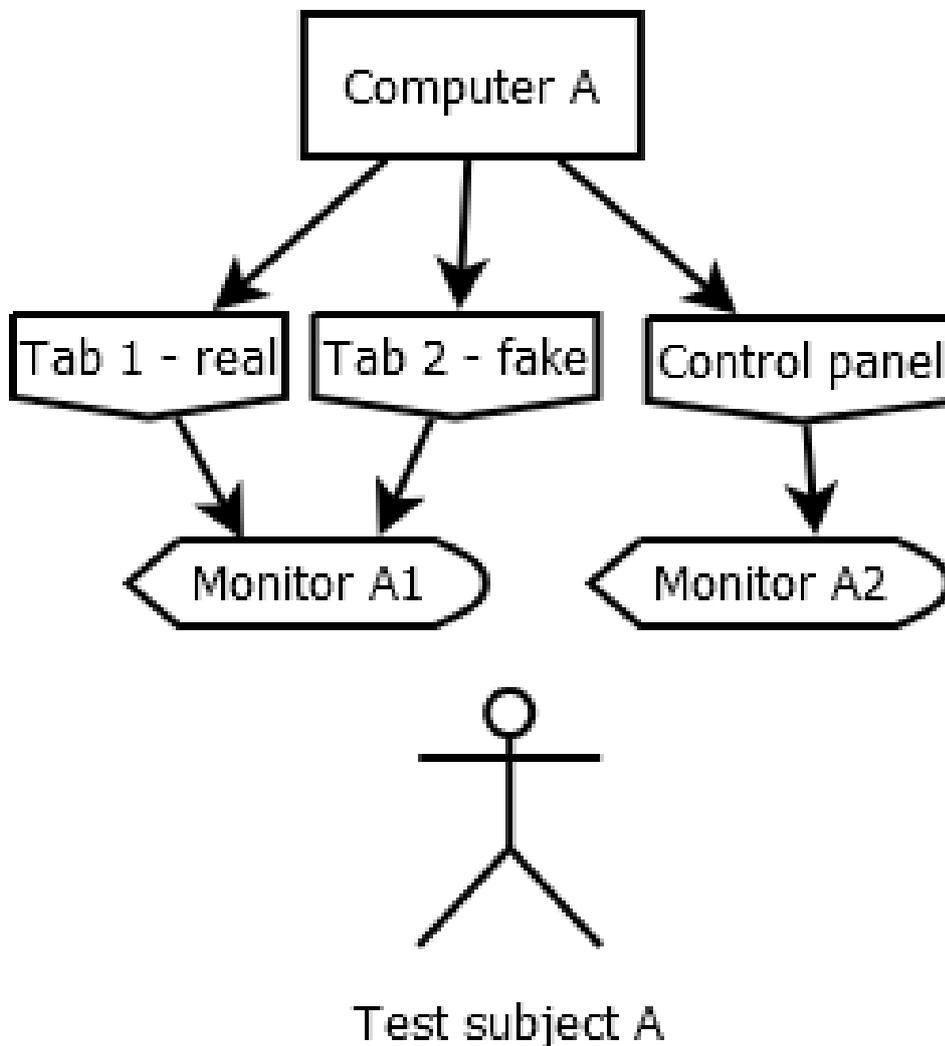


Figure 30 Equipment configuration for the confirmation bias tests in the final test.

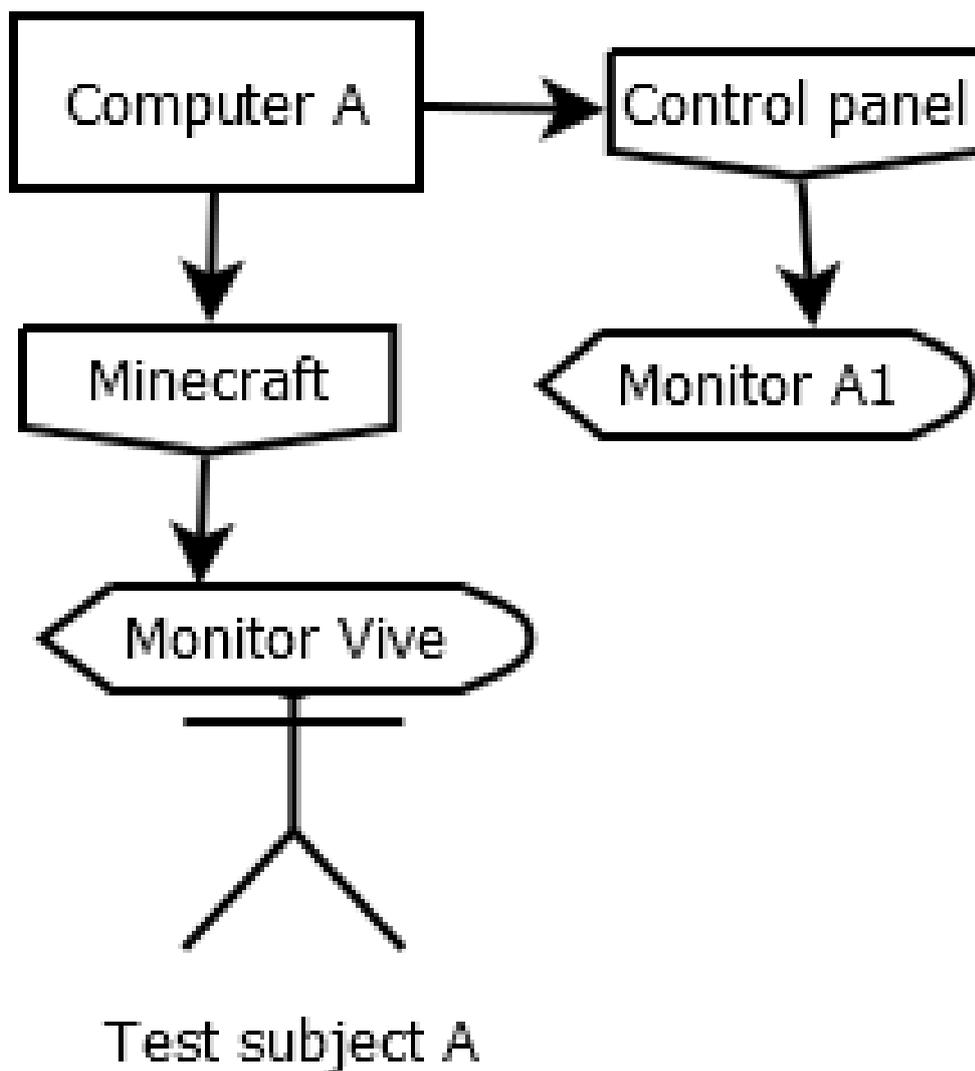


Figure 31 Equipment configuration for the reward after the testing in the final test.

Monitor A1 is used for displaying symbols when recording, displaying the calibration tool (FlappyBrain) and displaying the fake calibration tool with a video player.

Monitor A2 is used for the control panel or to mirror A1 during playing.

8.14 Test protocol used in the final test

The method for controlling FlappyBrain in this test and previous tests are the same.

One change from pre-test iteration 2 is that I did not present FlappyBrain as a “game” but as a “calibration tool” for playing Minecraft with “mind control” in VR using the HTC Vive and Emotiv Insight together. All 21 test subjects in this test understood the purpose of a calibration tool. I made this change in the test protocol after discussing the results of pre-test iteration 2 and the bonus test at SpillExpo with my supervisors.

8.14.1 Playing and gathering data:

The participant (Test subject A in Figure 8 and 9) is told that he or she needs to complete a calibration using a calibration tool called “FlappyBrain” before he or she can play Minecraft in VR with HTC Vive using “mind control” with the Emotiv Insight.

Before launching FlappyBrain, I asked the player to take a short break, close his or her eyes and relax while the calibration tool was prepared.

While the participant has his or her eyes closed, I alt-tabbed (Microsoft, 2017) to either FlappyBrain in a web browser in full screen mode (F11 key) or a full screen video of a round of FlappyBrain shown on Monitor A1. I mirrored monitor A1 to monitor A2 during playing and positioned the monitors so that the participant could only see Monitor A1 while I “spectated” on Monitor A2.

I used the open source media player VLC media player (VideoLAN, 2017) for displaying the fake rounds of FlappyBrain, with “On Screen Display” turned off in VLC Media Player to hide the media buttons in full screen mode. This made switching between FlappyBrain in a full screen browser and a full screen video in VLC indistinguishable. I asked the participants to take a short break while I restarted the calibration tool and close his or her eyes in between each round before switching between the real FlappyBrain and the video. During switching between the real and fake rounds of FlappyBrain I rotated the monitors so that only I could see them.

I had five fake videos in a playlist in VLC Media Player to skip to the next one when needed. The hotkey “N” in VLC Media player was used to go to the next video in a playlist. The participants was given earplugs to prevent disturbances while playing.

The participants were told before the calibration started that after each round they had to give me a number between 1 and 10 to indicate how much control over the game character they felt they had on a scale from 1 to 10.

The participants were told to then relax with their eyes closed until they felt a tap on the chair they were sitting on which was a signal to tell them that the next round started in 10 seconds and that they should open their eyes. 10 seconds after I tapped the chair, I pressed either the “F5” key reload a round of real FlappyBrain in the browser or “spacebar” to play a fake round of FlappyBrain in VLC Media Player.

The participants played 5 rounds of real FlappyBrain and spectated 5 rounds of recorded FlappyBrain footage where the test subject might think he or she is in control.

After the participants played FlappyBrain using motor imagery in 10 rounds and visual imagery in 10 rounds the testing (or “calibration”) was complete and I moved to the reward part with Minecraft.

I helped the participants so that they could test the HTC Vive while wearing the Emotive Insight and asked them to try flying upwards using motor or visual imagery. I let the test subjects try both motor and visual imagery in Minecraft to see which of them they would like to use during the play session, which is what I did in the bonus test at SpillExpo. The participants are genuinely in control during the “reward” part with Minecraft, no fake feedback.

After the participants selected either motor or visual imagery, I let them play Minecraft for 15 minutes.

8.15 The analysis

After each test (pilot test, pre-test iteration 1, pre-test iteration 2 and final test) the average ratings of control (control score) for motor and visual imagery rounds are collected. For each participant there will be four averages: Average ratings of control for when in control and not in control for motor imagery and average ratings of control for when in control and not in control for visual imagery.

Two T-Tests were done after each test (pilot test, pre-test iteration 1, pre-test iteration 2 and final test) to compare the average control scores for all the participants in each test.

If a T-test results in a p-value under 0.05 when comparing rounds where the participants were in control and not in control, then there is a statistically significant difference.

I compared rounds for when in control and not in control with T-testing for both motor and visual imagery.

In the first T-Test, I compared the average control scores for when the participants were in control to when they were not in control in the motor imagery rounds.

In the second T-Test, I compared the average control scores for when the participants were in control to when they were not in control in the visual imagery rounds.

The T-tests are used to see if there was a significant difference between motor and visual imagery in terms of perceived control VS. Real control (confirmation bias).

One T-test was done comparing the average "control score" for all the participants for when in control and not in control when playing using motor imagery.

Another T-test was done comparing the average "control score" for all of the participants for when in control and not in control when playing using visual imagery.

By comparing the reported feeling of control the participants had while using motor and visual imagery, and where half of the rounds were fake, I can check to see if there is a relationship between when the test subject rates their feeling of control as “high” while they are in control and if they rate their feeling of control as “low” when it is a fake round.

If a statistically significant number of participants report a higher feeling of control while they are watching a fake round for either motor or visual imagery, then motor or visual imagery could be more susceptible to confirmation bias.

By using a T-test to compare the average control scores for when in control VS. When not in control (fake) for both motor and visual imagery, I can determine if either motor or visual imagery is more susceptible to confirmation bias.

A spreadsheet called “T-test.xlsx” that contains all the T-tests is available in the appendices file.

9. Results

The purpose of this study was to compare real and perceived control (confirmation bias) between motor imagery and visual imagery when controlling a computer using the EEG-based BCI headsets Emotiv EPOC and Emotiv Insight. The EPOC and Insight can record EEG-patterns for both motor imagery where the user thinks about movement (standard method) and visual imagery where the user thinks about a picture or symbol. I compared the confirmation bias between motor imagery and visual imagery using symbols from the ideographic writing system Blissymbolics (Blissymbolics Communication International, 2017).

In the final test, 24 of 47 test subjects reported higher control when not in control for motor and 25 of 47 test subjects reported higher control when not in control for visual.

A T-test for the results in the final test resulted in a P-value less than 0.05, which means not statistically significant.

Data type	Pilot	Pre-test iteration 1	Pre-test iteration 2	Final test
Motor: In control avg.	3,93	3,98	3,22	4,19
Motor: Not in control avg.	3,73	3,06	3,84	4,00
Motor: T-Test P-Value	0,849	0,201	0,309	0,703
Visual: In control avg.	4,2	3,26	2,42	3,57
Visual: Not in control avg.	1,73	2,98	3,54	3,86
Visual: T-Test P-Value	0,005	0,791	0,098	0,533

Table 1 Summary of Averages and T-Test results from all the tests

9.1 The final results from the pilot test, Pre-test iteration 1 and Pre-test iteration 2:

9.1.1 Pilot test results:

3 of 6 test subjects reported higher control scores when not in control for motor imagery.

0 of 6 test subjects reported higher control scores when not in control for visual imagery.

I did a T-test on the control scores the test subjects reported and the p-values were $p = .849$ for motor and $p = .005$ for visual imagery. According to the t-test, there is not a significant difference between being in control and not in control for motor imagery ($p > .05$), but there is a significant difference for being in control and not in control for visual imagery ($p < .05$).

9.1.2 Pre-Test iteration 1 results:

3 of 10 test subjects reported higher control scores when not in control for motor imagery.

6 of 10 test subjects reported higher control scores when not in control for visual imagery.

I did a T-test on the control scores the test subjects reported and the p-values were $p = .201$ for motor and $p = .791$ for visual imagery. According to the t-test, there is not a significant difference between being in control and not in control for both motor imagery and visual imagery ($p > .05$). I was not able to reject the null hypothesis.

9.1.3 Pre-Test iteration 2 results:

6 of 10 test subjects reported higher control scores when not in control for motor imagery.

7 of 10 test subjects reported higher control scores when not in control for visual imagery.

1 of 10 test subjects reported the same control scores for both motor imagery and visual.

I did a T-test on the control scores the test subjects reported and the p-values were $p = .309$ for motor and $p = .098$ for visual imagery. According to the t-test, there is not a significant difference between being in control and not in control for both motor imagery and visual imagery ($p > .05$). I was not able to reject the null hypothesis.

9.1.4 Results for the pilot test, Pre-test iteration 1 and Pre-test iteration 2 combined:

12 of 26 test subjects reported higher control scores when not in control for motor.

13 of 26 test subjects reported higher control scores when not in control for visual.

1 of 26 test subjects reported the same control scores for both.

I did a T-test on the control scores the test subjects reported in all three tests and the p-values were $p = .803$ for motor and $p = .626$ for visual imagery. According to the t-test, there is not a significant difference between being in control and not in control for both motor imagery and visual imagery ($p > .05$). I was not able to reject the null hypothesis.

9.1.5 Bonus test at SpillExpo results:

6 test subjects preferred to play Minecraft in virtual reality using motor imagery.

6 test subjects preferred to play Minecraft in virtual reality using visual imagery.

1 test subject preferred both equally.

9.1.6 Final test results:

12 test subjects reported higher control when not in control for motor.

8 test subjects reported higher control when in control for motor.

1 test subject reported the same control when in control and not in control for motor.

12 test subjects reported higher control when not in control for visual.

8 test subjects reported higher control when in control for visual.

1 test subject reported the same control when in control and not in control for visual.

5 test subjects reported higher control when in control for both motor and visual.

9 test subjects reported higher control when not in control for both motor and visual.

23.8% were able to recognize when they were in control for both motor and visual imagery.

42.8% were not able to recognize when they were in control for both motor and visual imagery.

3 test subjects reported higher control when in control for motor but not for visual.

3 test subjects reported higher control when in control for visual but not for motor.

14.28% were able to recognize when they were in control for either motor or visual but not both.

T-test for the 11 participants on day one and 10 participants on day two:

Day one p-values: 0.95 for motor and 0.71 for visual, not statistically significant ($p > 0.05$).

Day two p-values: 0.62 for motor and 0.51 for visual, not statistically significant ($p > 0.05$).

9.1.7 Results from the pilot test, Pre-test iteration 1, iteration 2 and the Final test combined:

I did a T-test for all 47 test participants in the pilot test, Pre-test iteration 1, Pre-test iteration 2 and the final test as well:

P-Values for motor: 0,588, not statistically significant ($p > 0.05$).

P-Values for visual: 0,990, not statistically significant ($p > 0.05$).

24 of 47 test subjects (51%) reported higher control when not in control for motor.

25 of 47 test subjects (53%) reported higher control when not in control for visual.

10. Pilot test report

I will go through the results of three pairs of test subjects who played 20 rounds of “FlappyBrain” using motor imagery and visual imagery. I decided to discuss each of the tests individually because of some interesting findings in each test.

10.1 Test subject 1 and 2

The first pair were test subject 1 and test subject 2. I will present the control scores from the motor imagery rounds and visual imagery rounds separately, and then discuss the results.

10.1.1 Motor imagery results for test subject 1 and 2

In the five rounds that test subject 1 was in control, both test subjects 1 and 2 reported similar control scores that were no more than 2 points out of 10 points apart that had a correlation with the game scores. Test subject 1 reported slightly lower control scores than test subject 2 overall. In the five rounds that test subject 2 was in control, both test subjects 1 and 2 reported similar control scores that were no more than 2 points out of 10 points apart that had a correlation with the game scores. Test subject 1 reported slightly lower control scores than test subject 2. One exception was in a round where subject 1 reported a control score 6 points higher than test subject 2.

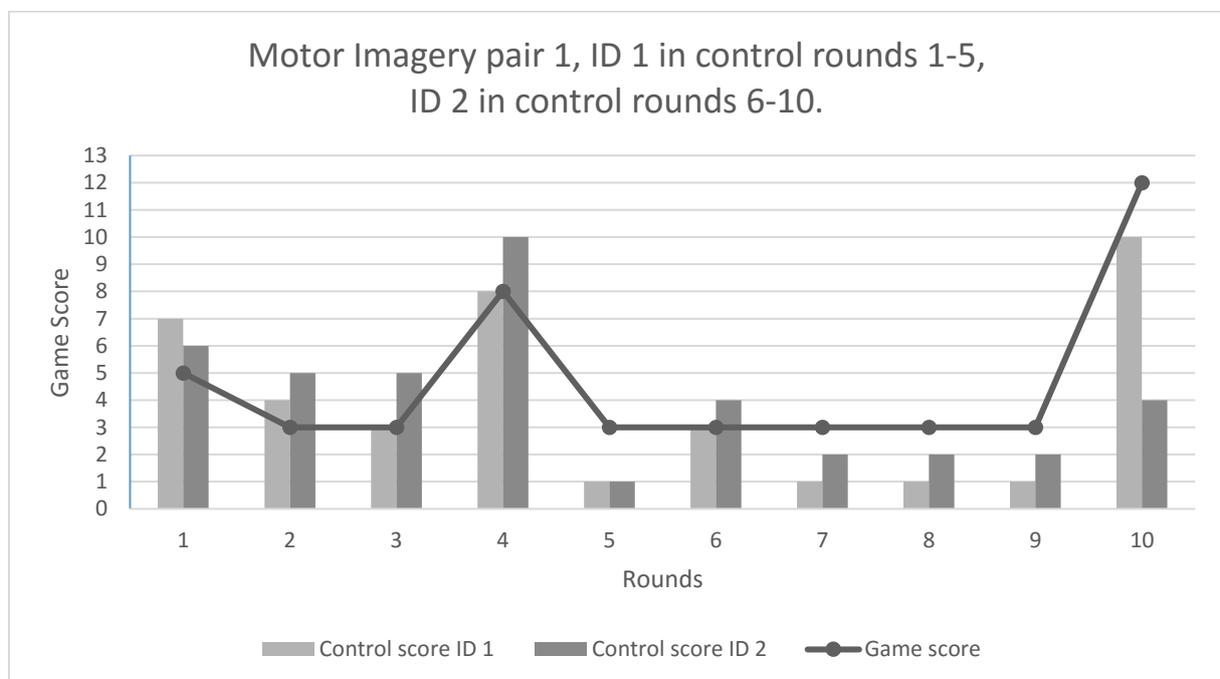


Figure 32 Motor imagery control scores for test subject 1 and 2

10.1.2 Visual Imagery results for test subject 1 and 2

In the five rounds that test subject 1 was in control, both test subjects 1 and 2 reported similar control scores that were no more than 1 points out of 10 points apart that had a correlation with the game scores. Test subject 1 reported slightly higher control scores than test subject 2.

In the five rounds that test subject 2 was in control, both test subjects 1 and 2 reported similar control scores that were no more than 1 points out of 10 points apart that had a correlation with the game scores. Two exceptions: one where test subject 1 reported a control score 4 points lower than test subject 2 and one where test subject 1 reported a control score 5 points lower than test subject 2.

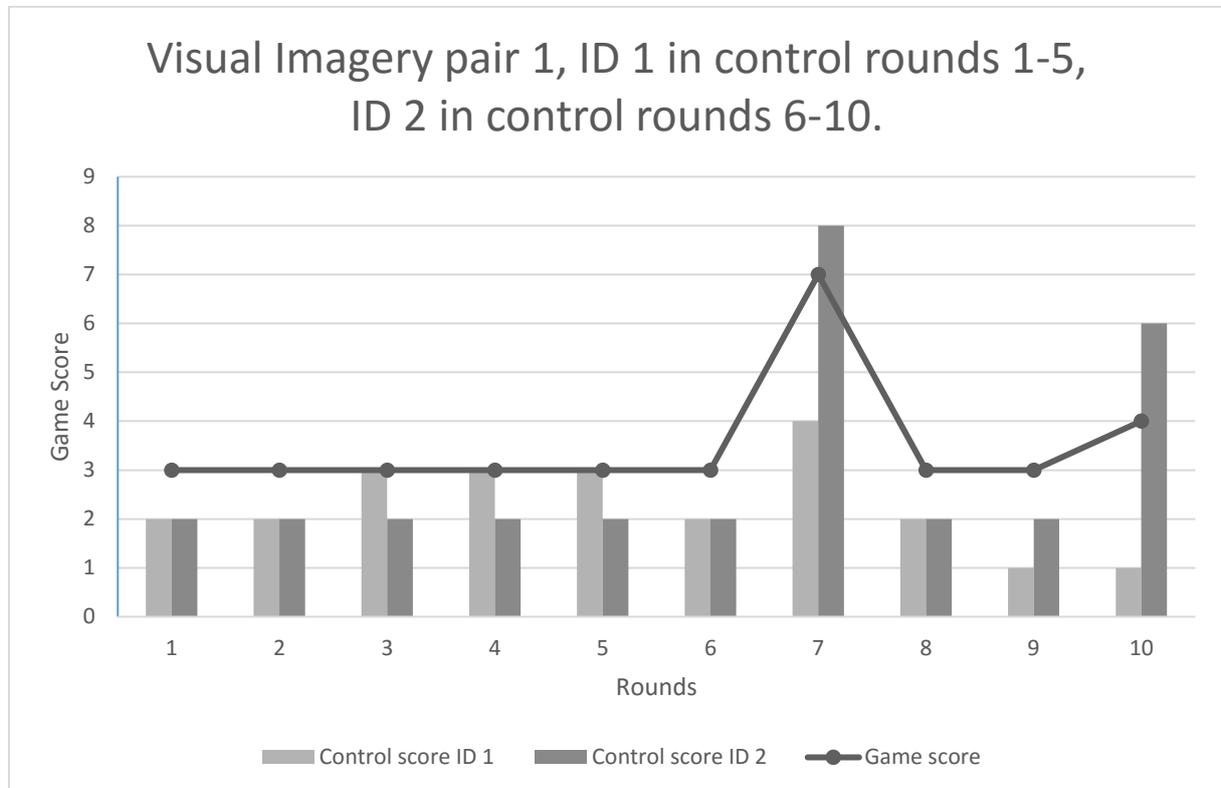


Figure 33 Visual imagery control scores for test subjects 1 and 2

10.1.3 Discussing the results for test subject 1 and 2

The average control scores from the motor imagery rounds while test subject 1 was in control were 4.6 for test subject 1 and 5.4 for test subject 2. The average control scores from the motor imagery rounds while test subject 2 was in control were 3.2 for test subject 1 and 2.8 for test subject 2. During the motor imagery rounds, both test subjects reported on average higher control scores when they were not in control.

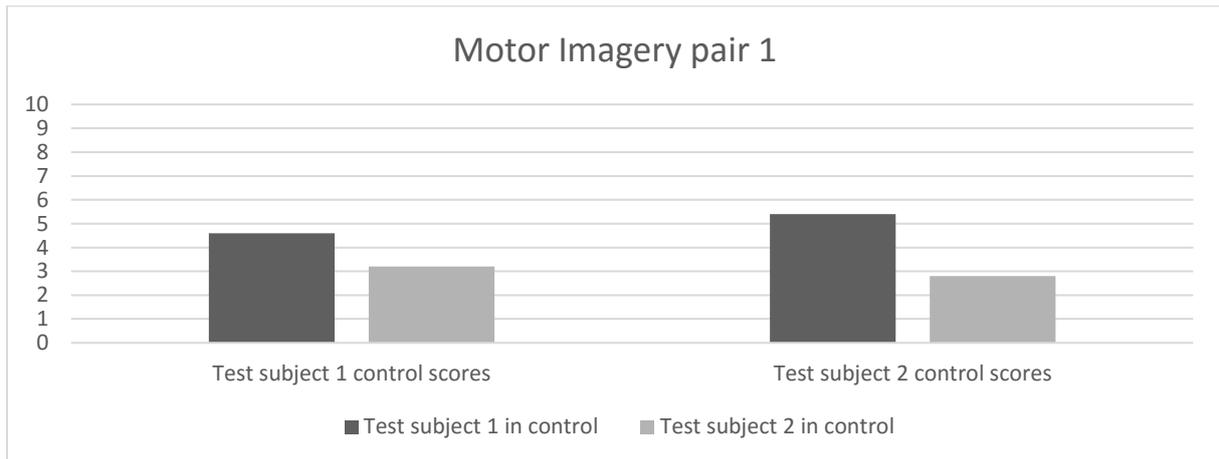


Figure 34 Average motor imagery control scores for test subject 1 and 2

The average control scores from the visual imagery rounds while test subject 1 was in control were 2.6 for test subject 1 and 2 for test subject 2.

The average control scores from the motor imagery rounds while test subject 2 was in control were 2 for test subject 1 and 4 for test subject 2.

During the visual imagery rounds, both test subjects reported on average higher control scores when they were in control.

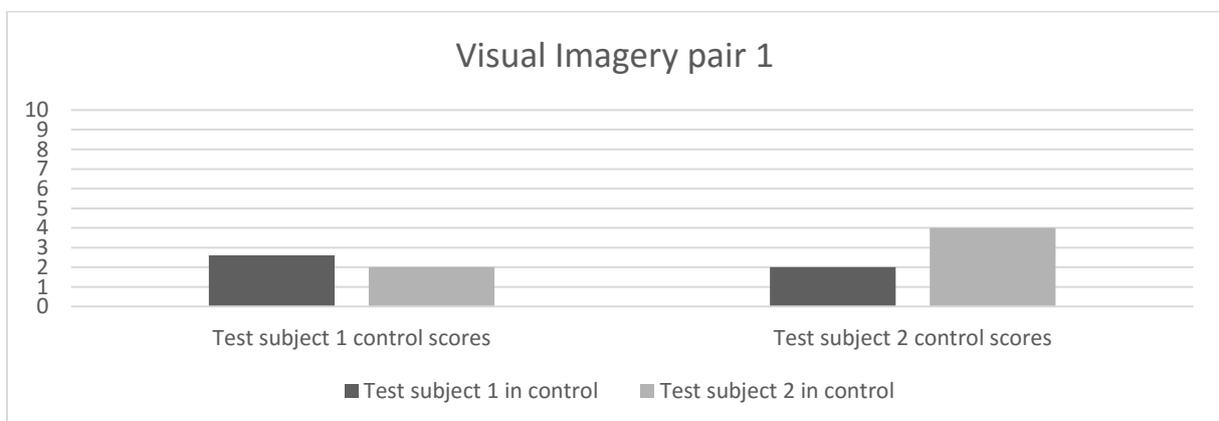


Figure 35 Average visual imagery control scores for test subject 1 and 2

10.2 Test subject 3 and 4

The second pair were test subject 2 and test subject 3. I will present the control scores from the motor imagery rounds and visual imagery rounds separately, and then discuss the results.

10.2.1 Motor imagery results for Test subject 3 and 4

In the five rounds that test subject 3 was in control, test subject 4 reported control scores of 1 while test subject 3 reported scores from 1 to 5. In three out of the five rounds that test subject 4 was in control, both test subjects reported similar control scores that were no more than 1 points out of 10 points apart that had a correlation with the game scores. In the other two rounds where test subject 4 was in control, test subject 3 reported a control score of 1 while test subject 4 reported control scores of 8 and 7.

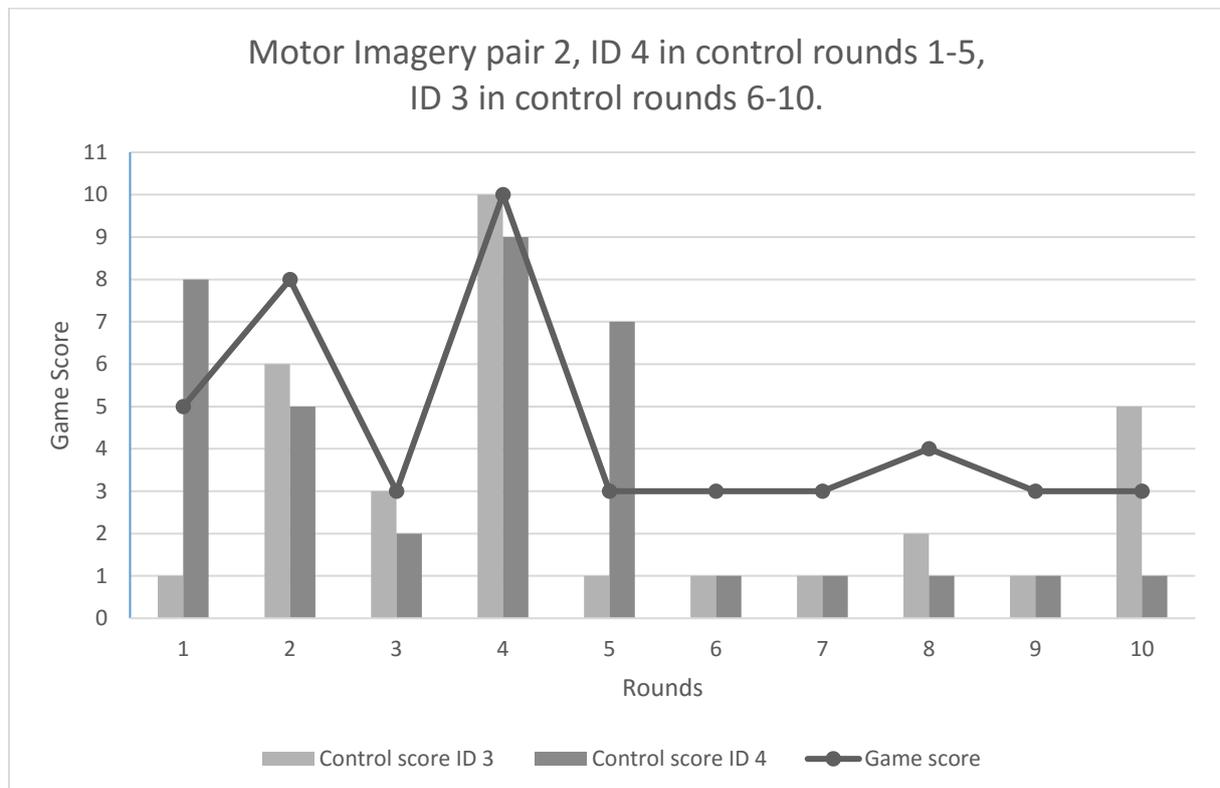


Figure 36 Motor imagery control scores for test subjects 3 and 4

10.2.2 Visual imagery scores for Test subject 3 and 4

In the five rounds where test subject 3 was in control, test subject 3 reported control scores 3 to 6 points higher than test subject 4.

In the five rounds that test subject 4 was in control, test subject 4 reported control scores 1 to 6 points higher than test subject 4. One exception was the first round where both test subject 3 and 4 reported a control score of 6.

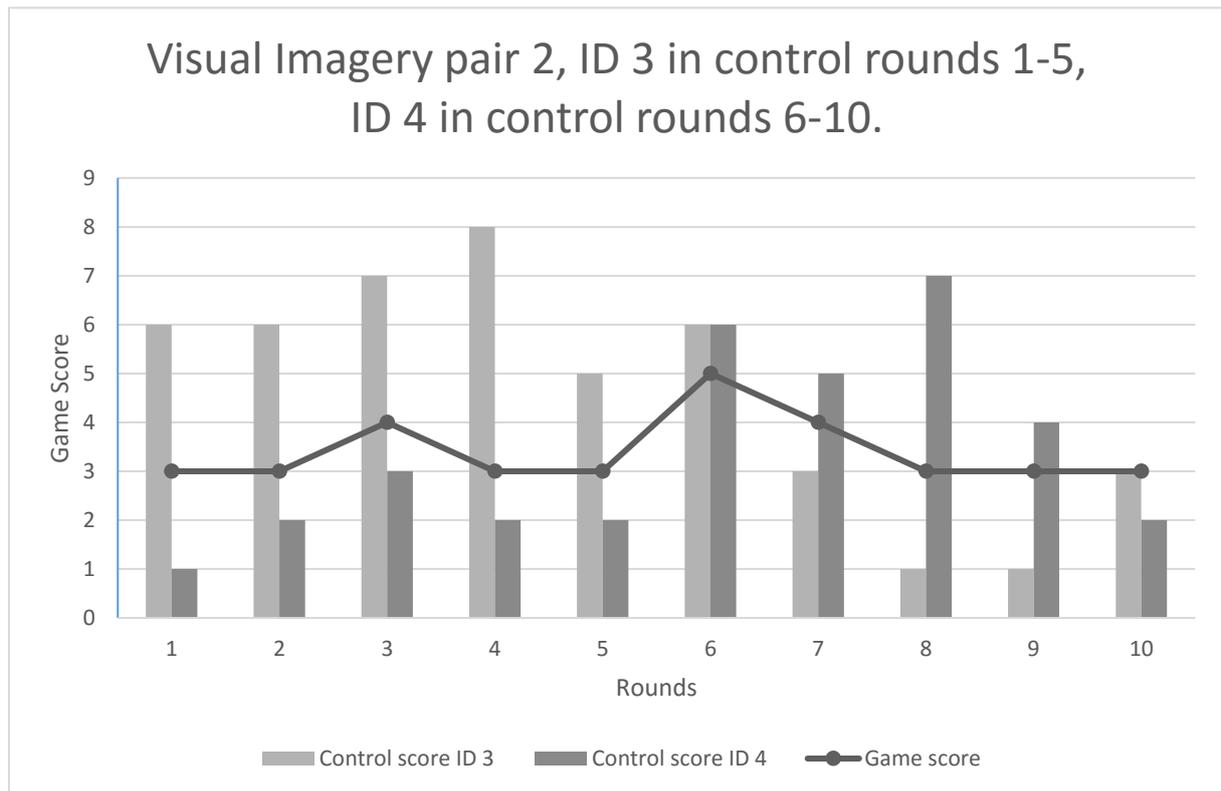


Figure 37 Visual imagery control scores for test subjects 3 and 4

10.2.3 Discussing the results of Test subject 3 and 4

The average control scores from the motor imagery rounds while test subject 3 was in control were 2 for test subject 3 and 4 for test subject 4. The average control scores from the motor imagery rounds while test subject 4 was in control were 4.2 for test subject 3 and 6.2 for test subject 4. Test subject 3 reported higher control scores when not in control, while test subject 4 reported higher control scores when in control.

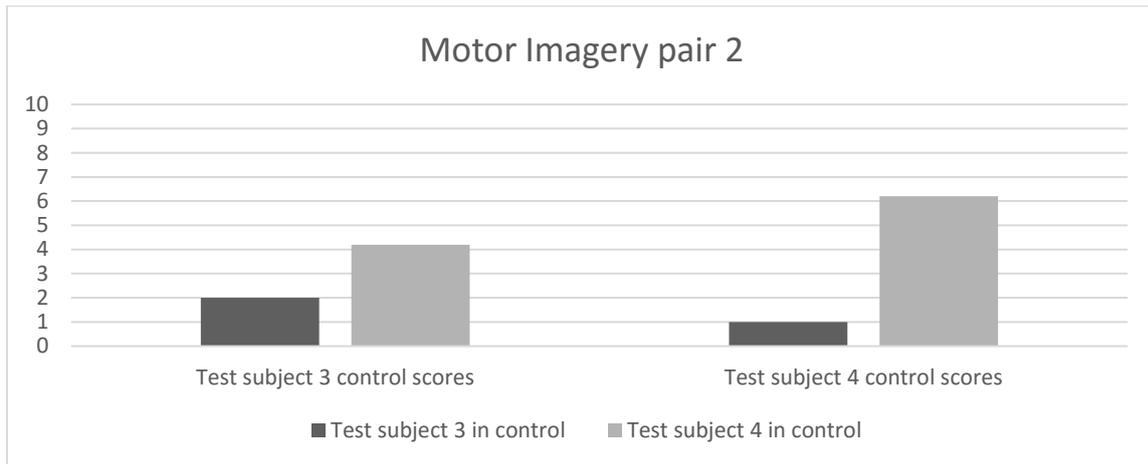


Figure 38 Average motor imagery control scores for test subjects 3 and 4

The average control scores from the visual imagery rounds while test subject 3 was in control were 6.4 for test subject 3 and 2 for test subject 4. The average control scores from the visual imagery rounds while test subject 4 was in control were 2.8 for test subject 3 and 4.8 for test subject 4. During the visual imagery rounds, both test subjects reported on average higher control scores when they were in control.

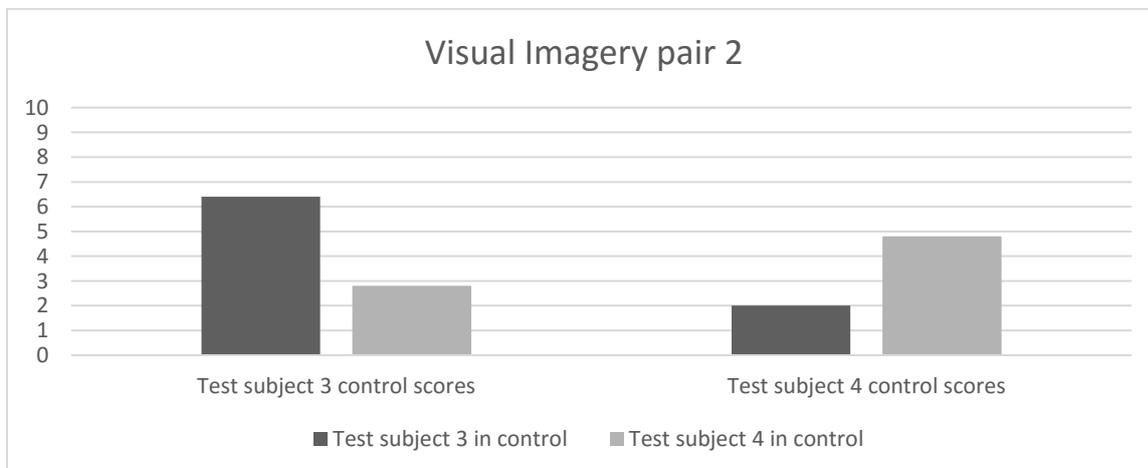


Figure 39 Average visual imagery control scores for test subjects 3 and 4

10.3 Test subject 5 and 6

The third pair were test subject 5 and test subject 6. I will present the control scores from the motor imagery rounds and visual imagery rounds separately, and then discuss the results.

10.3.1 Motor imagery results for Test subject 5 and 6

Both test subject 5 and 6 reported control scores that were no more than 3 points out of 10 points apart throughout all 10 rounds of the motor imagery testing. The control scores for both test subjects had a correlation with the game scores regardless of who was in control.

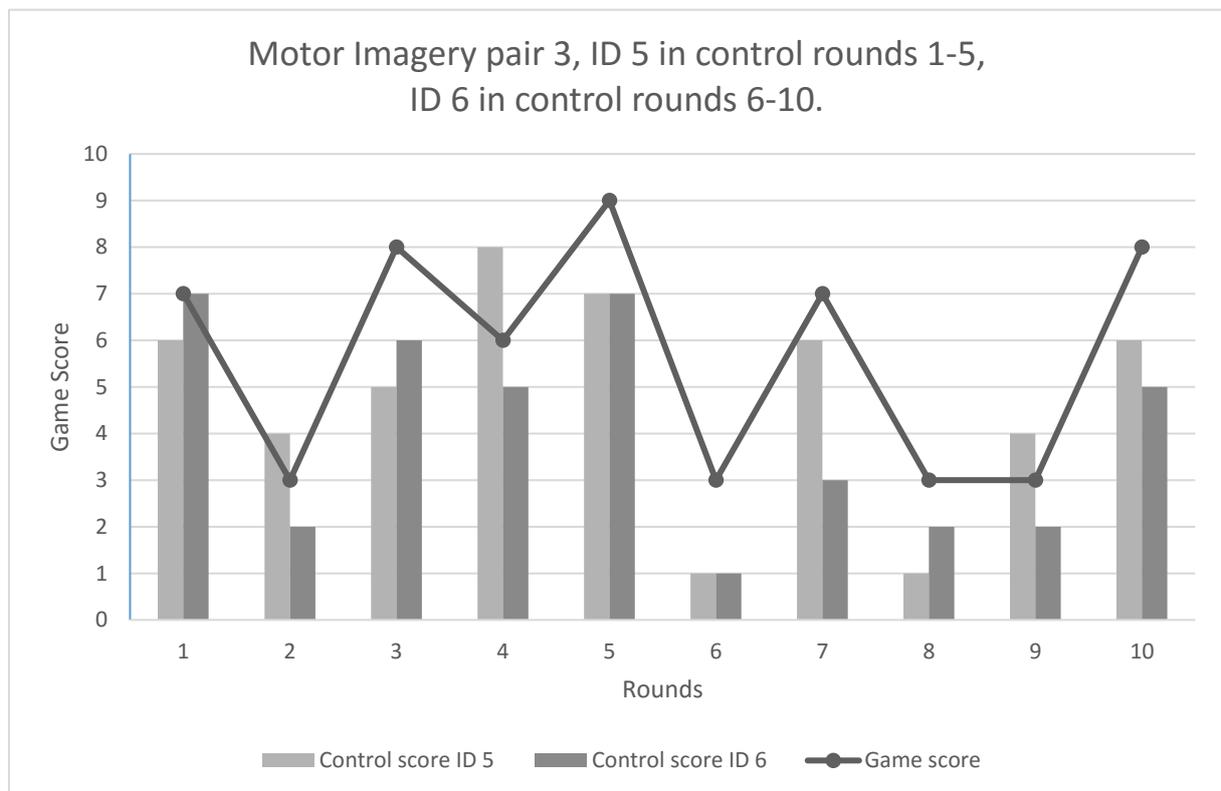


Figure 40 Motor imagery control scores for test subject 5 and 6

10.3.2 Visual imagery results for Test subject 5 and 6

In three of the five rounds where test subject 5 was in control, both test subjects reported the same control scores. In the remaining two of the five rounds, test subject 5 reported control scores higher than test subject 6.

In the first round of the five rounds where test subject 6 was in control, test subject 5 “instinctively” detached the EPOC reportedly because “the game was broken” and “I am not in control over the game anymore”. I asked test subject 5 to let the broken game play out for the remaining 5 rounds for debugging purposes. The reported control scores for test subject 5 while test subject 6 was in control has therefore been set to 0 (no control).

Test subject 6 reported significantly higher control scores during the rounds when test subject 6 was in control, compared to the rounds where test subject 5 was in control.

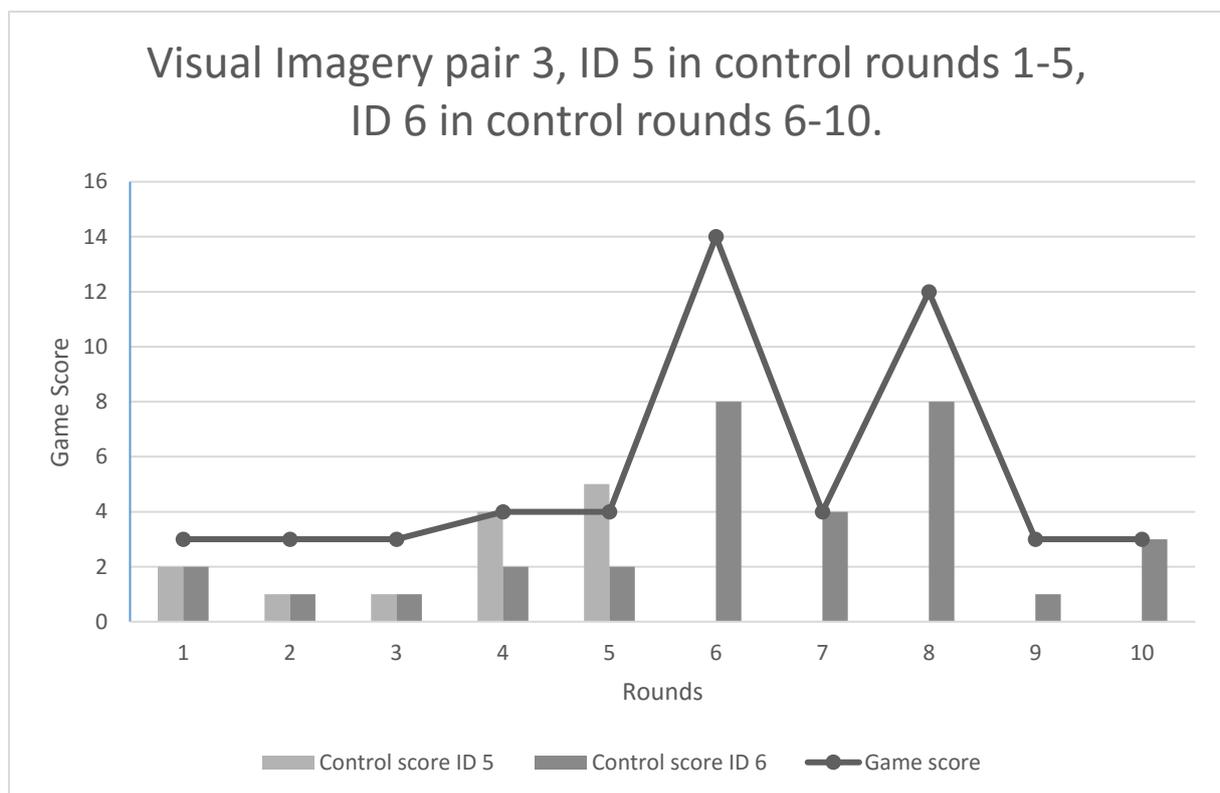


Figure 41 Visual imagery control scores for test subjects 5 and 6

10.3.3 Discussing the results of Test subject 5 and 6

The average control scores from the motor imagery rounds while test subject 5 was in control were 6 for test subject 5 and 5.4 for test subject 6.

The average control scores from the motor imagery rounds while test subject 6 was in control were 3.6 for test subject 5 and 2.6 for test subject 6.

During the motor imagery rounds, test subject 6 reported lower control scores when not in control, while test subject 5 reported higher control scores when in control.

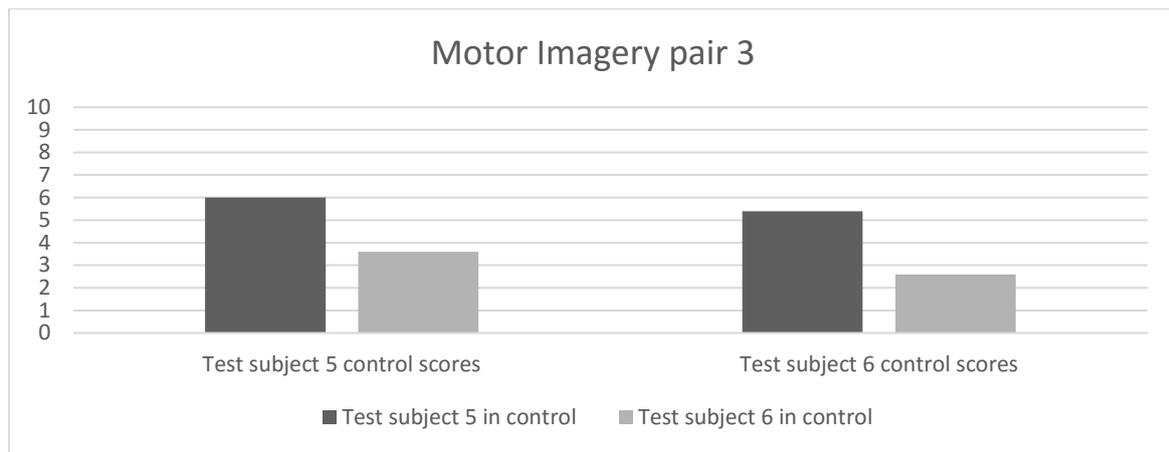


Figure 42 Average motor imagery control scores for test subject 5 and 6

The average control scores from the visual imagery rounds while test subject 5 was in control were 2.6 for test subject 5 and 1.6 for test subject 6. Test subject 5 detached the EPOC during the rounds where test subject 6 was in control and reported a control score of 0 for all these rounds. Both test subjects reported higher control scores when in control.

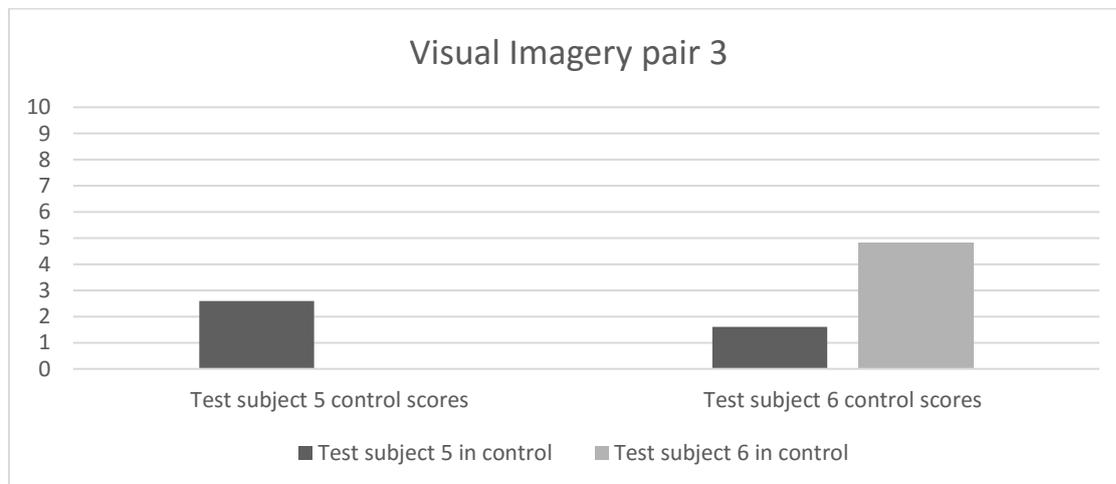


Figure 43 Average visual imagery control scores for test subject 5 and 6

10.4 Discussion

I will start by talking about the results from all the three tests in this pilot-test, and how they may relate to previous studies. I will then follow-up with a few issues I discovered during this pilot study and talk about how I can resolve these issues in the next tests.

10.4.1 The results

The control scores reported by either both or one of the test subjects were higher when the test subjects were not in control for all three motor imagery tests. The control scores reported by both of the test subjects were higher when the test subjects were in control for all three visual imagery tests. The visual imagery method performed better than the motor imagery method for all three tests in terms of correlation between perceived control and real control.

These results are interesting in relation to previous studies done with the EPOC, because all of the studies I have found has focused on either motor imagery or visual imagery as a method in the tests. Neither of the previous studies I found has compared motor and visual imagery with the EPOC. This is the strongest aspect of this research, and could open up for more research comparing motor imagery and visual imagery for different use-cases. It is possible that the difference in confirmation bias are not the same for “down”, “left”, “right” etc. as it was for “up” in this pilot study.

The results from the pilot study does only show that there is a difference between motor and visual, but only for the case of “up”. If results from more cases with larger groups of participants indicates the same difference, it would be possible to generalize more. Directions which are harder to illustrate with symbols might be harder for some people to imagine visually in their mind. One example is the motor imagery used in the Emotiv panel called “disappear” where the orange 3d cube disappears.

Critics might say that because both the motor imagery and visual imagery are used to move the video game character “up”, the recording for one of the imagery methods could be influenced by the other. One way to prevent this could be by creating several simple games and choose one or more games randomly for each test that uses different directions.

This approach would however not compare the motor imagery for “up” against the visual imagery with the symbol for “up”, but rather a random motor imagery against a random visual imagery. This method could be used to compare the confirmation bias between motor imagery and visual imagery for the same direction with motor imagery and visual imagery for different directions used to active the same button in a game.

10.4.2 Offline game

During the testing I experienced some problems with the internet connection on a Windows 10 computer which was caused by a common bug. This caused a small hiccup during one of the tests but was resolved quickly. I have decided to create an offline version of the game that prevents such problems in the future.

10.4.3 Feeling of disconnect

During pre-test iteration 2, one test subject detached the EPOC claiming “the game was broken” and “I am not in control of the game anymore”. To prevent this from happening again, I suggest informing the test subjects to complete all 20 rounds without detaching the EPOC and instead put down a control score of “0” for the rounds where the game stopped working, rather than a control score of 1 to 10. One suggested explanation that can be given to the test subjects during testing for why the EPOC might stop working temporarily is Bluetooth interference. By using this approach, I could differentiate between “very poor” control and “no” control.

10.4.2 Conflict of interest

Some critics may argue that this research is biased, because I am trying to prove that the “visual imagery” method with Blissymbolics works better in some cases than the standard “motor imagery” method. And by proving this make it seem like the BlissBrain system created by the company I’m part of is better than the EPOC Control Panel in some way. While I agree that I am trying to prove that “visual imagery” with Blissymbolics might work better in some cases, I doubt it can work better in all cases. More research needs to be done on more cases and on larger sample sizes. Either way, the BlissBrain system is open-source and aims to use more methods than just “visual imagery”.

Any research that compares “motor imagery”, “visual imagery” and other methods will improve the BlissBrain system to use either in different cases. It is for that reason that I have described how I performed the tests in great detail so that other researchers can repeat the experiments or make better experiments. The lack of good descriptions on how a BCI experiment was conducted is a problem that has been discussed before, and I wish to not be a part of that problem.

10.5 Conclusion: Pilot test

The first conclusion I draw from the pilot-test so far, is that there is a significant difference between using motor imagery and visual imagery for playing the game “FlappyBrain”.

And the second conclusion I draw is that visual imagery is better than motor imagery for this case. Only the first research question was tested in the pilot study due to time constraints.

The results from the pilot study did only test one motor imagery EEG-pattern for the direction “up” compared to the Blissymbol for “up”. Before I can conclude that this difference appears in more cases than the case of controlling the game “FlappyBrain”, I need to complete experiments on more cases.

11. Pre-Test iteration 1 report

11.1 Method:

I decided to use the same method as I used in the pilot test for the first pre-test iteration 1 at the LAN party to see if I got similar results.

11.2 Equipment:

The same equipment as used in the pilot test was used in this test, with the same configuration.

11.3 Test protocol:

The method for controlling the game in this test and the pilot test are the same.

Both test subjects A and B are told that they will be competing in the “Neurogaming” (XTech, 2017) tournament for this LAN party. Both subjects have to play “FlappyBrain” using motor imagery in 10 rounds and visual imagery in 10. After 20 rounds of practice, the test subjects plays 3 rounds at the same time. The player with the best score during these 3 rounds wins. The test subject with the highest score of all the test subjects at the LAN party wins a 500 NOK gift card. Both players were actually in control during the last 3 rounds.

11.4 Recording:

The method for recording in this test and the pilot test are the same.

11.5 Playing and gathering data:

The method for playing and gathering the data in this test and the pilot test are the same.

11.6 Results from Pre-test iteration 1

A total of 10 people participated in this test, and I will discuss each of the five pairs individually like I did in the pilot test before the conclusion of this test. I decided to start the test subject numbering at 10 to prevent mix-ups with previous tests.

11.6.1 Test subject 10 and 11

The first pair were test subject 10 and 11. I will present the control scores from the motor imagery rounds and visual imagery rounds separately, and then discuss the results.

11.6.1.1 Motor imagery results for test subject 10 and 11

In the five rounds that test subject 10 was in control, test subject 10 reported a higher control-score on average than test subject 11. In the five rounds that test subject 11 was in control, test subject 11 reported on average higher control scores than test subject 10.

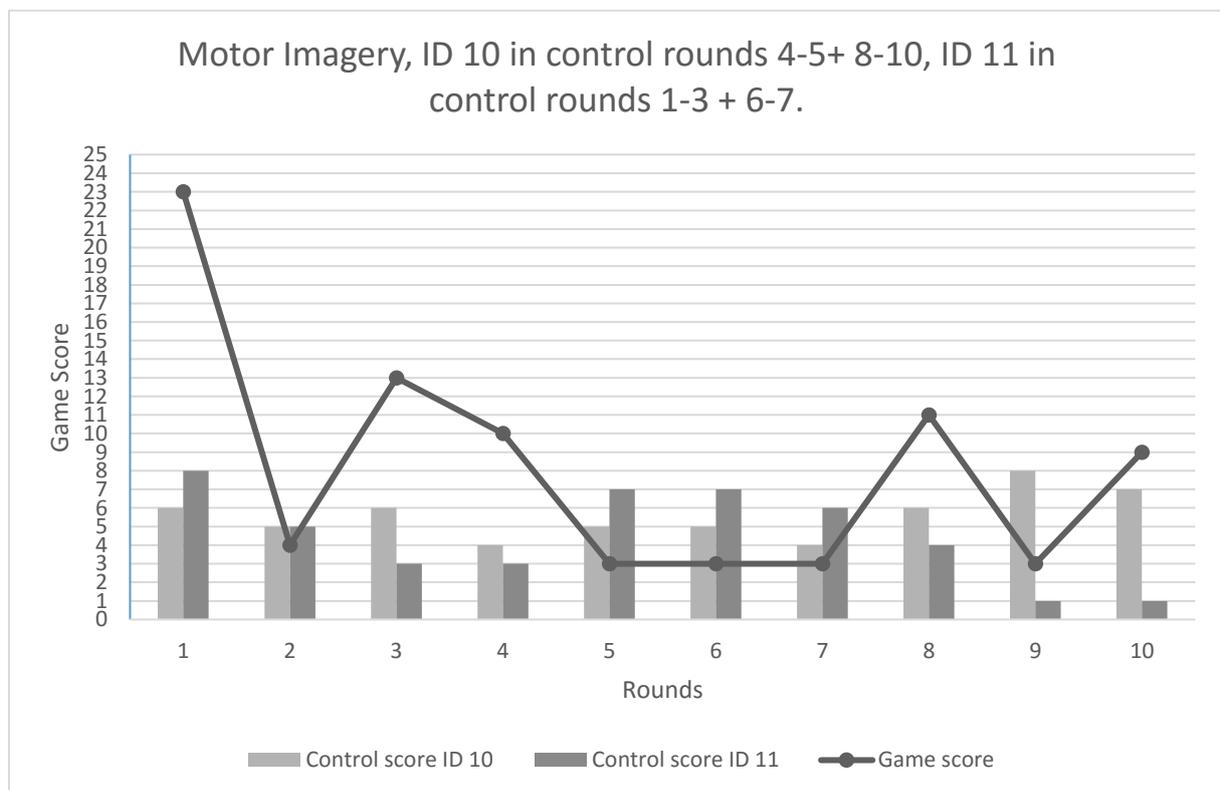


Figure 44 Motor imagery control scores for test subject 10 and 11

11.6.1.2 Visual Imagery results for test subject 10 and 11

In the five rounds that test subject 10 was in control, test subject 10 reported on average higher control scores than test subject 11. Test subject 10 did also report higher control scores than test subject 11 when not in control. Test subject 11 reported higher control scores in the rounds in control than in the rounds not in control.

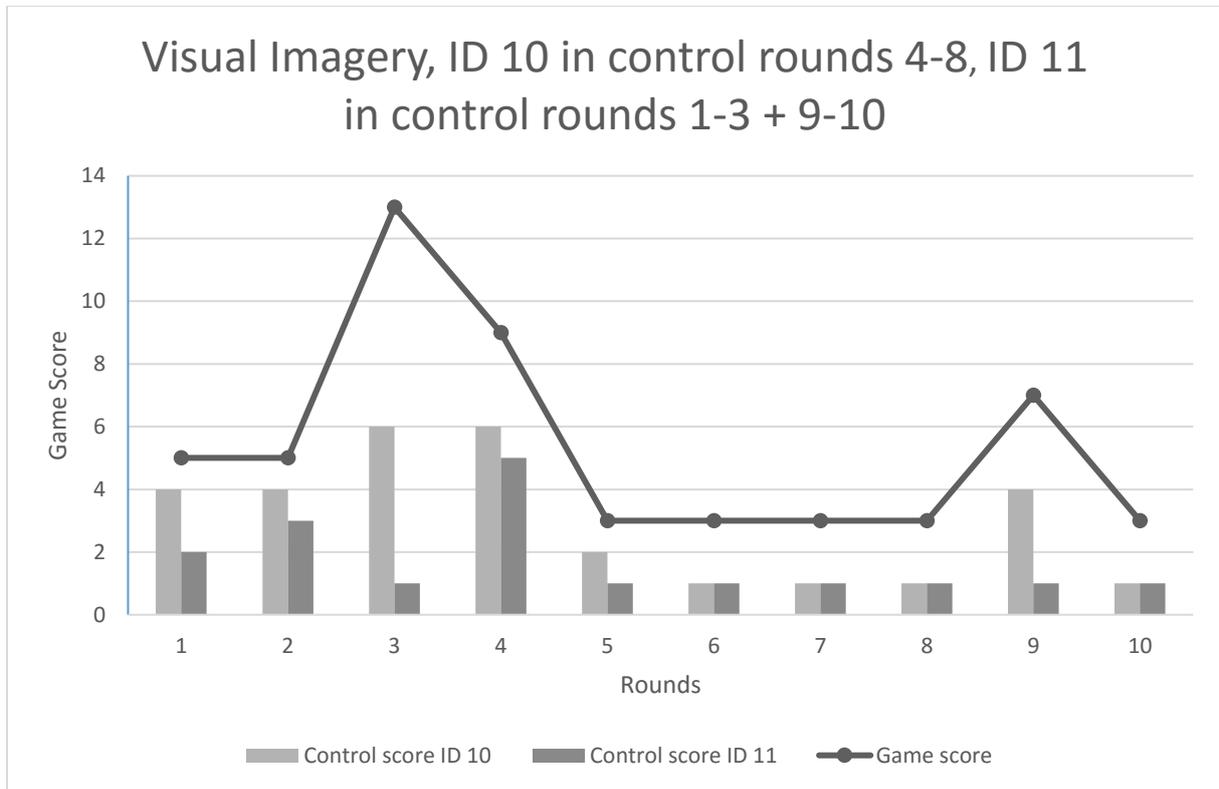


Figure 45 Visual imagery control scores for test subject 10 and 11

11.6.1.3 Discussing the results from test subject 10 and 11

The average control scores from the motor imagery rounds while test subject 10 was in control were 6 for test subject 10 and 3.2 for test subject 11. The average control scores from the motor imagery rounds where test subject 11 was in control were 5.2 for test subject 10 and 5.8 for test subject 11. Both test subjects reported higher control scores when in control than not in control.

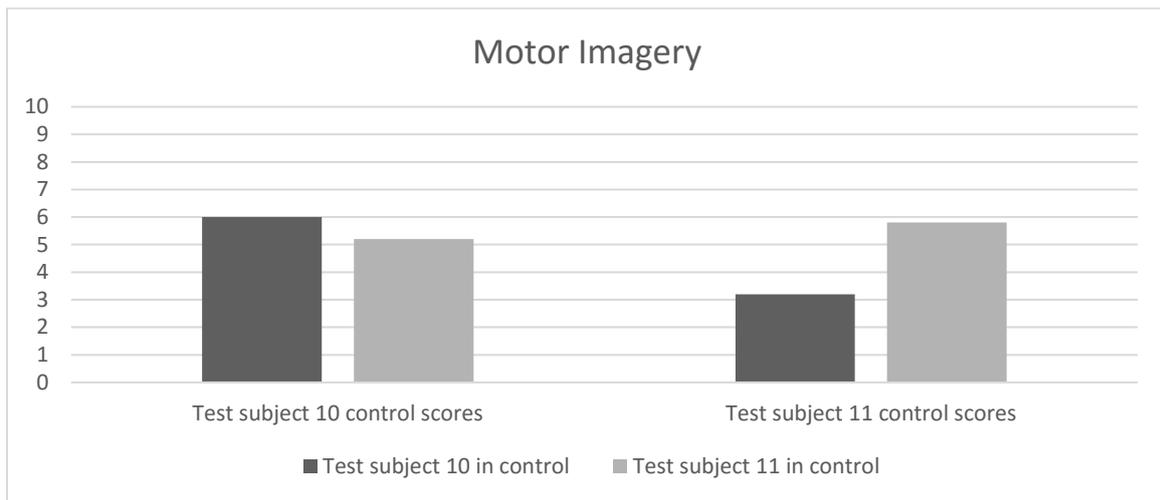


Figure 46 Average motor imagery control scores for test subject 10 and 11

The average control scores from the visual imagery rounds while test subject 10 was in control were 2.2 for test subject 10 and 1.8 for test subject 11. The average control scores from the motor imagery rounds while test subject 11 was in control were 3.8 for test subject 10 and 1.6 for test subject 11. Both players reported higher control scores when they were not in control.

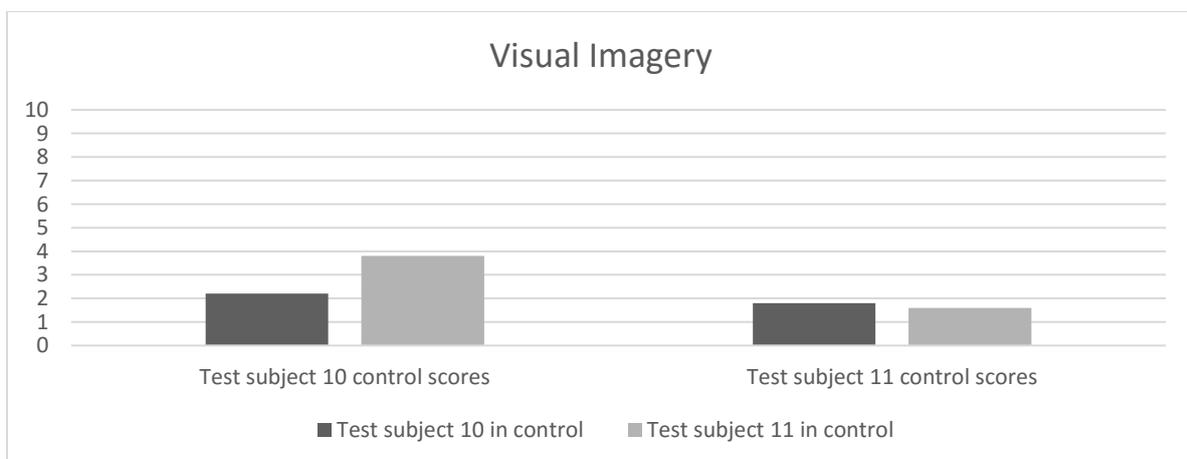


Figure 47 Average visual imagery control scores for test subject 10 and 11

11.6.2 Test subject 12 and 13

The second pair were test subject 12 and 13. I will present the control scores from the motor imagery rounds and visual imagery rounds separately, and then discuss the results.

11.6.2.1 Motor imagery results for test subject 12 and 13

In the five rounds that test subject 12 was in control, test subject 12 reported higher control scores than test subject 13. In the rounds where test subject 13 was in control, test subject 12 reported higher control scores than test subject 13. Test subject 13 only reported a higher score than test subject 12 once, while not in control.

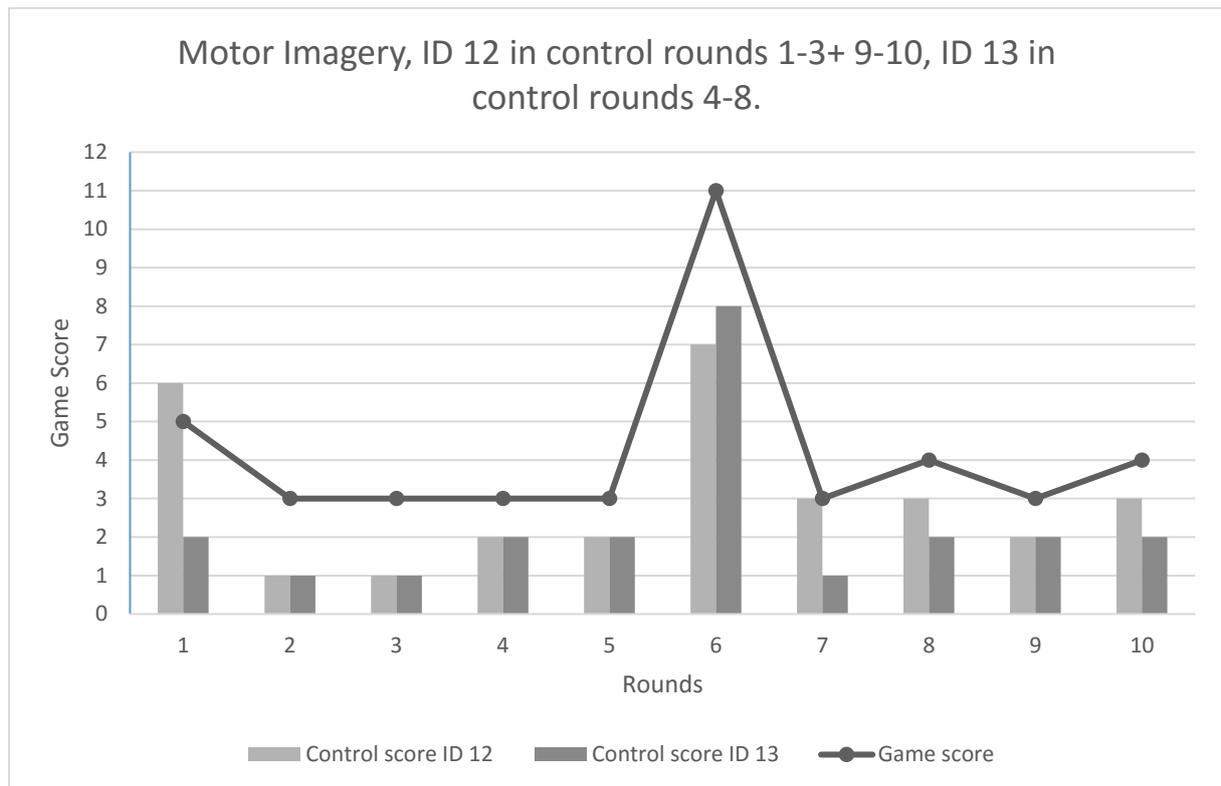


Figure 48 Motor imagery control scores for test subject 12 and 13

11.6.2.2 Visual imagery scores for test subject 12 and 13

In the five rounds that test subject 12 were in control, test subject 12 reported higher control scores than test subject 13. In the five rounds that test subject 13 was in control, both players reported the same score of 1 which is the lowest control score possible.

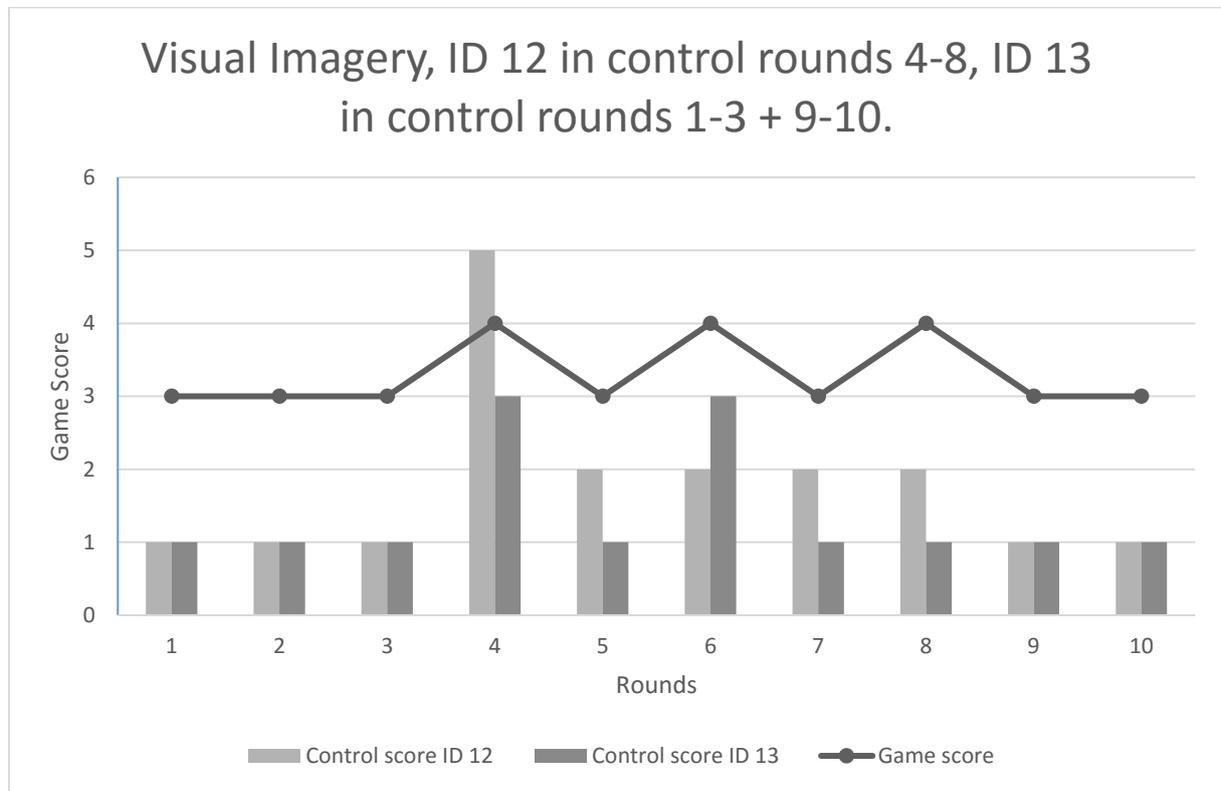


Figure 49 Visual imagery control scores for test subject 12 and 13

11.6.2.3 Discussing the results from test subject 12 and 13

The average control scores from the motor imagery rounds while test subject 12 was in control were 2.6 for test subject 12 and 1.6 for test subject 13. The average control scores from the motor imagery rounds while test subject 13 was in control were 3.4 for test subject 12 and 3 for test subject 13. Test subject 12 gave higher control scores when not in control. Test subject 13 gave higher control scores when in control.

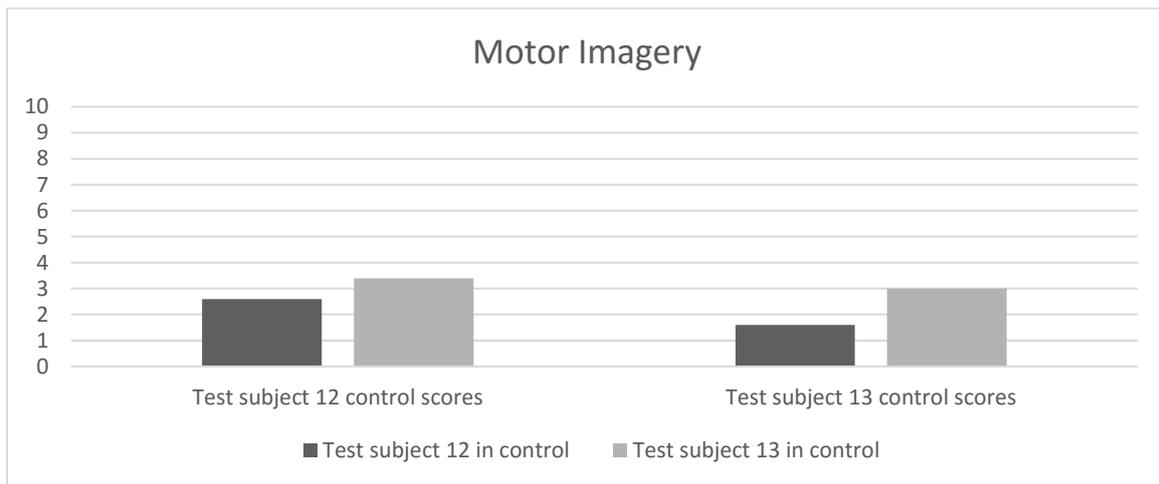


Figure 50 Average motor imagery control scores for test subject 12 and 13

The average control scores from the visual imagery rounds while test subject 12 was in control were 2.6 for test subject 12 and 1.8 for test subject 13. The average control scores when test subject 13 was in control were 1 for both test subject 12 and 13. Test subject 12 reported higher control scores when in control.

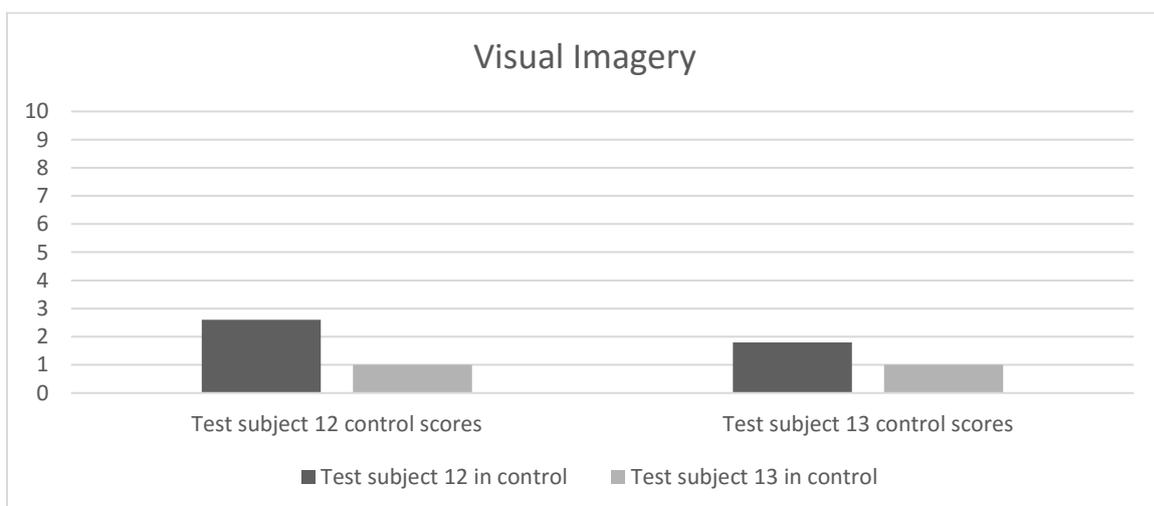


Figure 51 Average visual imagery control scores for test subject 12 and 13

11.6.3 Test subject 14 and 15

The third pair were test subject 14 and 15. I will present the control scores from the motor imagery rounds and visual imagery rounds separately, and then discuss the results.

11.6.3.1 Motor imagery results for test subject 14 and 15

In the five rounds where test subject 14 was in control, test subject 14 reported on average higher control scores than test subject 15. In the five rounds where test subject 15 was in control, test subject 14 and 15 reported a higher control score each for one round and the same score for three rounds.

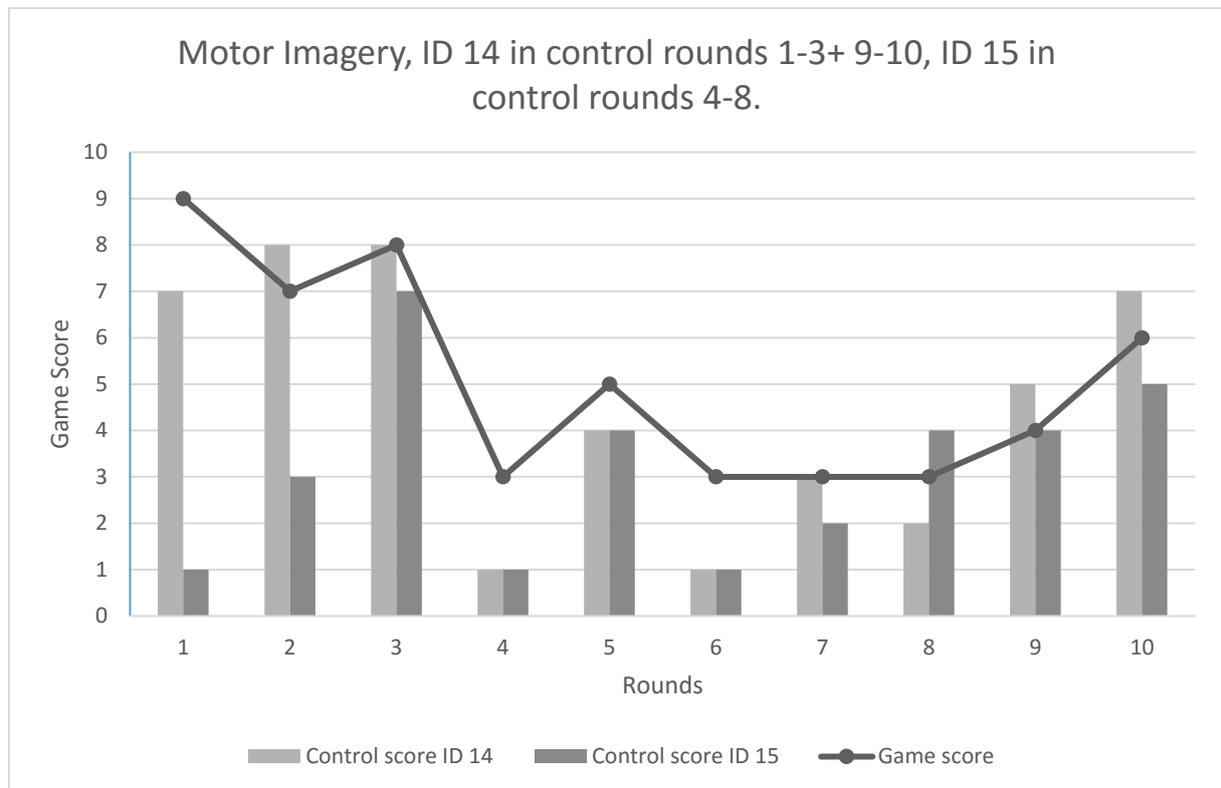


Figure 52 Motor imagery control scores for test subject 14 and 15

11.6.3.2 Visual imagery results for test subject 14 and 15

In the five rounds where test subject 14 was in control, test subject 15 reported on average higher control scores. In the rounds where test subject 15 was in control, test subject 15 reported on average higher control scores.

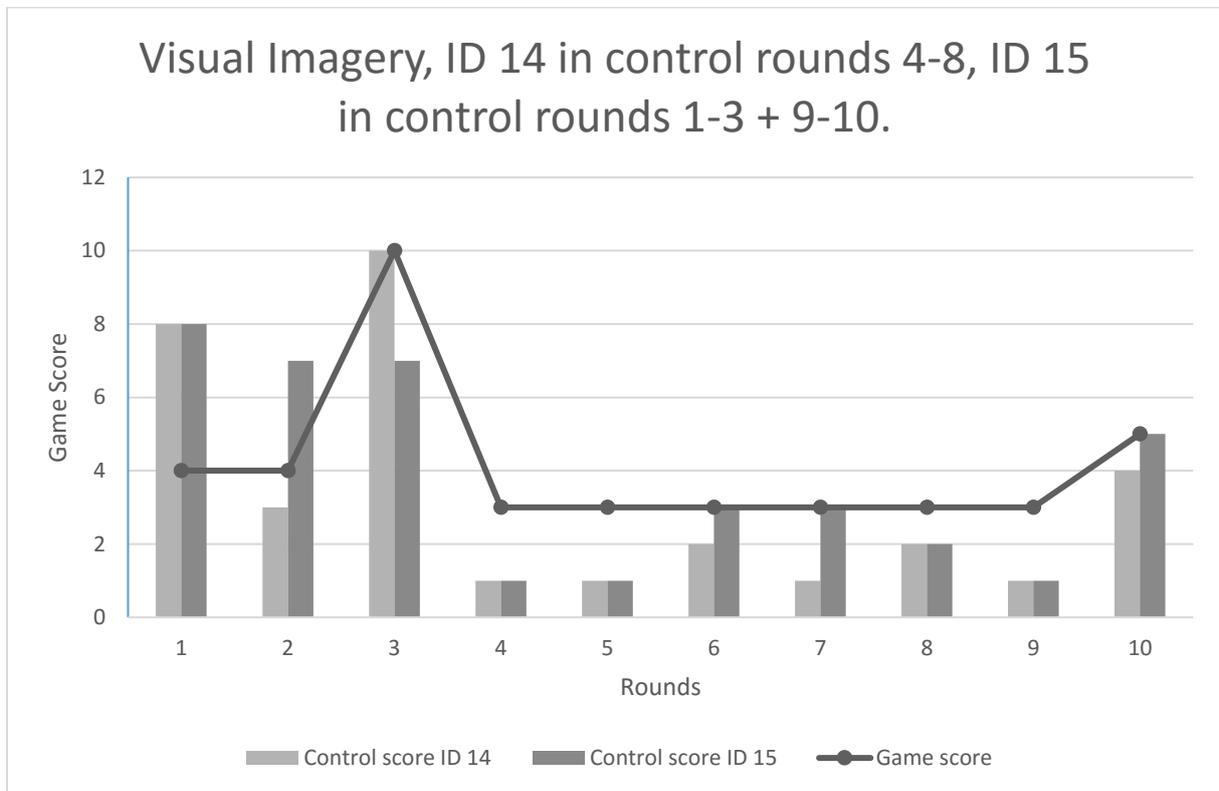


Figure 53 Visual imagery control scores for test subject 14 and 15

11.6.3.3 Discussing the results from test subject 14 and 15

The average control scores from the motor imagery rounds while test subject 14 was in control were 7 for test subject 14 and 4 for test subject 15. The average control scores for when test subject 15 was in control were 2.2 for test subject 14 and 2.4 for test subject 15. Test subject 14 reported higher control scores when in control. Test subject 15 reported higher control scores when not in control.

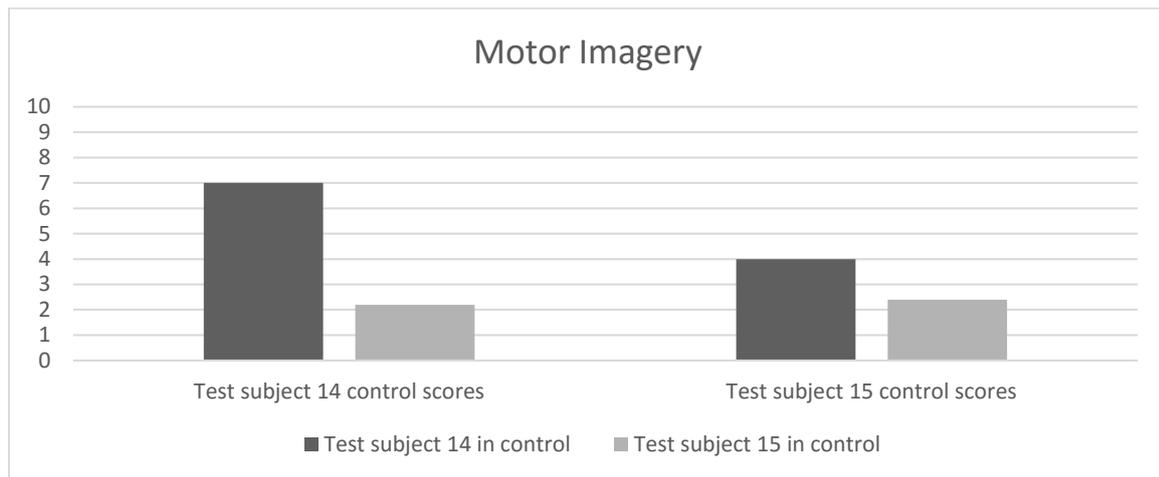


Figure 54 Average motor imagery control scores for test subject 14 and 15

The average control scores from the visual imagery rounds while test subject 14 was in control were 1.4 for test subject 14 and 2 for test subject 15. The average scores for when test subject 15 was in control where 5.2 for test subject 14 and 5.6 for test subject 15. Test subject 14 reported higher control scores when not in control. Test subject 15 reported higher control scores when in control.

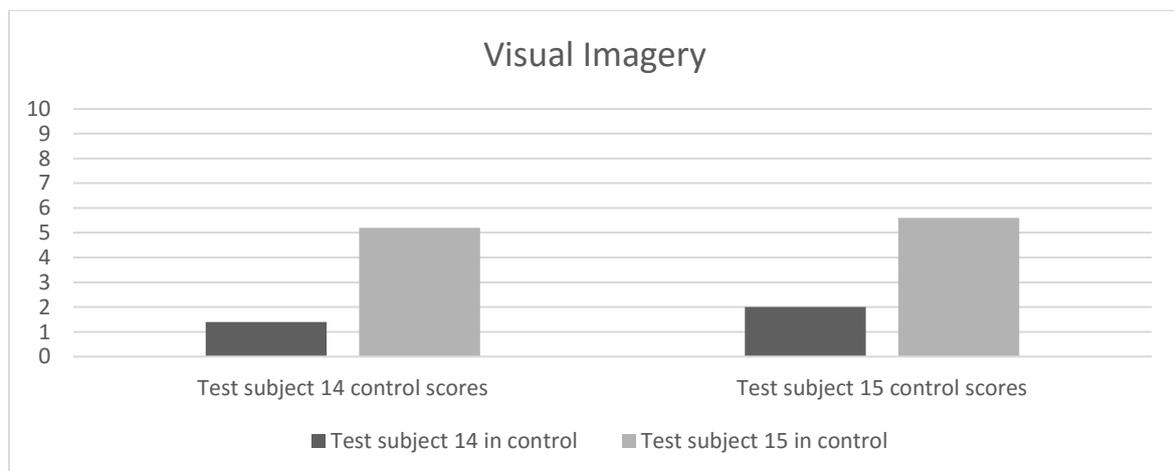


Figure 55 Average visual imagery control scores for test subject 14 and 15

11.6.4 Test subject 16 and 17

The fourth pair were test subject 16 and 17. I will present the control scores from the motor imagery rounds and visual imagery rounds separately, and then discuss the results.

11.6.4.1 Motor imagery results for test subject 16 and 17

In the five rounds where test subject 16 was in control, test subject 16 reported slightly higher control scores on average. In the five rounds where test subject 17 was in control, test subject 17 reported much higher control scores than test subject 16.

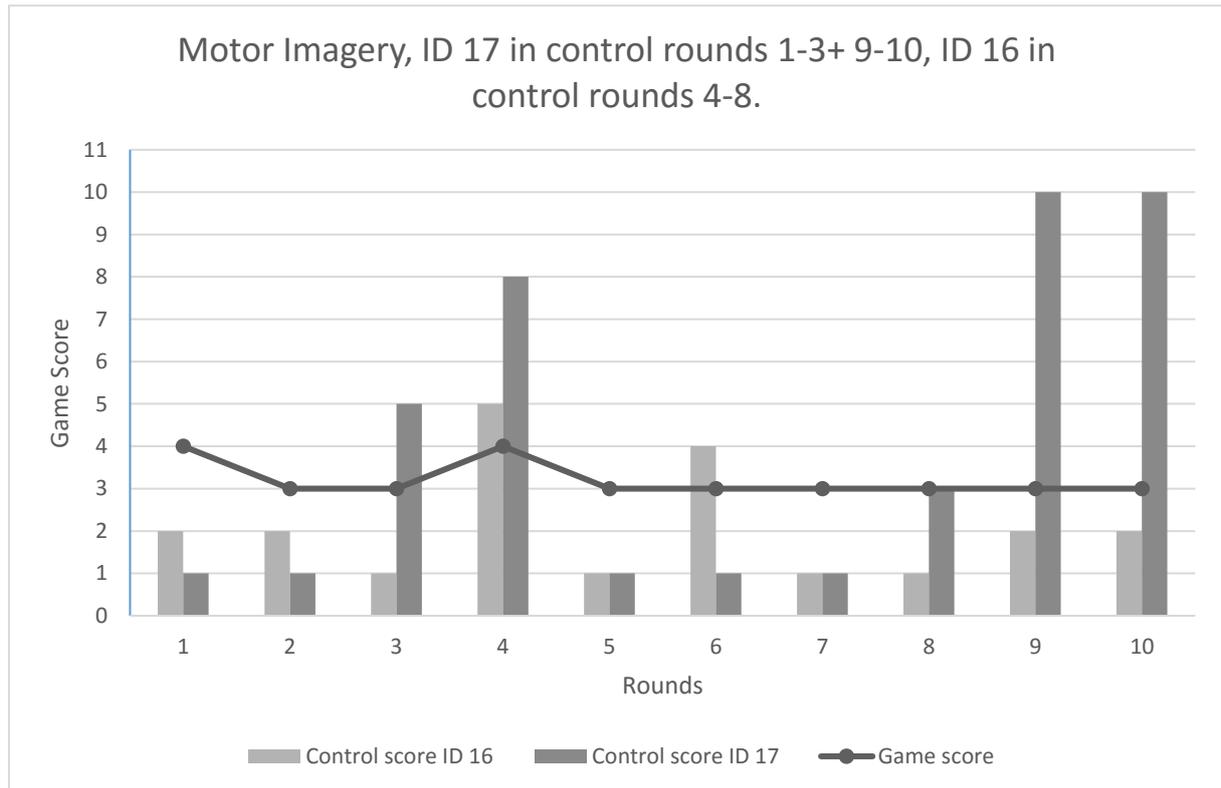


Figure 56 Motor imagery control scores for test subject 16 and 17

11.6.4.2 Visual imagery scores for test subject 16 and 17

In the five rounds where test subject 16 were in control, test subject 16 reported higher control scores than test subject 17. In the five rounds where test subject 17 were in control, test subject 17 reported higher control scores than test subject 16. Test subject 16 reported higher control scores when not in control. Test subject 17 reported higher control scores when in control.

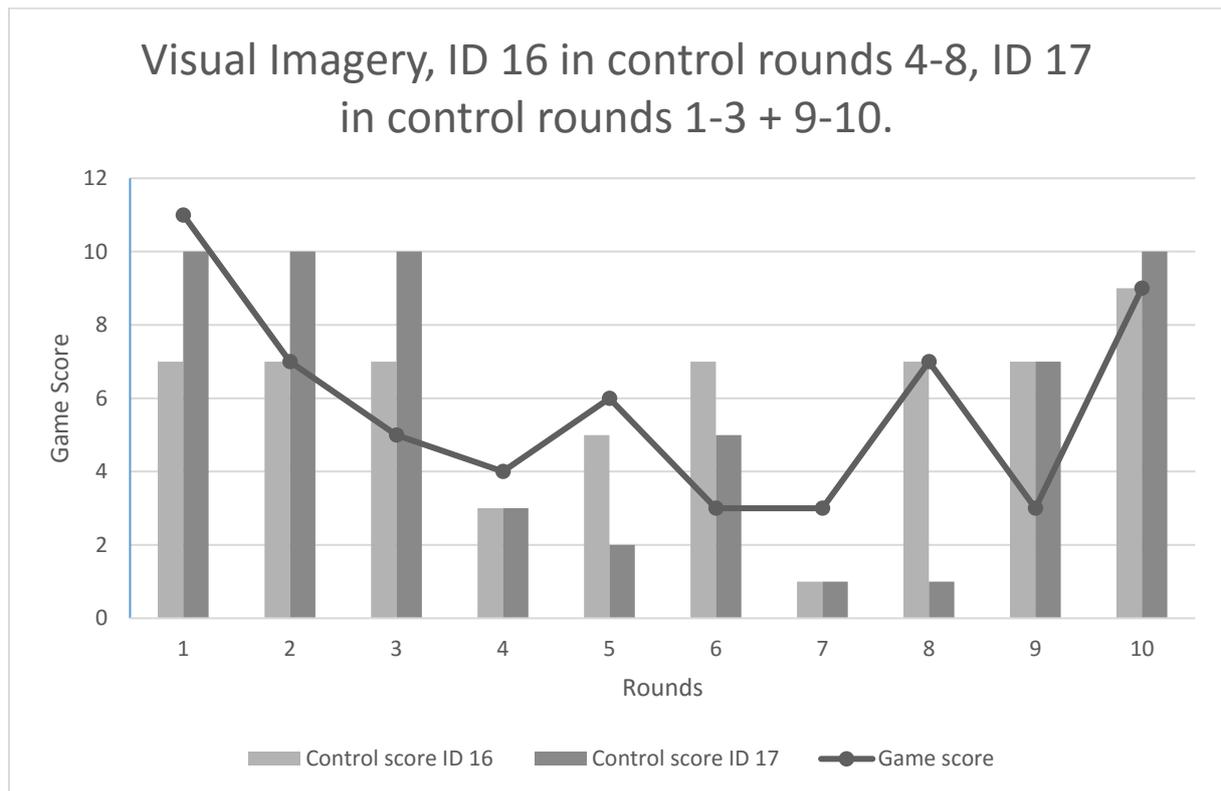


Figure 57 Visual imagery control scores for test subject 16 and 17

11.6.4.3 Discussing the results from test subject 16 and 17

The average control scores during the motor imagery rounds while test subject 16 was in control were 2.4 for test subject 16 and 2.8 for test subject 17. The average scores when test subject 17 was in control were 1.8 for test subject 16 and 5.4 for test subject 17. Both test subjects 16 and 17 reported higher control scores when in control.

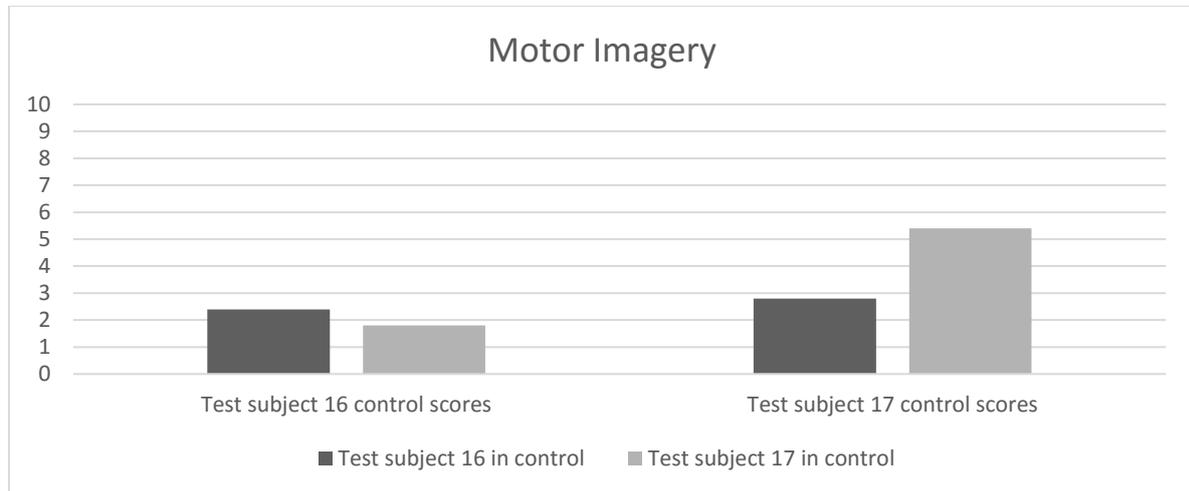


Figure 58 Average motor imagery control scores for test subject 16 and 17

The average control scores during the visual imagery rounds while test subject 16 was in control were 4.6 for test subject 16 and 2.4 for test subject 17. The average scores when test subject 17 were in control were 7.4 for test subject 16 and 9.4 for test subject 17. Both test subjects reported higher control scores when test subject 17 were in control. Test subject 17 reported lower control scores when not in control.

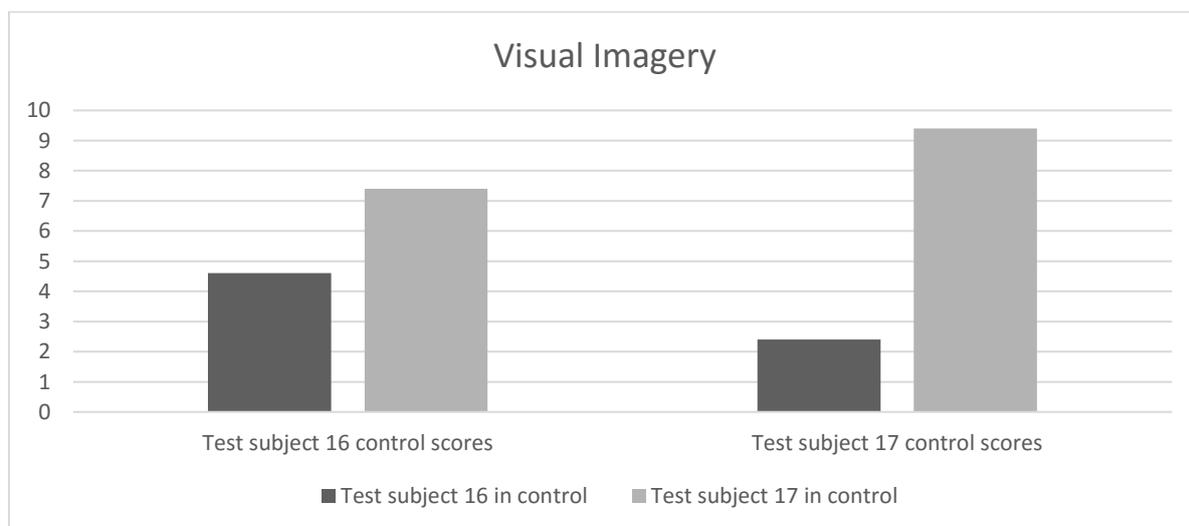


Figure 59 Average visual imagery control scores for test subject 16 and 17

11.6.5 Test subject 18 and 19

The fifth pair were test subject 18 and 19. I will present the control scores from the motor imagery rounds and visual imagery rounds separately, and then discuss the results.

11.6.5.1 Motor imagery results for test subject 18 and 19

In the five rounds where test subject 18 were in control, test subject 18 reported on average lower scores than test subject 19. In the five rounds where test subject 19 were in control, test subject 19 reported higher control scores. Interestingly, subject 18 reported higher control score than test subject 19 in round 6 where test subject 19 was in control. In the round after (round 7) test subject 19 was still in control, and achieved the highest game-score of all the tests so far (29 zombies), this time test subject 18 reported a score of 1, feeling not in control.

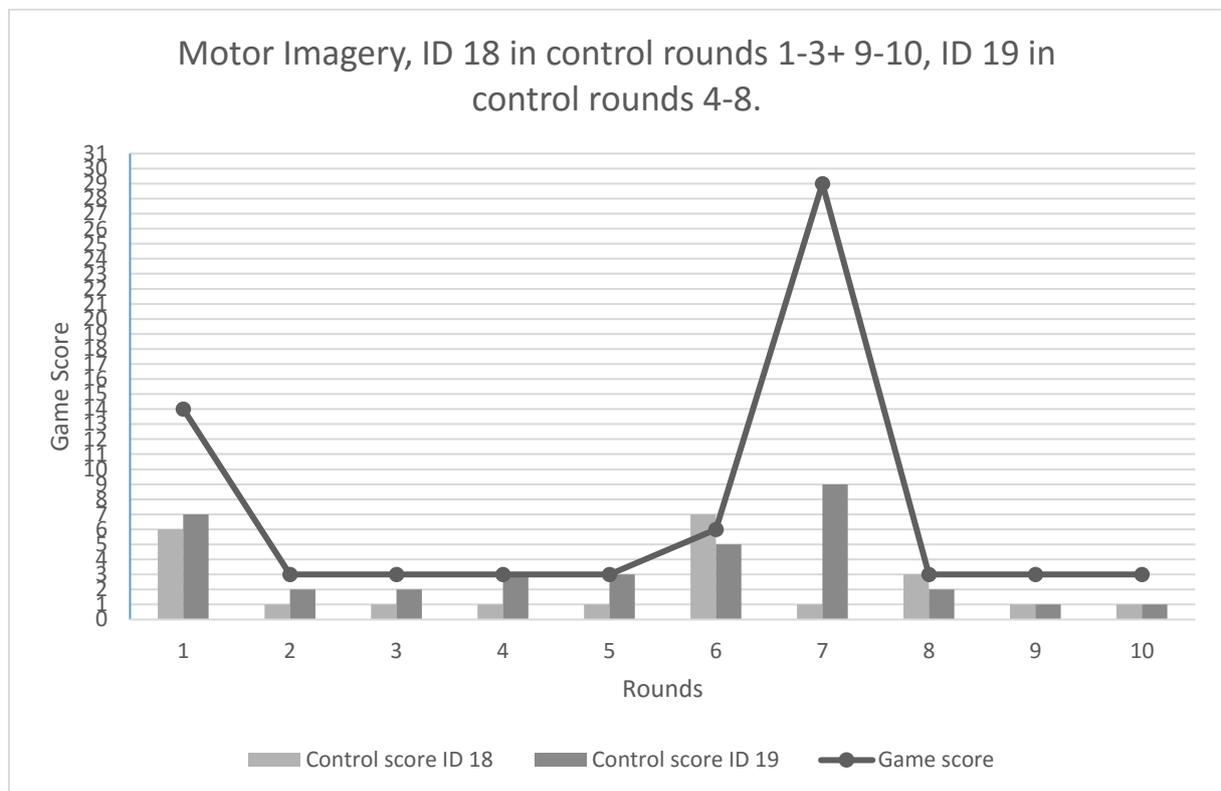


Figure 60 Motor imagery control scores for test subject 18 and 19

11.6.5.2 Visual imagery scores for subject 18 and 19

In the five rounds that test subject 18 was in control, test subject 19 reported higher scores on average than test subject 18. In the five rounds when test subject 19 was in control, test subject 19 reported higher control scores than test subject 18. Test subject 18 did however only report a control score above 1 out of 10 once, and it was during a round where test subject 19 was in control. Test subject 19 reported scores above 1 out of 10 both when in control and not in control.

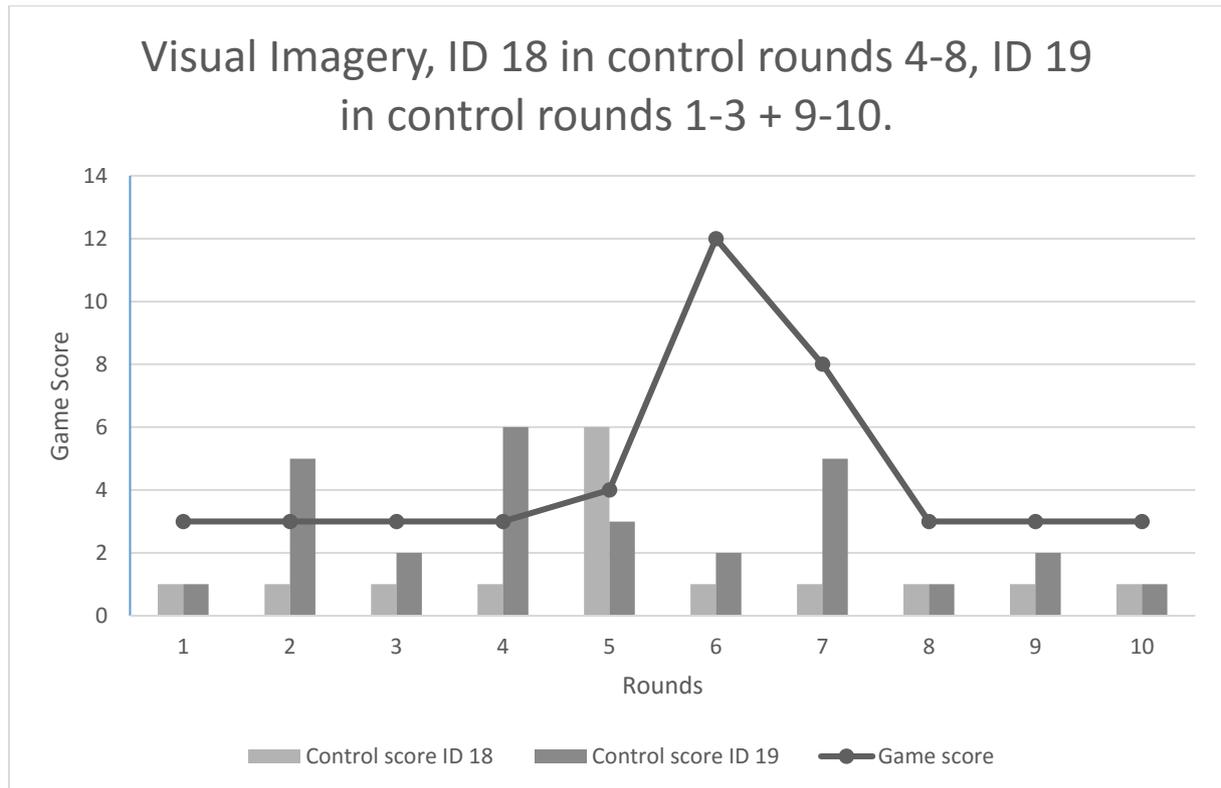


Figure 61 Visual imagery control scores for test subject 18 and 19

11.6.5.3 Discussing the results from test subject 18 and 19

The average control scores from the motor imagery rounds while test subject 18 was in control were 2.6 for test subject 18 and 4.4 for test subject 19. The average control scores from the motor imagery rounds while test subject 19 was in control were 2 for test subject 18 and 2.6 for test subject 19. Test subject 18 reported higher control score when in control. Test subject 19 reported higher control scores when not in control.

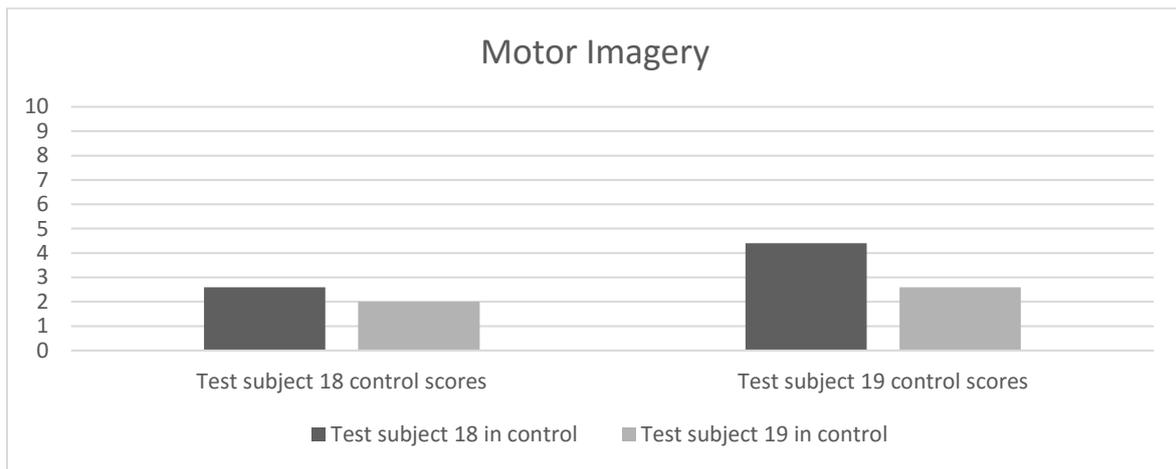


Figure 62 Average motor imagery control scores for test subject 18 and 19

The average control scores from the visual imagery rounds while test subject 18 was in control were 2 for test subject 18 and 3.4 for test subject 19. The average control scores from the motor imagery rounds while test subject 19 was in control were 1 for test subject 18 and 2.2 for test subject 19. Test subject 18 reported higher control score when in control. Test subject 19 reported higher control scores when not in control.

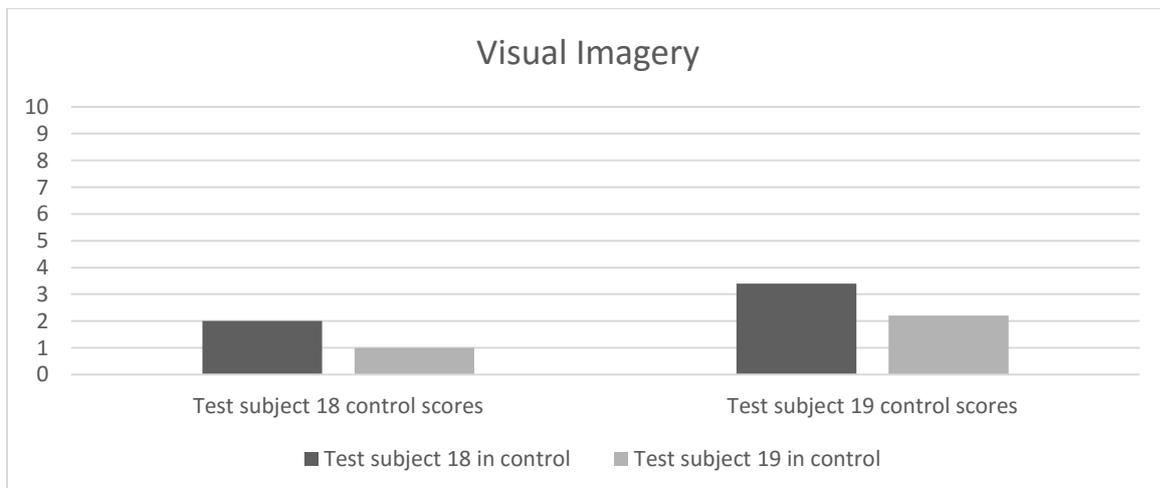


Figure 63 Average visual imagery control scores for test subject 18 and 19

11.7 Discussion Pre-test iteration 1

The results from this test were much different than from the pilot test.

The most interesting comparison between the pilot test and Pre-test iteration 1 is if you look at how many test subjects were “tricked” to believe they were in control while the other test subject was actually in control of the game, and reported higher control scores.

In the pilot test, 3 of 6 test subjects were “tricked” in the motor imagery rounds and 0 of 6 test subjects were “tricked” in the visual imagery rounds.

In Pre-test iteration 1, 3 of 10 test subjects were “tricked” in the motor imagery rounds and 6 of 10 were “tricked” in the visual imagery rounds.

In the pilot test, the conclusion seemed to be that visual imagery was less prone to confirmation bias because 0 of the test subjects were “tricked” during the visual imagery rounds and never reported higher control scores when not in control. But in Pre-test iteration 1 the result is almost the opposite, with twice as many test subjects being “tricked” when using visual imagery compared to motor imagery. If you combine the results from the pilot test and pre-test iteration 1, there is no difference between motor and visual imagery. A total 6 of 16 test subjects were “tricked” when using motor and 6 of 16 test subjects were “tricked” when using visual imagery.

11.8 Possible factors

During the planning of pre-test iteration 1 the LAN party was supposed to take place in the same building as the pilot test, which would allow me to test again in the same room. The organizers of the LAN were unable to get permission to use this building and I had to find another room for pre-test iteration 1.

11.9 Changes in procedure from pre-test iteration 1 to pre-test iteration 2

I discussed the results and suggested changes for the next test with my supervisor.

The setup was changed from 2 test subjects playing with/against each other, to one test subject playing with/against a video-simulation of the game. This way I can run five rounds with the same fake game-scores on all test subjects to get a better comparison between test subjects. The different “style” of rating between test subjects could be difficult to handle if comparing the control scores between two test subjects with vastly different styles and measuring averages.

I decided to buy earplugs to prevent noise from the LAN party to be any factor.

11.10 Conclusion pre-test iteration 1

When combining the results from the Pilot test and pre-test iteration 1, and disregarding the difference in the testing environment in the Pilot test and pre-test iteration 1, there is no difference between motor imagery and visual imagery when measuring confirmation bias. 6 out of 16 test subjects reported higher control scores when not in control for both motor and visual imagery. More tests must be done.

12. Pre-Test iteration 2 report

12.1 Method:

The method was changed after a discussion with my supervisor after pre-test iteration 1.

In this variant, instead of two test subjects who takes turns taking control of the game while the other test subject unknowingly spectates, I only test on one test subject at a time.

12.2 Equipment:

I decided to use one Emotiv Insight headset rather than one of the Emotiv EPOC headsets because both headsets have the same capabilities and uses the same control panel. The hardware is newer and more comfortable to use for the user. I only have one Emotiv Insight so I could not use two Emotiv Insight headsets in the previous tests.

In addition to either an Emotiv EPOC or Insight headset, you need one computer that fills the requirements for the EPOC/Insight. If the computer is a desktop, it must have at least two video outputs which will allow it to be connected to two monitors simultaneously. If you are using a laptop, it must have at least one video output for it to be connected to a monitor in addition to the laptop screen. The figure below shows how the equipment is configured.

Monitor A1 is used for displaying symbols when recording, displaying the game, displaying the fake game with a video player and to display the challenge mode.

Monitor A2 is used for the control panel or to mirror A1 during playing if the instructor prefers it (optional).

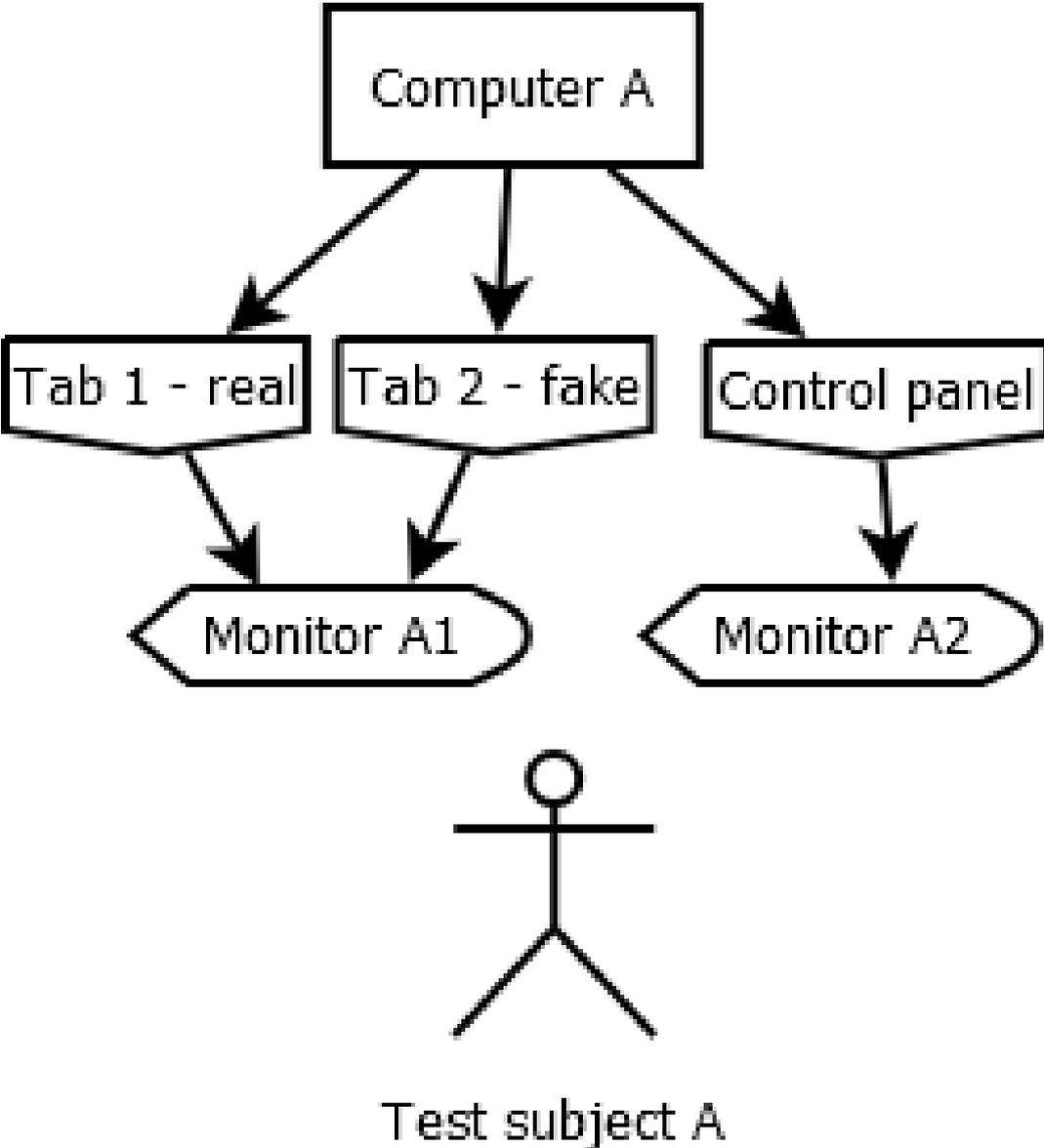


Figure 64 Equipment configuration for the confirmation bias tests in pre-test iteration 2

12.3 Test protocol:

The method for controlling the game in this test and the pilot and pre-test iteration 1 are the same. The change is in how many players are participating in each test and how the tournament rules has changed.

One test subject A is told that he or she will be competing in the “Neurogaming” tournament for this LAN party. Test subject A plays “FlappyBrain” using motor imagery in 10 rounds and visual imagery in 10 rounds. After 20 rounds of practice, the test subjects plays 3 rounds of “challenge mode” in the Emotiv Control Panel.

Test subject A choses either motor imagery or visual imagery for the 3 rounds in “challenge mode”, whichever he or she feels more confident in using after practicing. The test subject with the highest score in “challenge mode” of all the test subjects at the LAN party wins a 500 NOK gift card. Test subject A is actually in control during the 3 last rounds of “challenge mode”.

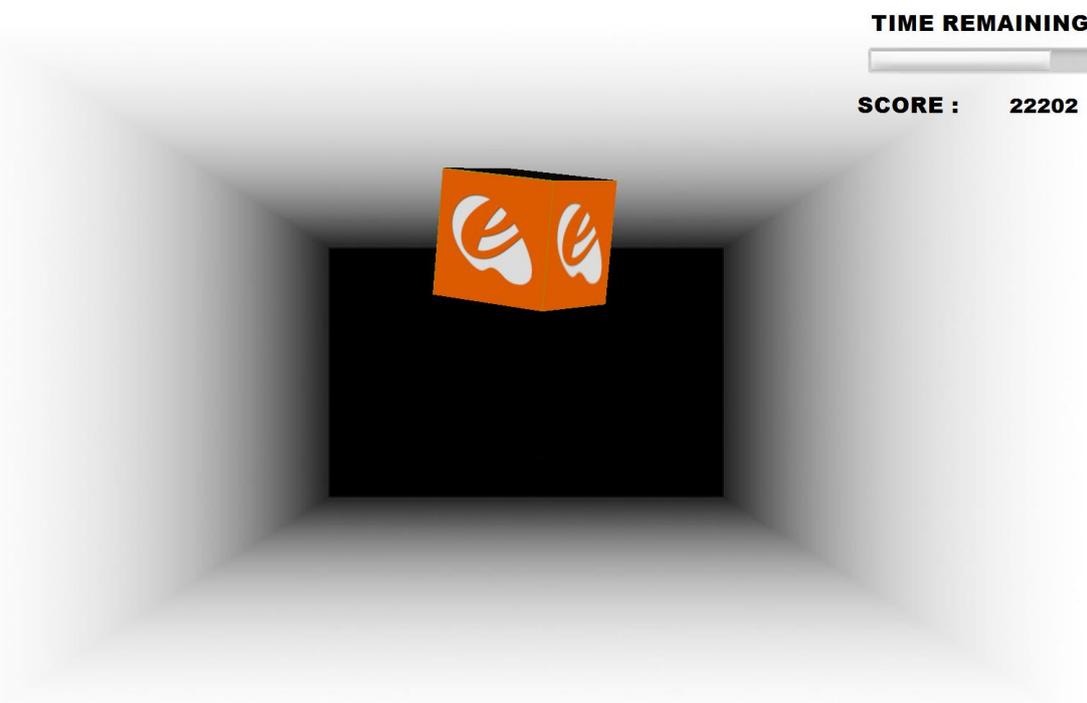


Figure 65 Screenshot from a round of Challenge mode in Emotiv Control Panel

12.4 Recording:

The method for recording in this test is the same as in the pilot test and pre-test iteration 1.

12.5 Playing and gathering data:

Before launching the game, the instructor will ask the player to take a short break, close his or her eyes and relax while the game is prepared.

While the test subject has his or her eyes closed, the instructor will alt-tab to either the game FlappyBrain in a web browser in full screen mode (F11 key) or a full screen video of a round of FlappyBrain shown on Monitor A1. If the instructor wants to, he or she can mirror monitor A1 to monitor A2 during playing (optional).

I recommend the open source media player “VLC media player” (VideoLAN, 2017) for displaying the fake rounds of FlappyBrain, with “On Screen Display” turned off to hide the media buttons in full screen. This will make switching between FlappyBrain in a full screen browser and a full screen video in VLC indistinguishable. Ask the player to take a short break and close his or her eyes in between each round before switching between the real game and the video. I recommend that you have five fake videos in a playlist in VLC so that you can skip to the next one when needed. The hotkey “N” in VLC Media player can be used to go to the next video in a playlist.

The test subjects will be given earplugs to prevent disturbances while playing.

The test subjects are told before the games starts that after each round they have to put down a number between 1 and 10 in “Table 1” to indicate how much control over the game character they felt they had on a scale from 1 to 10.

The test subjects are also told to then relax with their eyes closed until they feel a tap on the shoulder from the instructor which is a signal to tell them that the next round starts in 10 seconds and that they should open their eyes. 10 seconds after the instructor has tapped the test subject on the shoulder, the instructor either hits “F5” button on the computer to reload the game or “spacebar” to play the movie. The test subject plays 5 rounds of FlappyBrain and spectates 5 rounds of recorded FlappyBrain footage where the test subject might think he or she is in control of the game.

12.6 Results from pre-test iteration 2

I will go through the results of the 10 test subjects who participated in this test, first the results from the confirmation bias test and then the results from the challenge mode.

Because this test did not have pairs, I will only discuss the results for every test subject individually because the game-scores during the fake rounds; round 5,6,7,9 and 10, were always the same for each test subject: 3,3,9,3 and 7 respectively. The test subjects were numbered 20 to 29 to prevent mix-ups with previous tests subjects.

12.6.1 Test subject 20

The average control scores from the motor imagery rounds: 6.6 while in control, 6 while not in control. Average scores from the visual imagery rounds: 2.4 while in control, 7.2 while not in control. Test subject 20 reported higher control scores while in control during motor imagery rounds, and lower control scores while in control during visual imagery rounds.

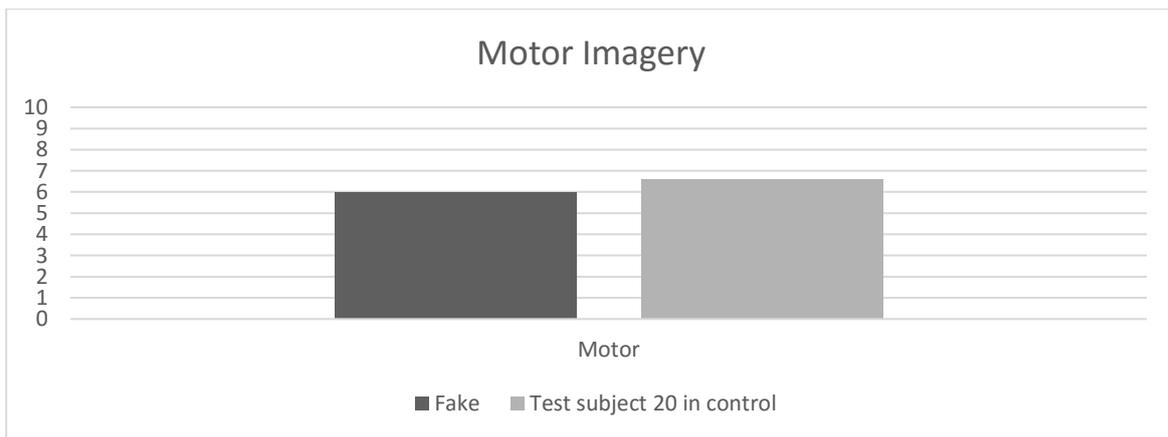


Figure 66 Average motor imagery control scores for test subject 20

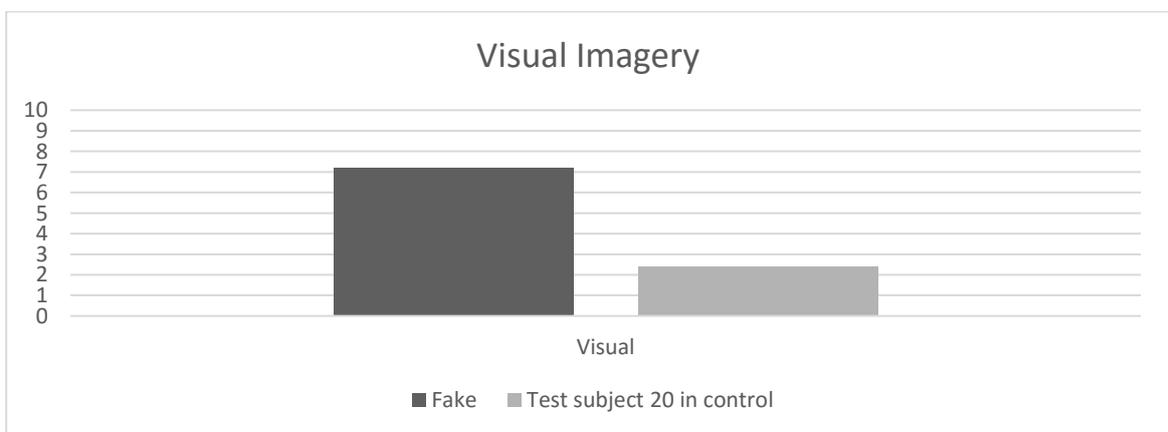


Figure 67 Average visual imagery control scores for test subject 20

12.6.2 Test subject 21

The average control scores from the motor imagery rounds: 2.2 while in control, 3.4 while not in control. Average scores from the visual imagery rounds: 5.2 while in control, 2.6 while not in control. Test subject 21 reported lower control scores while in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

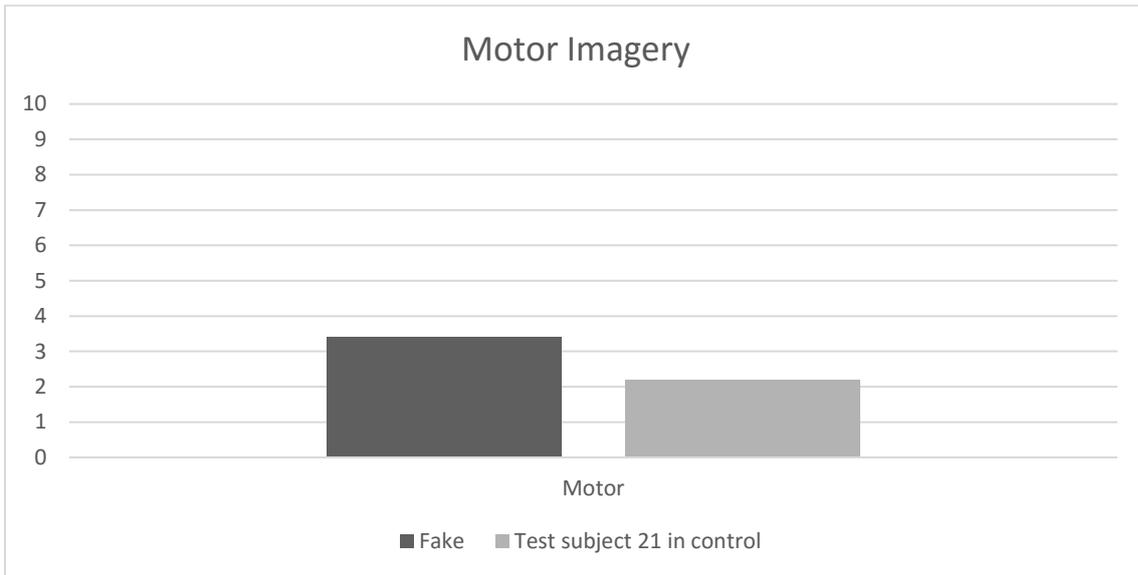


Figure 68 Average motor imagery control scores for test subject 21

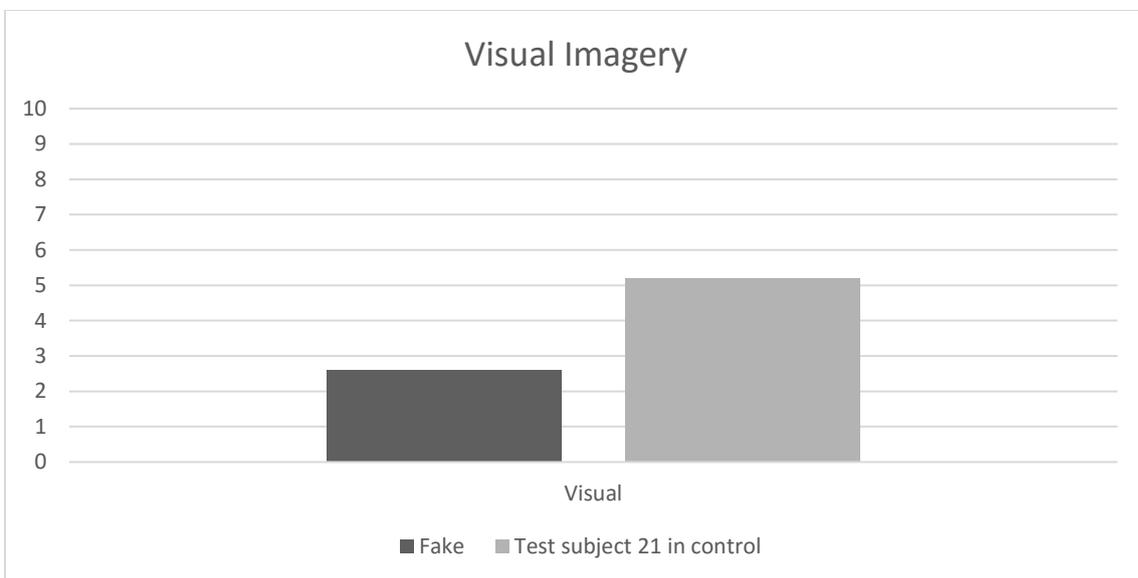


Figure 69 Average visual imagery control scores for test subject 21

12.6.3 Test subject 22

The average control scores from the motor imagery rounds: 5 while in control, 3.4 while not in control. Average scores from the visual imagery rounds: 1 while in control, 2.6 while not in control. Test subject 22 reported higher control scores while in control during motor imagery rounds, and lower control scores while in control during visual imagery rounds.

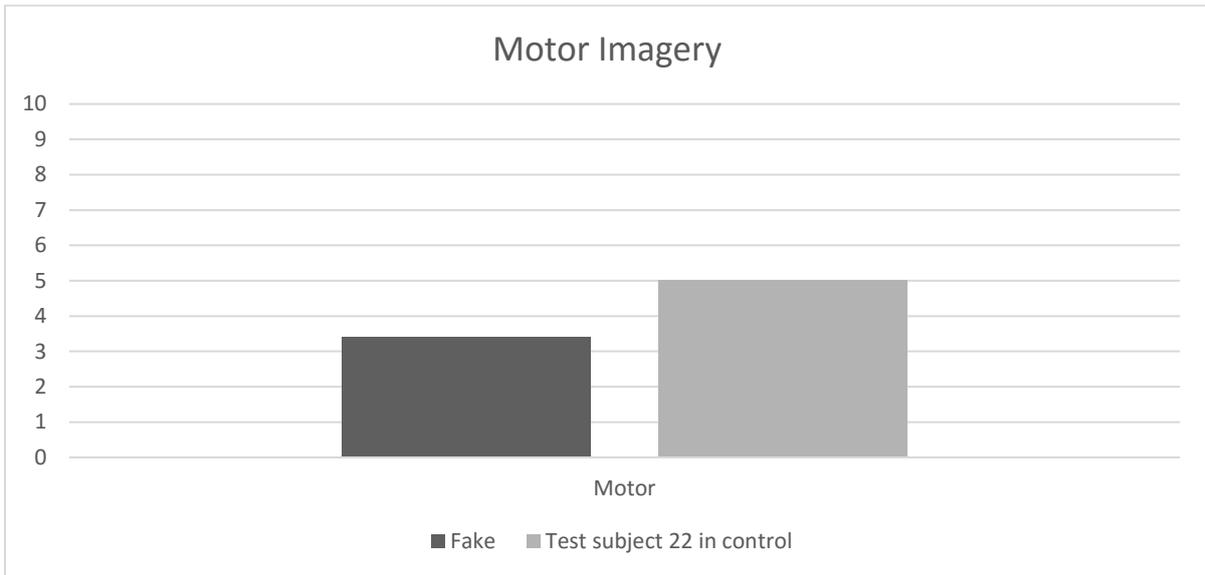


Figure 70 Average motor imagery control scores for test subject 22

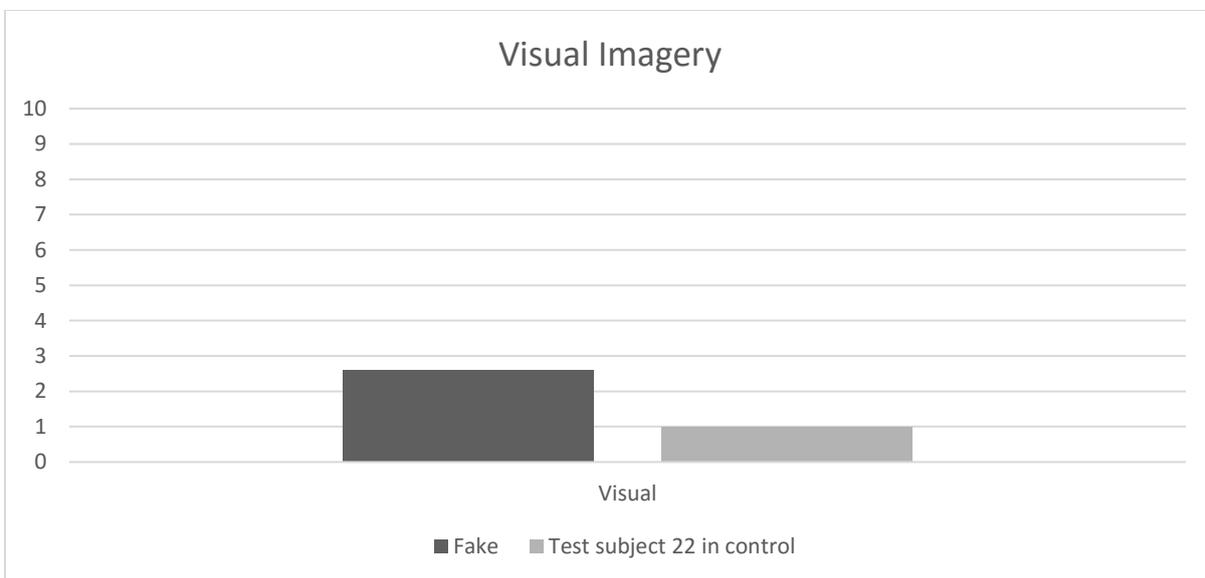


Figure 71 Average visual imagery control scores for test subject 22

12.6.4 Test subject 23

The average control scores from the motor imagery rounds: 3.2 while in control, 4.2 while not in control. Average scores from the visual imagery rounds: 1 while in control, 2.2 while not in control. Test subject 23 reported lower control scores while in control during motor imagery rounds, and lower control scores while in control during visual imagery rounds.

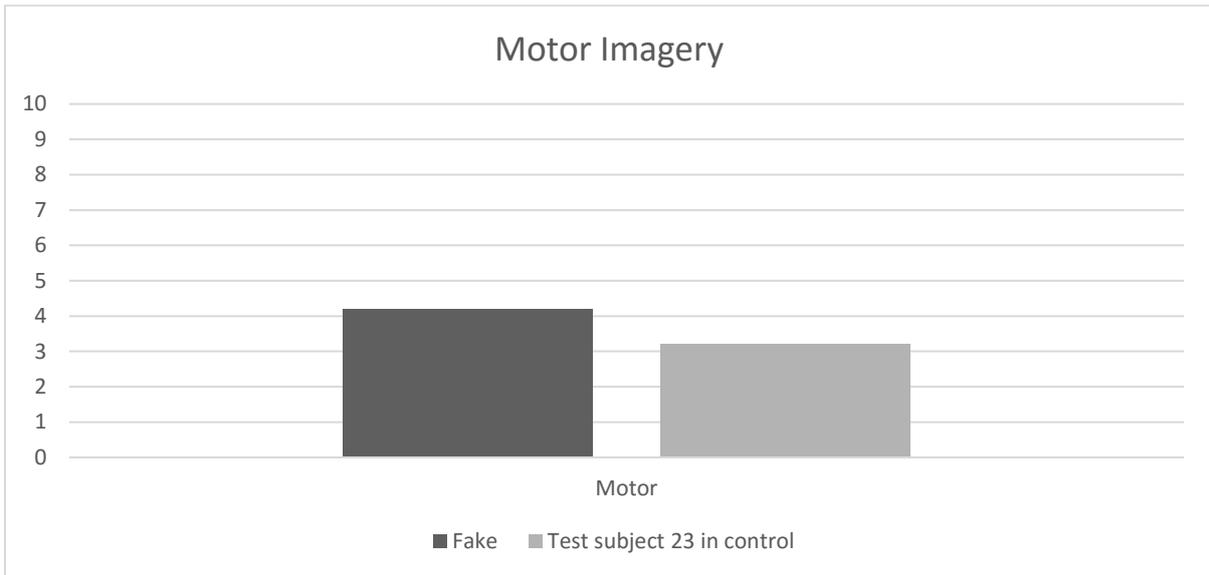


Figure 72 Average motor imagery control scores for test subject 23

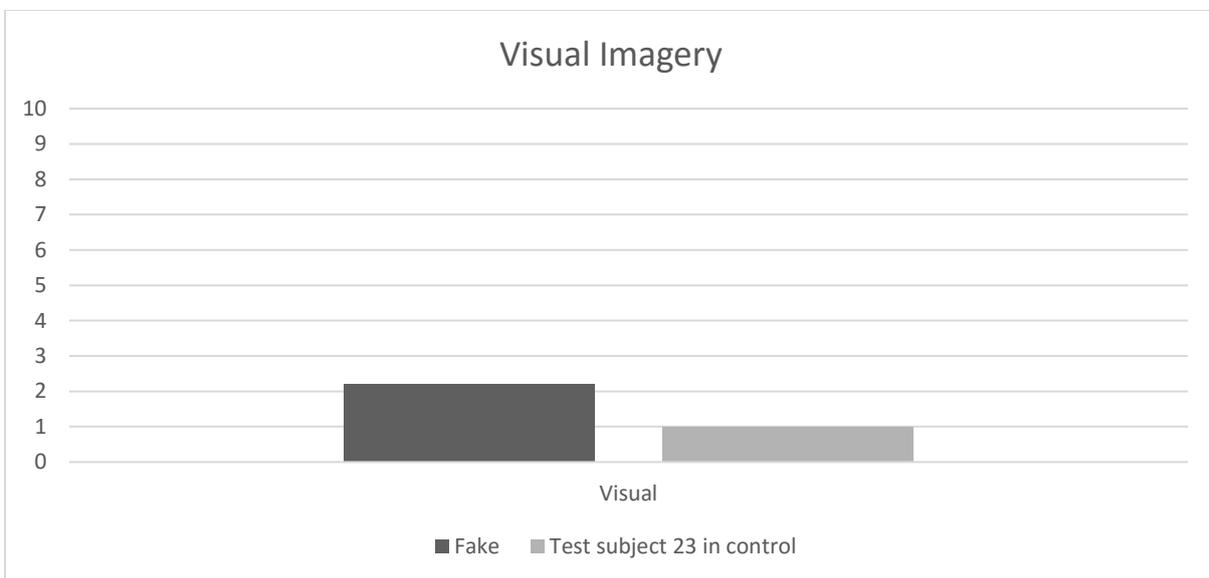


Figure 73 Average visual imagery control scores for test subject 23

12.6.5 Test subject 24

The average control scores from the motor imagery rounds: 3.2 while in control, 3.8 while not in control. Average scores from the visual imagery rounds: 2.2 while in control, 3.2 while not in control. Test subject 24 reported lower control scores while in control during motor imagery rounds, and lower control scores while in control during visual imagery rounds.

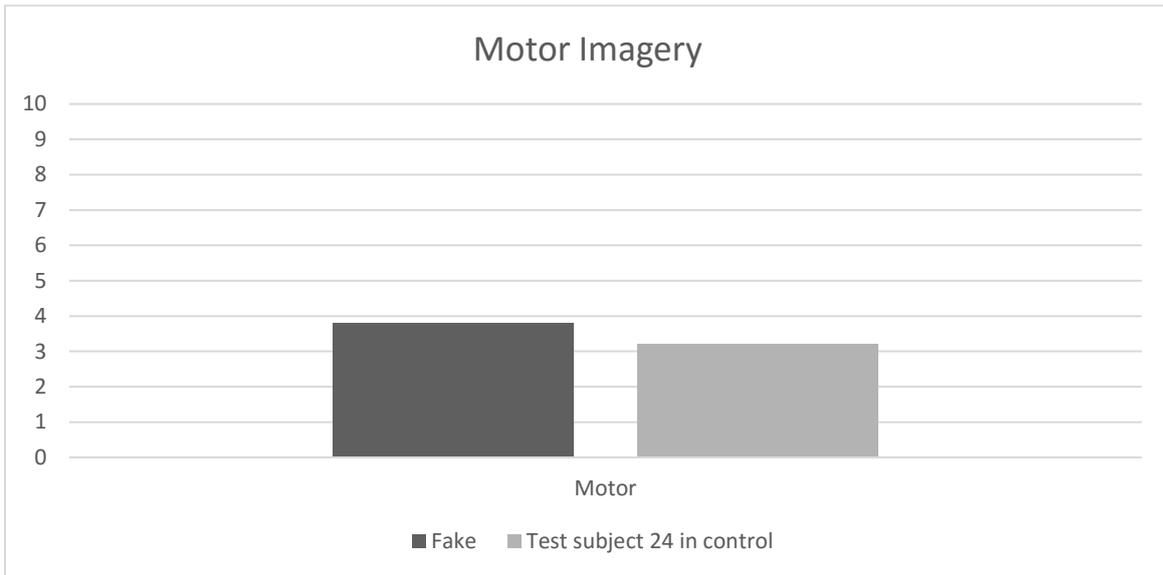


Figure 74 Average motor imagery control scores for test subject 24

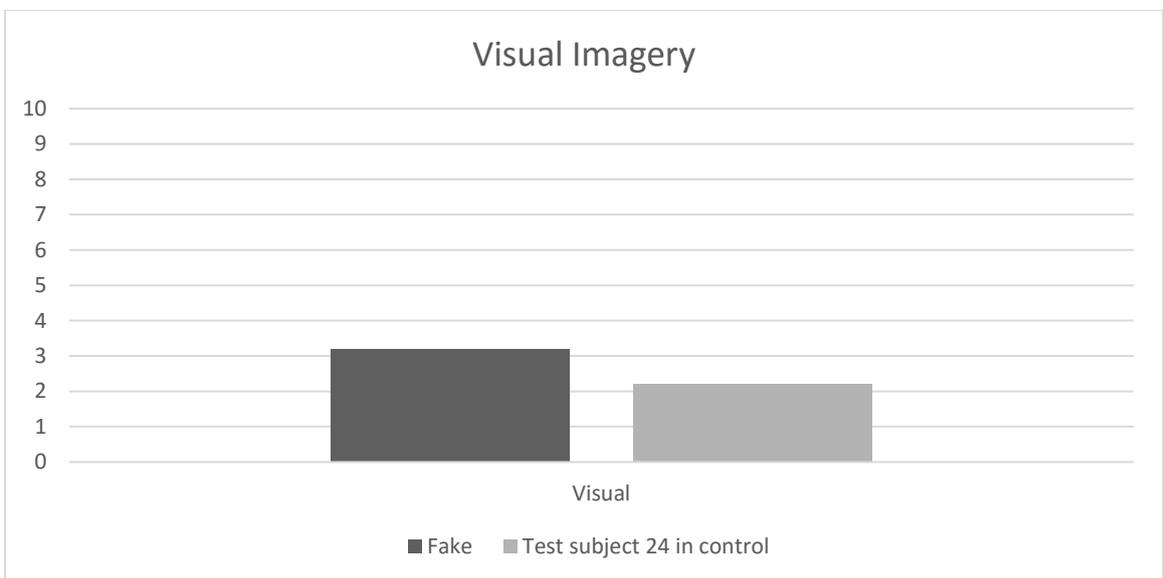


Figure 75 Average visual imagery control scores for test subject 24

12.6.6 Test subject 25

The average control scores from the motor imagery rounds: 2.6 while in control, 2.6 while not in control. Average scores from the visual imagery rounds: 2.6 while in control, 2.6 while not in control. Test subject 25 reported on average the same score during both motor imagery rounds and visual imagery rounds regardless of if in control or not. The test subject reported different scores each round, which on average became 2.6.

Because this is a rare case:

Control scores for motor imagery: 2,3,3,3,2 for not in control, 2,3,4,1,3 for in control, both averages to 2.6.

Control scores for visual imagery: 2,2,4,2,3 for not in control, 2,3,1,3,4 for in control, both averages to 2.6

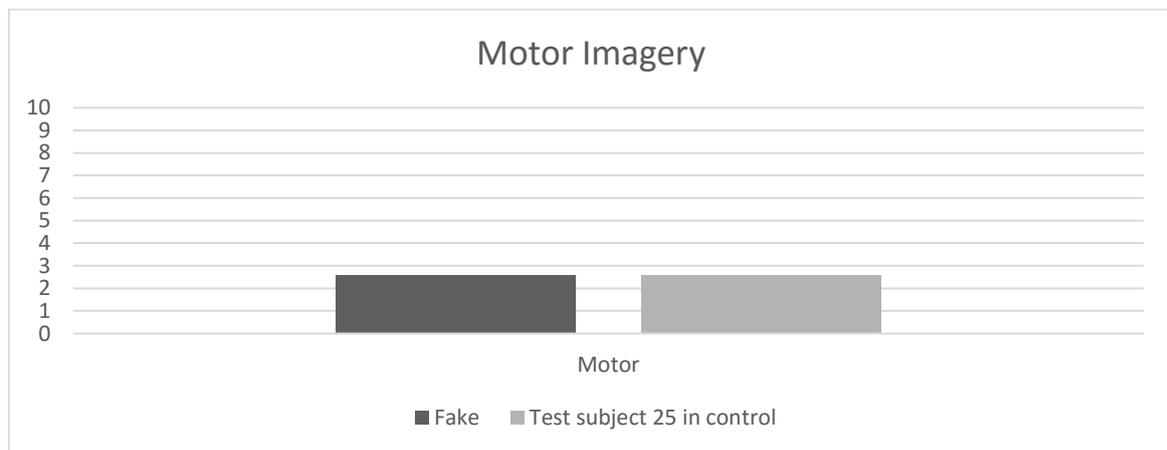


Figure 76 Average motor imagery control scores for test subject 25

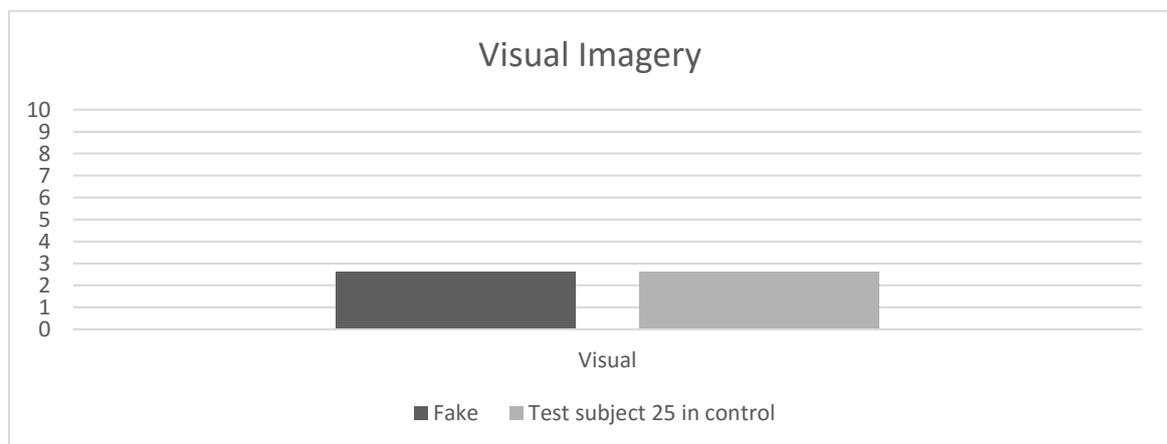


Figure 77 Average visual imagery control scores for test subject 25

12.6.7 Test subject 26

The average control scores from the motor imagery rounds: 2.4 while in control, 4 while not in control. Average scores from the visual imagery rounds: 4.2 while in control, 4 while not in control. Test subject 26 reported lower control scores while in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

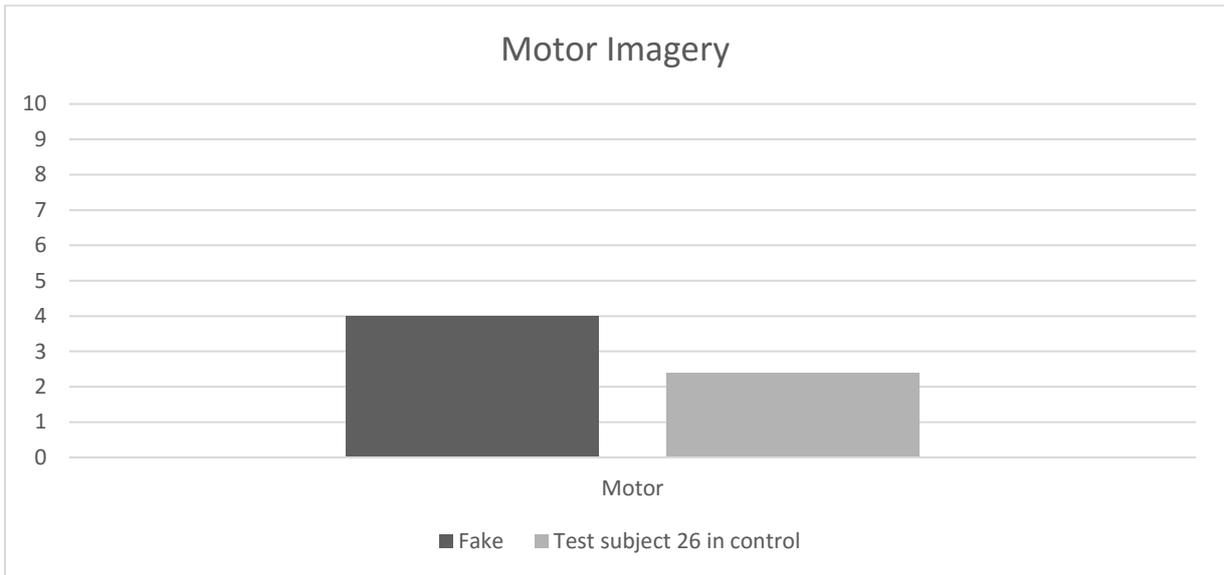


Figure 78 Average motor imagery control scores for test subject 26

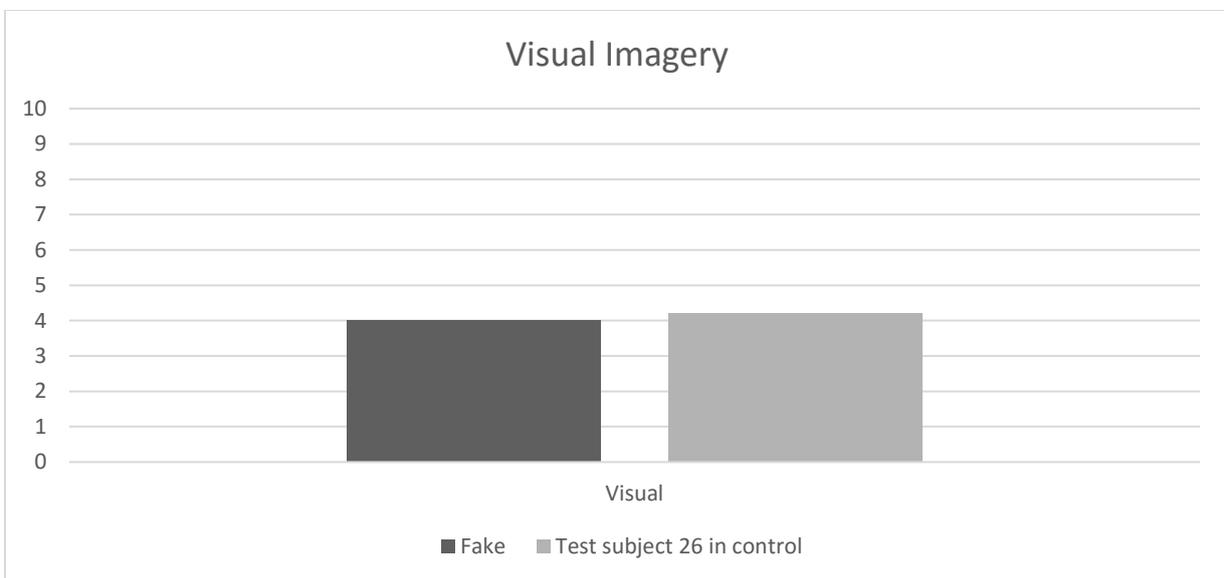


Figure 79 Average visual imagery control scores for test subject 26

12.6.8 Test subject 27

The average control scores from the motor imagery rounds: 4.2 while in control, 4 while not in control. Average scores from the visual imagery rounds: 1.8 while in control, 4.6 while not in control. Test subject 27 reported higher control scores while in control during motor imagery rounds, and lower control scores while in control during visual imagery rounds.

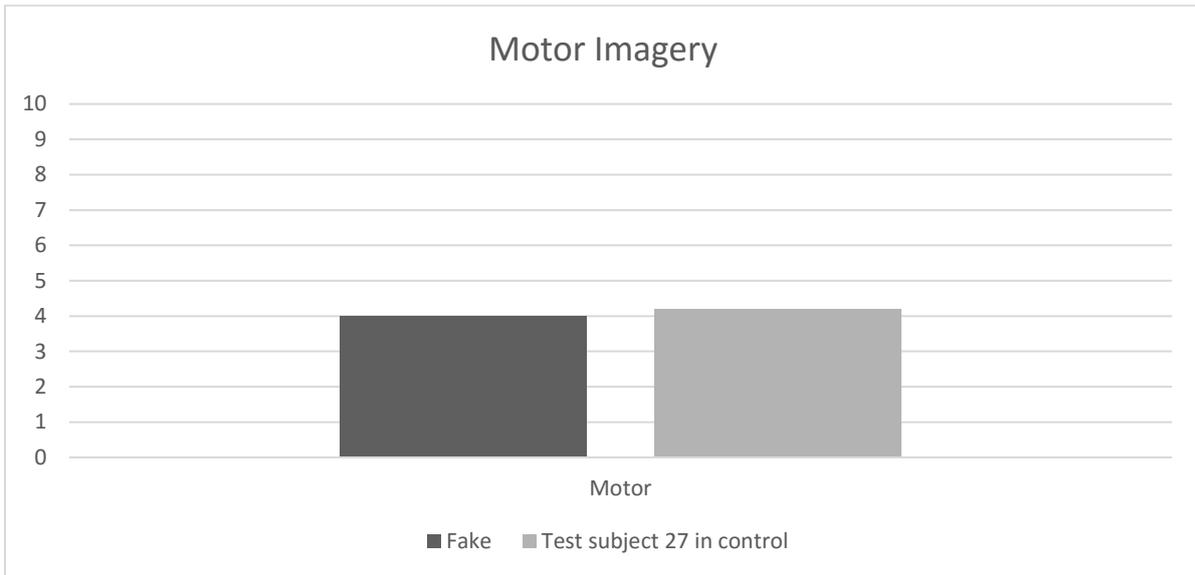


Figure 80 Average motor imagery control scores for test subject 27

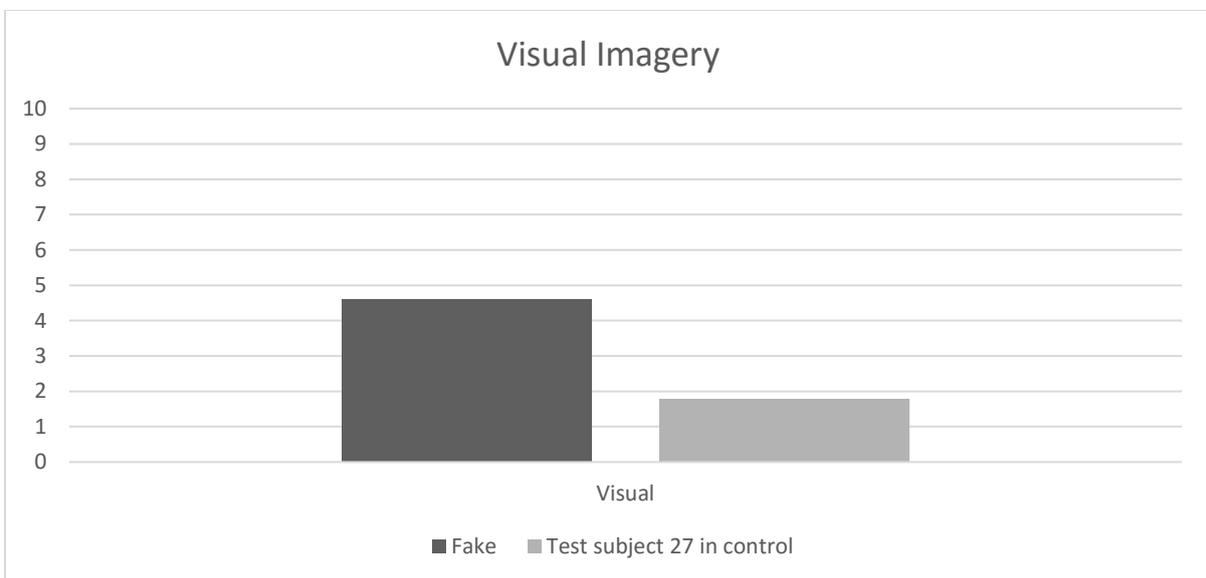


Figure 81 Average visual imagery control scores for test subject 27

12.6.9 Test subject 28

The average control scores from the motor imagery rounds: 1 while in control, 3.6 while not in control. Average scores from the visual imagery rounds: 1 while in control, 3.4 while not in control. Test subject 28 reported lower control scores while in control during motor imagery rounds, and lower control scores while in control during visual imagery rounds.

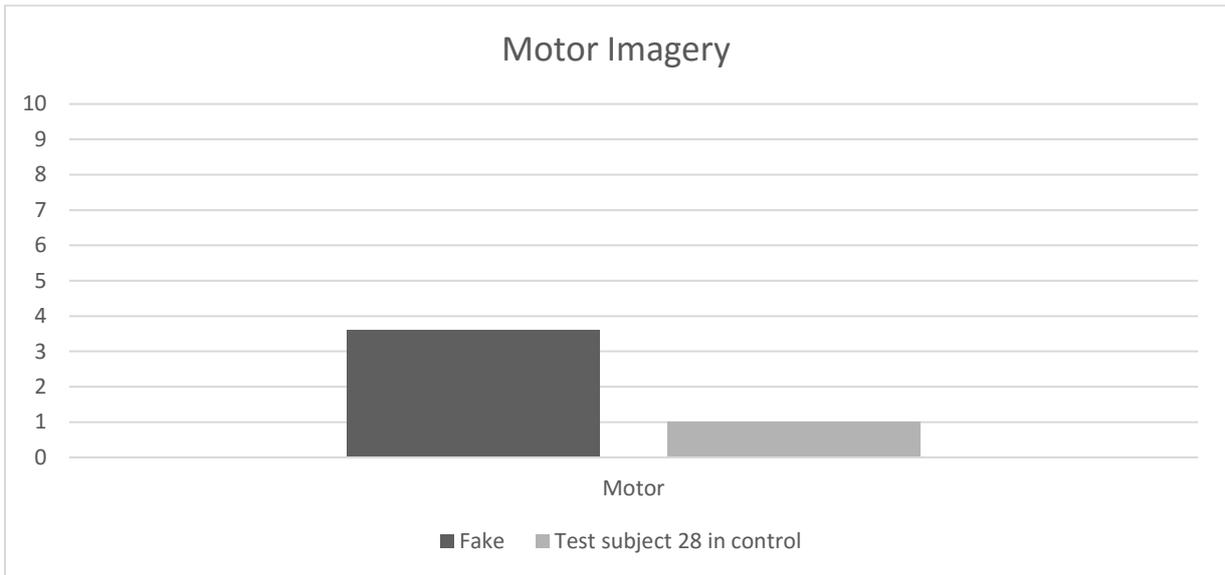


Figure 82 Average motor imagery control scores for test subject 28

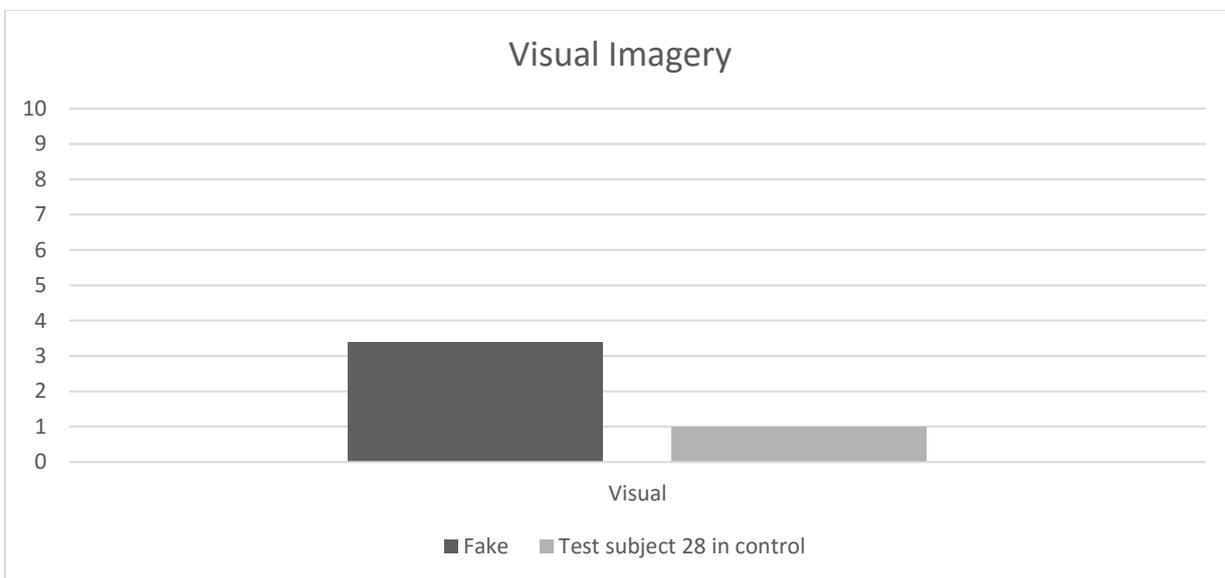


Figure 83 Average visual imagery control scores for test subject 28

12.6.10 Test subject 29

The average control scores from the motor imagery rounds: 1.8 while in control, 3.4 while not in control. Average scores from the visual imagery rounds: 2.8 while in control, 3 while not in control. Test subject 29 reported lower control scores while in control during motor imagery rounds, and lower control scores while in control during visual imagery rounds.

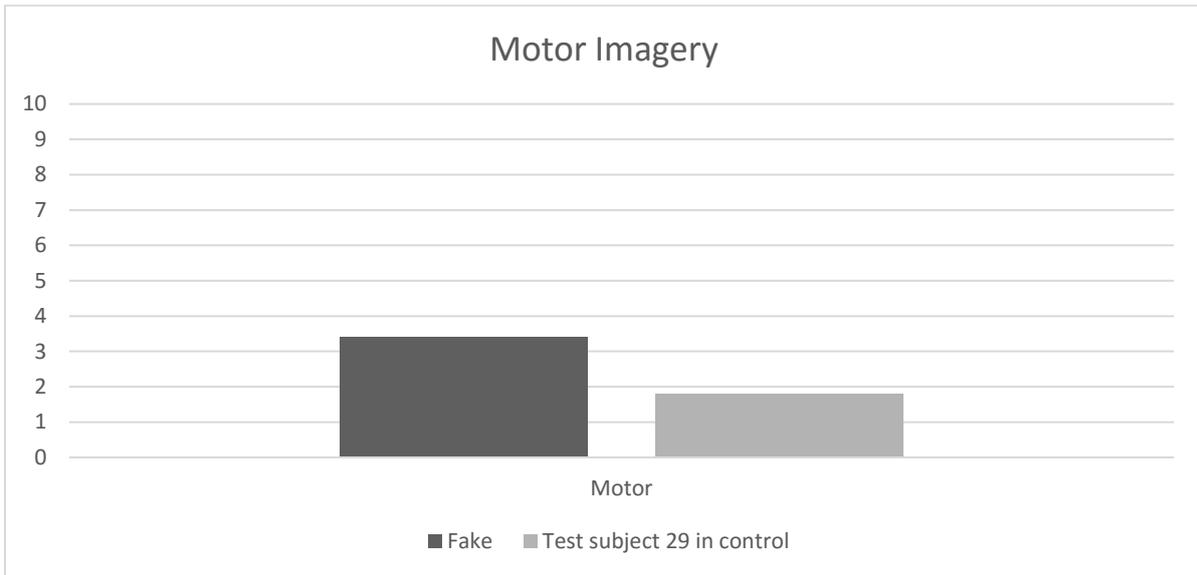


Figure 84 Average motor imagery control scores for test subject 29

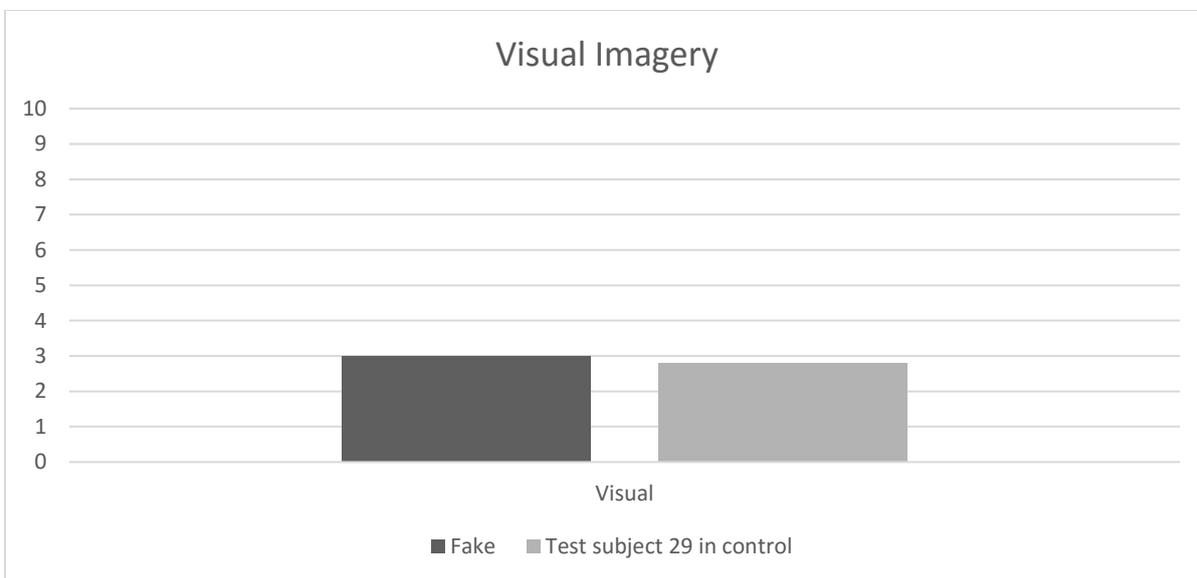


Figure 85 Average visual imagery control scores for test subject 29

12.6.11 Challenge mode scores

In the last part of each test, each test subject played 3 rounds of “challenge mode” and their scores for each round is added to the high score list. The test subjects were asked to choose between motor or visual imagery. I allowed the test subjects to switch from either motor or visual imagery in between rounds of challenge mode if they wanted.

Some players decided to just play one or two rounds rather than three rounds.

4 of 10 test subjects (Number 20,22,24 and 25) only used motor imagery, 3 of 10 test subjects (Number 21,23,29) only used visual imagery and 3 of 10 test subjects (Number 26,27,28) switched between motor and visual imagery. A total of 12 rounds were played with motor imagery and 13 rounds were played with visual imagery.

12.6.12 Challenge mode high scores:

Player ID	Score
Motor24	134562
Symbol29	127218
Motor22	113081
Symbol29	101326
Symbol26	84152
Motor22	77902
Motor25	77637
Motor20	62923
Motor25	61158
Symbol21	60984
Motor25	54305
Motor27	54205
Symbol26	48641
Motor20	34879
Symbol23	23007
Symbol27	18910
Symbol29	14247
Symbol27	12968
Symbol23	12329
Motor27	11057
Symbol28	9721
Symbol26	6102
Symbol23	4271
Motor28	4188
Motor26	3124

Table 2 Challenge mode high scores from pre-test iteration 2.

12.7 Discussion pre-test iteration 2

The results from this test was similar to the previous test (pre-test iteration 1) in that motor imagery and visual imagery performed almost the same.

4 of 10 test subjects reported lower control scores when in control for both motor imagery and visual imagery.

3 of 10 test subjects reported lower control scores when in control during visual imagery but not in motor imagery.

2 of 10 test subjects reported lower control scores when in control during motor imagery but not in visual imagery.

1 of 10 test subjects reported the same control scores for both motor imagery and visual imagery regardless of in control or not (very rare).

The conclusion from pre-test iteration 1 was that when combining the results from the pilot test and pre-test iteration 1, and disregarding the difference in the testing environment in the pilot test and pre-test iteration 1, there is no difference between motor imagery and visual imagery when measuring confirmation bias. And if you combine the 16 test subjects from the pilot test and pre-test iteration 1 with the 10 test subjects from pre-test iteration 2 (disregarding the difference in the testing environment in the pilot test):

12 of 26 test subjects reported higher control scores when not in control for motor.

13 of 26 test subjects reported higher control scores when not in control for visual.

1 of 26 test subjects reported the same control scores for both.

It is possible that switching from two test subjects each round in the pilot test and pre-test iteration 1 to one test subject in pre-test iteration 2 makes it impossible to combine the results from the pilot test and pre-test iteration 1 with pre-test iteration 2. The test subjects also started using earplugs in pre-test iteration 2. Even so, the results from the pilot test and pre-test iteration 1 combined gives a similar result compared with the results from pre-test iteration 2: No significant difference between motor and visual imagery.

After discussing the results with my supervisor, a different procedure was made for the Bonus test at SpillExpo which was arranged at HiOA Gaming's stand at SpillExpo (Norgesexpo AS, 2017). SpillExpo is the largest gaming expo in Norway. Because the stand was used to promote HiOA as a school and HiOA Gaming as a student organization, I had to use a different game that could compete with the other games at the expo. Nobody would want to play a silly 2d-game (FlappyBrain) if there is any "cooler" games around.

After some brainstorming I decided to use a HTC Vive virtual reality headset (HTC Corporation, 2017) combined with the Emotiv Insight to control the very popular game Minecraft (Mojang AB, 2017) (With the Vivecraft (Vivecraft, 2017) mod) using brain control while in Virtual reality . This setup would be able to compete with anything at SpillExpo. I made a guide on how to set up this combination on YouTube (TurboDevs AS, 2017), which is the first video on YouTube showing a combination of the Vive and an Emotiv headset.

12.8 Conclusion pre-test iteration 2

When combining the results from Pilot test, pre-test iteration 1 and pre-test iteration 2, disregarding the difference in the testing environment, there is no significant difference between motor imagery and visual imagery when measuring confirmation bias.

12 of 26 test subjects reported higher control scores when not in control for motor.

13 of 26 test subjects reported higher control scores when not in control for visual.

1 of 26 test subjects reported the same control scores for both.

More tests must be done.

13. Bonus test at SpillExpo report

13.1 Method:

In this test I did not want to test for confirmation bias, I just wanted to know if the test subjects preferred to play Minecraft in virtual reality using brain control with either motor imagery or visual imagery. The goal of this test was to see if there was a significant difference between choice of motor imagery and visual imagery.

SpillExpo 2016 estimated to have 20.000 visitors, which gives me a nice pool of randomly selected test subjects who happen to wander by the HiOA Gaming stand.

13.2 Equipment:

I used a computer with Minecraft (Mojang AB, 2017) and the Vivecraft mod (Vivecraft, 2017) installed and the HTC Vive VR headset (HTC Corporation, 2017).

I use the Emotiv insight headset for this test as the Emotiv EPOC is too large and will not fit under the HTC Vive VR headset. One might be able to mod their own mounting solution for the virtual reality headset that can allow the Emotiv EPOC and HTC Vive to be used together for this test.

The figure on the next page shows how the equipment is configured.

Monitor A1 shows the Emotiv control panel and is used to display symbols when recording and to mirror Minecraft when playing.

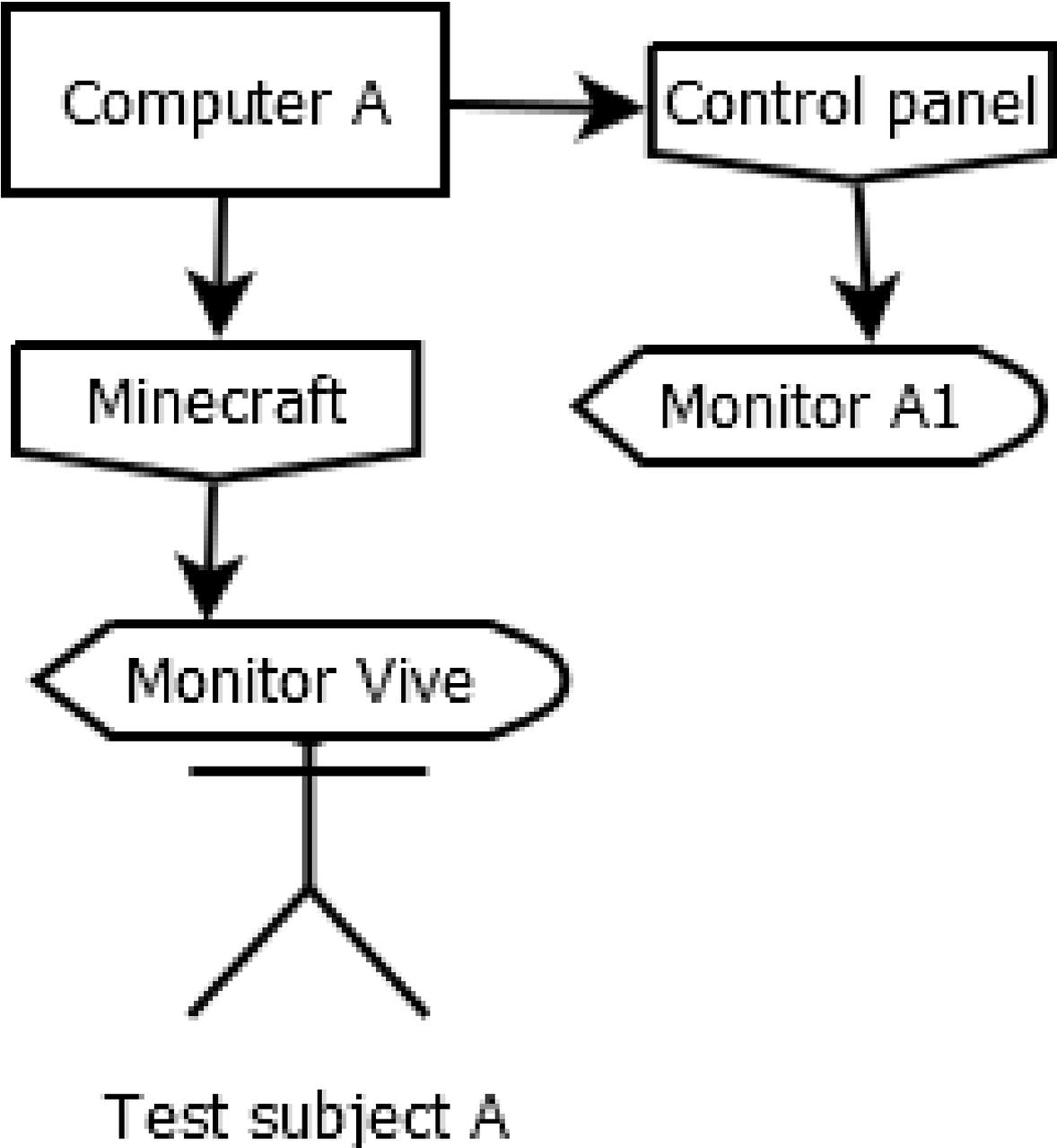


Figure 86 Equipment configuration for bonus test at SpillExpo.

13.3 Test protocol:

The test subjects are told that they will be testing brain controlled Minecraft in virtual reality. The game is played as usual but with the flying button (spacebar) linked to a specific thought recorded in Emotiv Control Panel by using EmoKey (The same tools used in the Pilot test, pre-test iteration 1 and pre-test iteration 2).

13.4 Recording:

The method for recording in this test is the same as in the Pilot test, pre-test iteration 1 and pre-test iteration 2.

13.5 Playing and gathering data:

After the test subject is finished with the recordings, the instructor displays the spectator window for Minecraft that mirrors what is happening inside the Vive on Monitor A1. The instructor then asks the test subject to try thinking about “lift” using motor imagery and then visual imagery, to check if the control is working. When it is confirmed that the control is working and the game character in Minecraft is flying (remember to use “creative” game mode to enable flying), the instructor will ask the test subject to move to the designated virtual reality play area.

The instructor then helps the test subject with attaching the virtual reality headset over the Emotiv Insight headset. The instructor then checks that all sensors of the Emotiv Insight is marked with green colour to indicate a good signal after the virtual reality headset has been attached. Reposition the Emotiv Insight if necessary.

When the Emotiv Insight and virtual reality headset has been attached properly, ask the test subject to first try flying up using motor imagery and afterwards with visual imagery.

Repeat three times so that the test subject have tried flying using motor and visual imagery three times. Then ask the test subject if he or she wants to play Minecraft in virtual reality for 10 minutes using either motor or visual imagery.

13.6 Results and conclusion from Bonus test at SpillExpo

A total of 13 test subjects participated.

6 test subjects preferred to play Minecraft in virtual reality using motor imagery.

6 test subjects preferred to play Minecraft in virtual reality using visual imagery.

1 test subject preferred both equally.

From these results I cannot find any difference between motor and visual imagery preference.

14. Final test report

14.1 Method:

The method was changed slightly after a discussion with my supervisor after pre-test iteration 2 and Bonus test at SpillExpo. In this test the same general method from pre-test iteration 2 applies, with one change:

Rather than presenting “FlappyBrain” as a game, I presented it as a “calibration tool” that was necessary for the test subjects to use before they could play Minecraft with mind control in VR with the HTC Vive (which was also used in the bonus test at SpillExpo).

Like before, I will explain how this variant was set up so that you can re-create the experiments.

14.2 Equipment

I decided to use one Emotiv Insight headset in this test as well, because the Emotiv EPOC headsets cannot be used together with the HTC Vive virtual reality headset that will be used in the “reward” for the test subjects after the test. Because both the Emotiv Insight and Emotiv EPOC headsets have the same capabilities and uses the same control panel the difference should be negligible.

If someone wants to re-create this test they can use the Emotiv EPOC instead without any change in the method or procedure except for using the Emotiv EPOC and HTC Vive together in the “reward” as I did. One might be able to mod their own mounting solution for the virtual reality headset that can allow the Emotiv EPOC and HTC Vive (or equivalent VR headset) to be used together for the reward after the test. In addition to an Emotiv Insight headset, one would need a computer that fills the requirements for both the Emotiv Insight and HTC vive. If the computer is a desktop, it must have at least two video outputs which will allow it to be connected to two monitors simultaneously. If you are using a laptop, it must have at least one video output for it to be connected to a monitor in addition to the laptop screen. The figure below shows how the equipment is configured.

Monitor A1 is used for displaying symbols when recording, displaying the calibration tool (FlappyBrain) and displaying the fake calibration tool with a video player.

Monitor A2 is used for the control panel or to mirror A1 during playing if the instructor prefers it (optional).

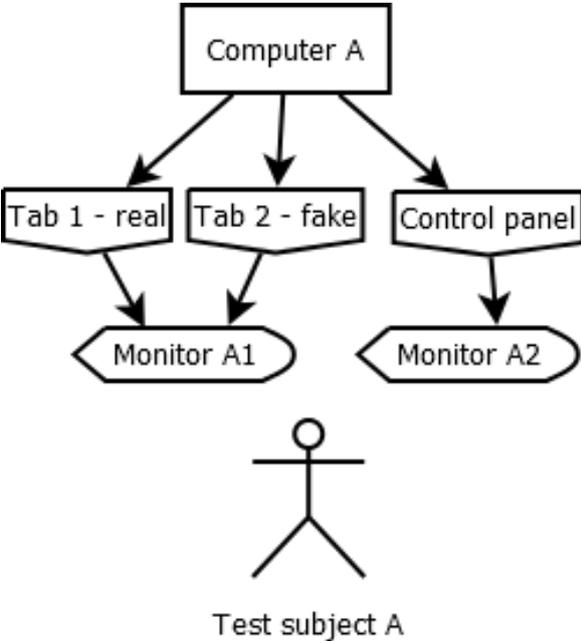


Figure 87 Equipment configuration for the confirmation bias tests in the final test.

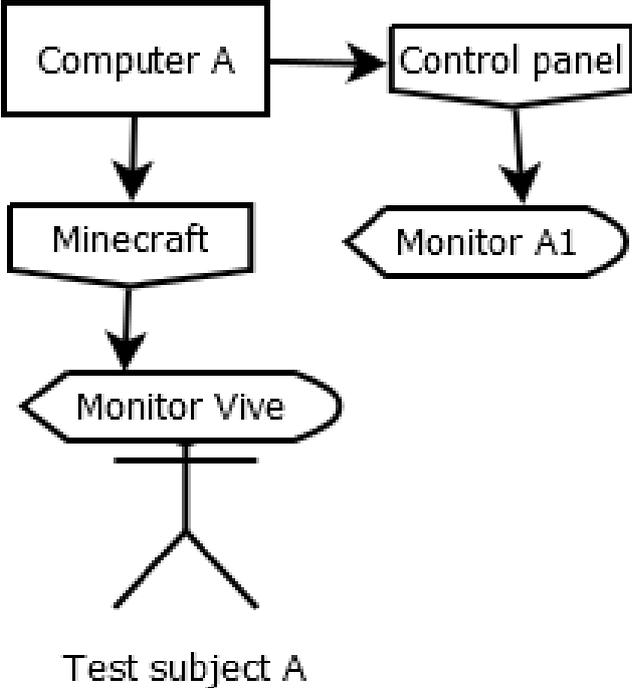


Figure 88 Equipment configuration for the reward after the testing in the final test.

14.3 Test protocol:

The method for controlling the game in this test and Pilot test, pre-test iteration 1 and pre-test iteration 2 are the same.

One change from pre-test iteration 2 is that I do not present “FlappyBrain” as a “game” but as a “calibration tool” for playing Minecraft with “mind control” in VR using the HTC Vive and Emotiv Insight together. All 21 test subjects in this test understood the purpose of a calibration tool. I made this change in the test protocol after discussing the results of pre-test iteration 2 and Bonus test at SpillExpo with my supervisors. By changing the presentation of “FlappyBrain” as a “game” where the test participants compete against each other, to a “calibration tool” where their scores will not be compared to other participants we theorized that it could result in a significant difference in the results (compared to previous tests). If the test subjects did not think of “FlappyBrain” as a game where they had to perform, but a “calibration” where the performance did not matter, it could make the participants more relaxed during testing.

If this change in presentation could result in a significant difference between motor and visual imagery, then it might be important to consider how a BCI test is presented to participants.

Procedure:

Test subject A is told that he or she needs to complete a calibration using a calibration tool called “FlappyBrain” before he or she can play Minecraft in VR with HTC Vive using “mind control” with the Emotiv Insight.

Test subject A plays “FlappyBrain” using motor imagery in 10 rounds and visual imagery in 10 rounds. After the testing is complete, the test subject may put on the HTC Vive over the Emotiv Insight and try flying upwards on using motor and visual imagery. I recommend that the test subjects try both motor and visual imagery in Minecraft to see which of them they would like to use during the play session. Test subject A is actually in control during the Minecraft playing, no fake feedback during Minecraft.

14.4 Recording:

The method for recording in this test is the same as in Pilot test, pre-test iteration 1, pre-test iteration 2 and the Bonus test at SpillExpo.

14.5 Playing and gathering data:

Before launching FlappyBrain, the instructor will ask the player to take a short break, close his or her eyes and relax while the game is prepared.

While the test subject has his or her eyes closed, the instructor will alt-tab to either FlappyBrain in a web browser in full screen mode (F11 key) or a full screen video of a round of FlappyBrain shown on Monitor A1. If the instructor wants to, he or she can mirror monitor A1 to monitor A2 during playing (optional).

I recommend the open source media player “VLC media player” (VideoLAN, 2017) for displaying the fake rounds of FlappyBrain, with “On Screen Display” turned off to hide the media buttons in full screen. This will make switching between FlappyBrain in a full screen browser and a full screen video in VLC indistinguishable. Ask the player to take a short break and close his or her eyes in between each round before switching between the real game and the video. I recommend that you have five fake videos in a playlist in VLC so that you can skip to the next one when needed. The hotkey “N” in VLC Media player can be used to go to the next video in a playlist.

The test subjects will be given earplugs to prevent disturbances while playing.

The test subjects are told before the games starts that after each round they have to put down a number between 1 and 10 in “Table 1” to indicate how much control over the game character they felt they had on a scale from 1 to 10.

The test subjects are also told to then relax with their eyes closed until they feel a tap on the shoulder from the instructor which is a signal to tell them that the next round starts in 10 seconds and that they should open their eyes. 10 seconds after the instructor has tapped the test subject on the shoulder, the instructor either hits “F5” button on the computer to reload the game or “spacebar” to play the movie. The test subject plays 5 rounds of FlappyBrain and spectates 5 rounds of recorded FlappyBrain footage where the test subject might think he or she is in control of FlappyBrain.

14.6 Results from the Final test

I will go through the results of the 21 test subjects who participated in this test. Because this test did not have pairs, I will only discuss the results for each test subject because the game-scores during the fake rounds; round 4 to 6 and 9 to 10, were always the same for each test subject: 3, 3, 9 and 3, 7 respectively. The test subjects have been numbered 40 to 60 to prevent mix-ups with previous tests subjects.

14.6.1 Test subject 40

The average control scores from the motor imagery rounds: 4 while in control, 5.2 while not in control. Average scores from the visual imagery rounds: 6 while in control, 5.4 while not in control. Test subject 40 reported higher control scores while not in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

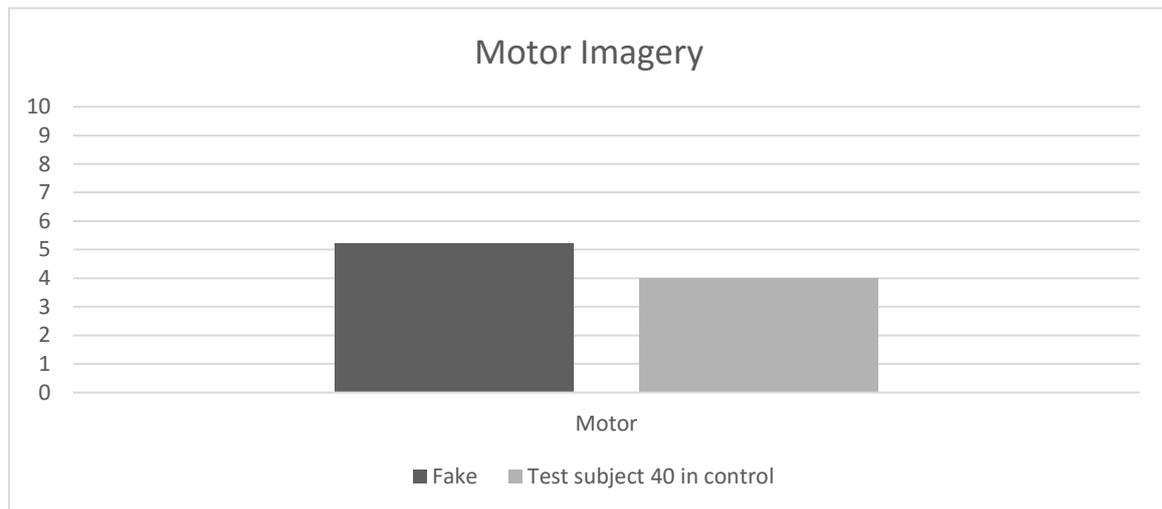


Figure 89 Average motor imagery control scores for test subject 40

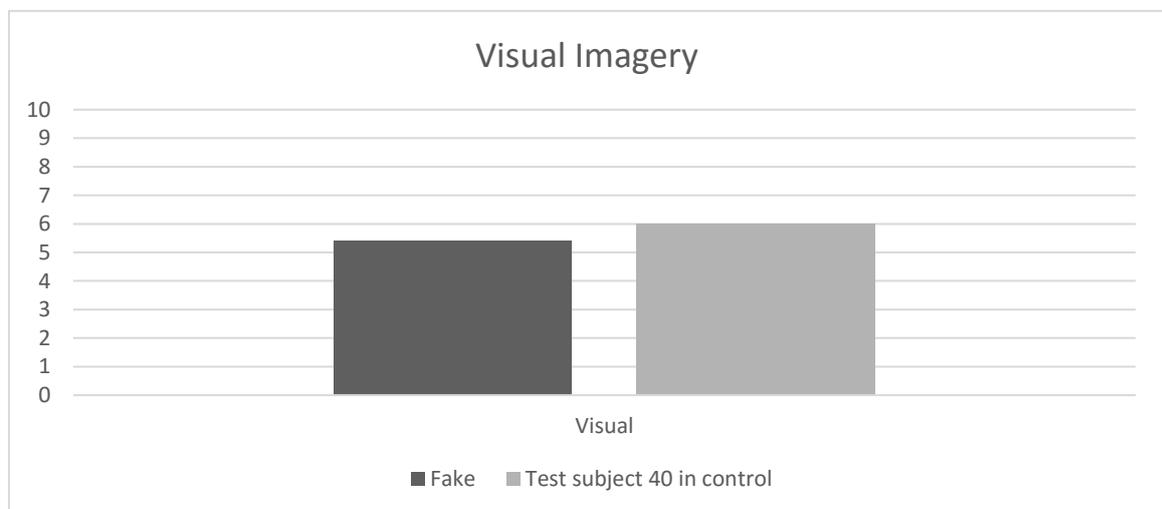


Figure 90 Average visual imagery control scores for test subject 40

14.6.2 Test subject 41

The average control scores from the motor imagery rounds: 5 while in control, 6 while not in control. Average scores from the visual imagery rounds: 4.2 while in control, 5.2 while not in control. Test subject 41 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

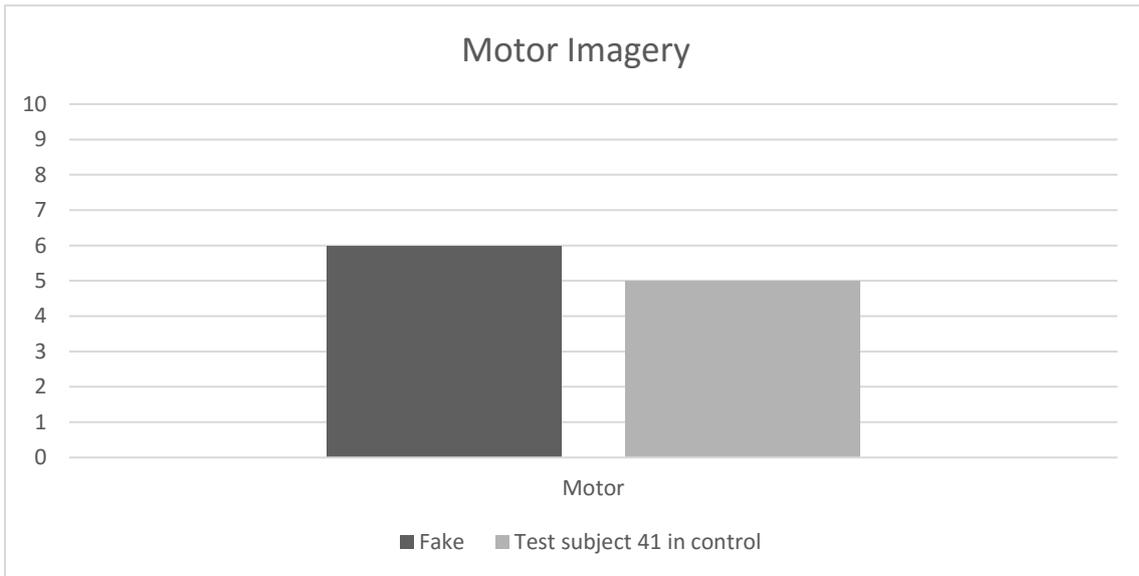


Figure 91 Average motor imagery control scores for test subject 41

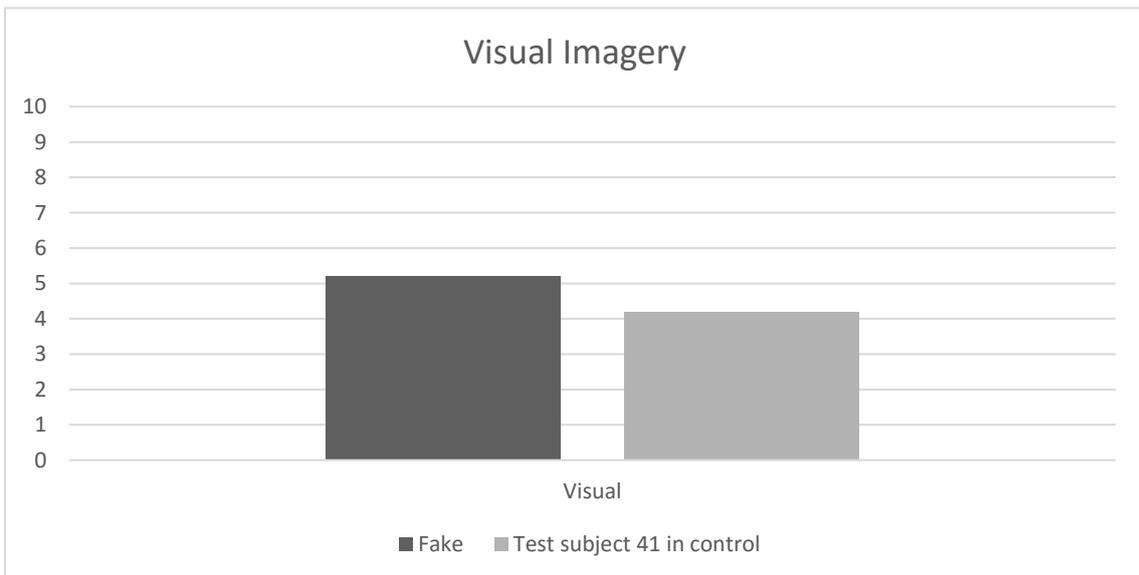


Figure 92 Average visual imagery control scores for test subject 41

14.6.3 Test subject 42

The average control scores from the motor imagery rounds: 6 while in control, 3 while not in control. Average scores from the visual imagery rounds: 4.4 while in control, 3.4 while not in control. Test subject 42 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

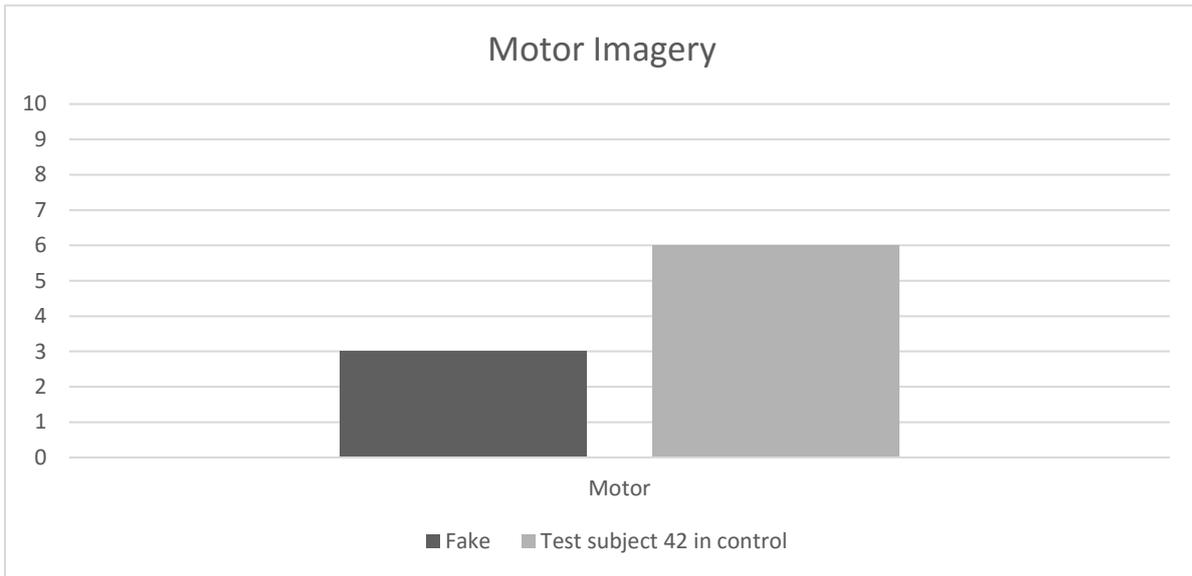


Figure 93 Average motor imagery control scores for test subject 42

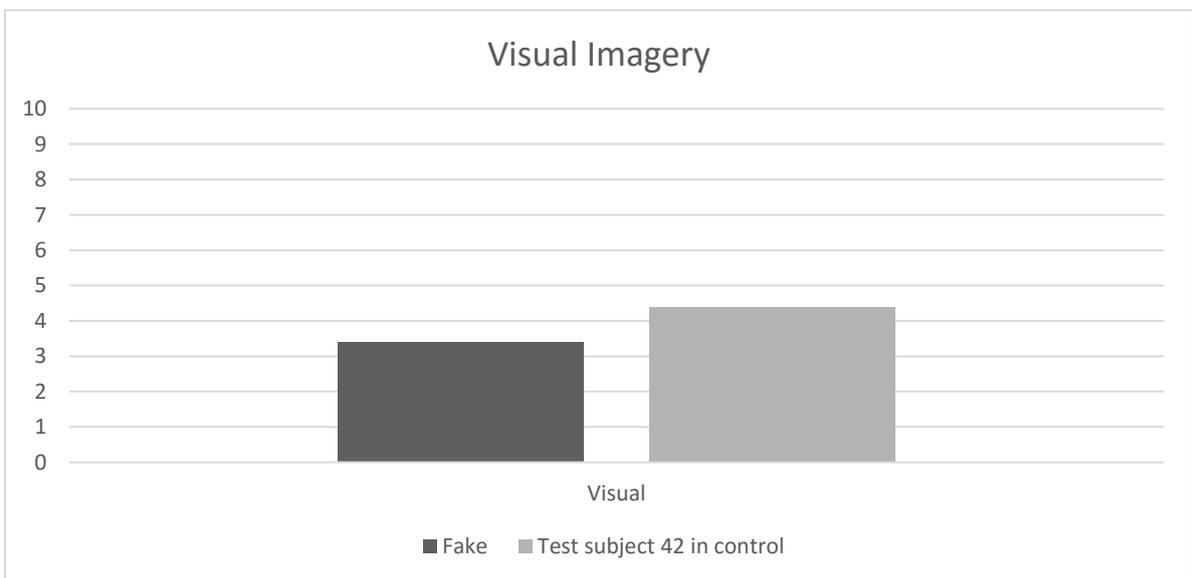


Figure 94 Average visual imagery control scores for test subject 42

14.6.4 Test subject 43

The average control scores from the motor imagery rounds: 3.4 while in control, 4.6 while not in control. Average scores from the visual imagery rounds: 6.2 while in control, 5.4 while not in control. Test subject 43 reported higher control scores while not in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

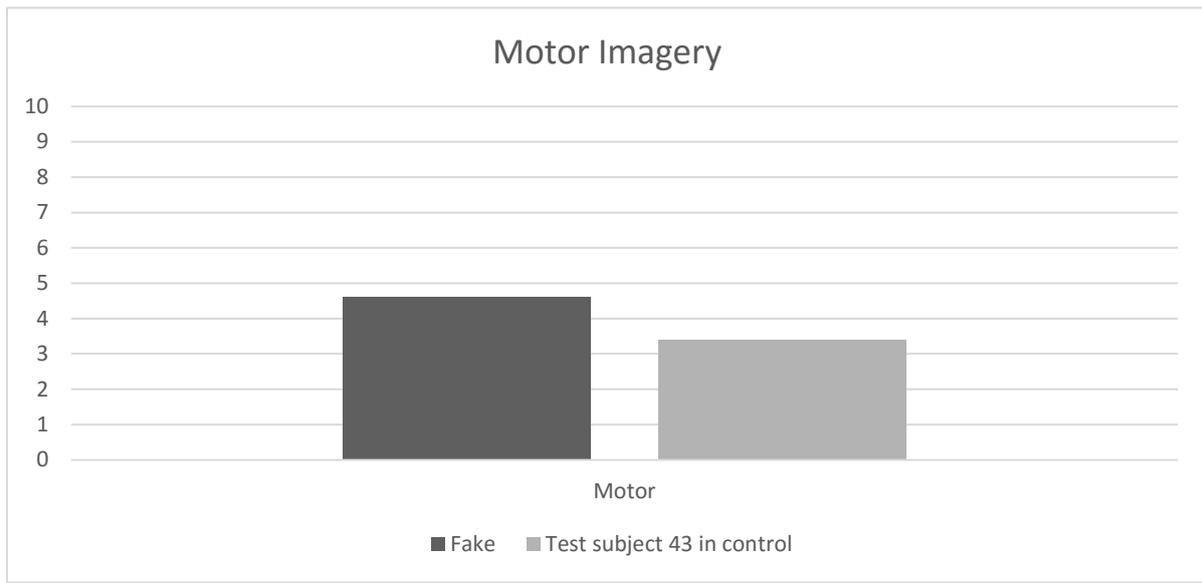


Figure 95 Average motor imagery control scores for test subject 43

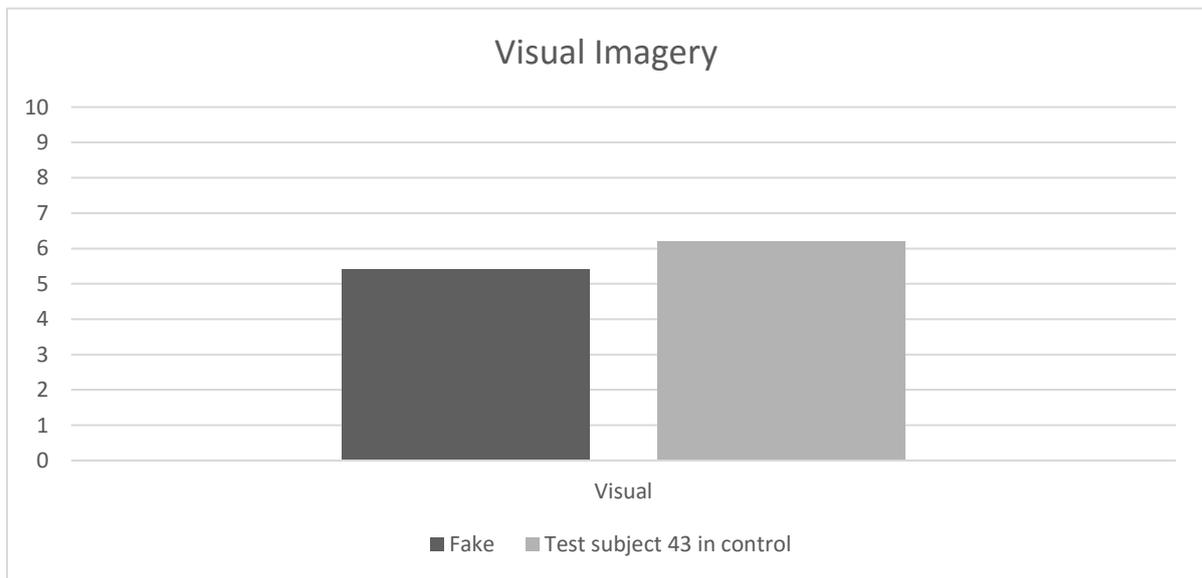


Figure 96 Average visual imagery control scores for test subject 43

14.6.5 Test subject 44

The average control scores from the motor imagery rounds: 2.6 while in control, 2 while not in control. Average scores from the visual imagery rounds: 2.4 while in control, 2.2 while not in control. Test subject 44 reported higher control scores while in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

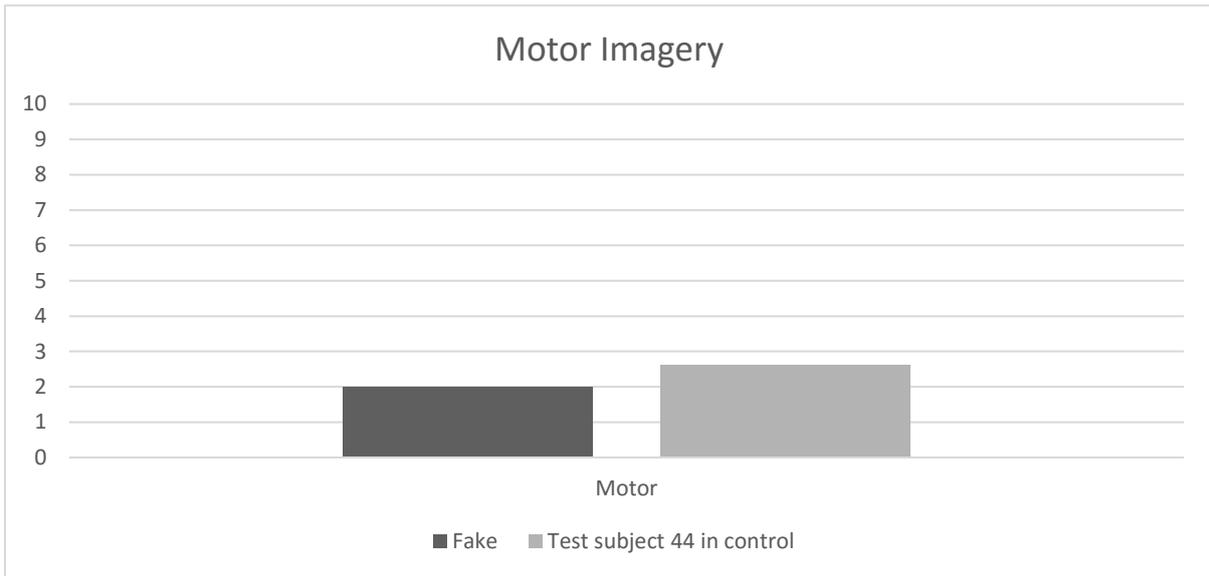


Figure 97 Average motor imagery control scores for test subject 44

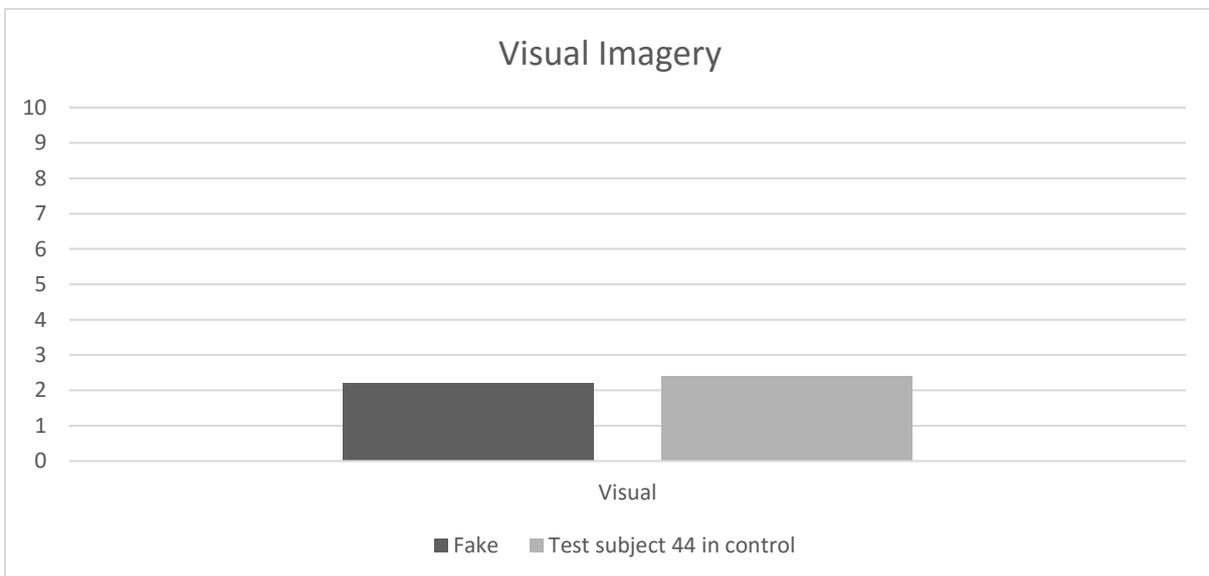


Figure 98 Average visual imagery control scores for test subject 44

14.6.6 Test subject 45

The average control scores from the motor imagery rounds: 6.8 while in control, 4 while not in control. Average scores from the visual imagery rounds: 4.2 while in control, 3.8 while not in control. Test subject 45 reported higher control scores while in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

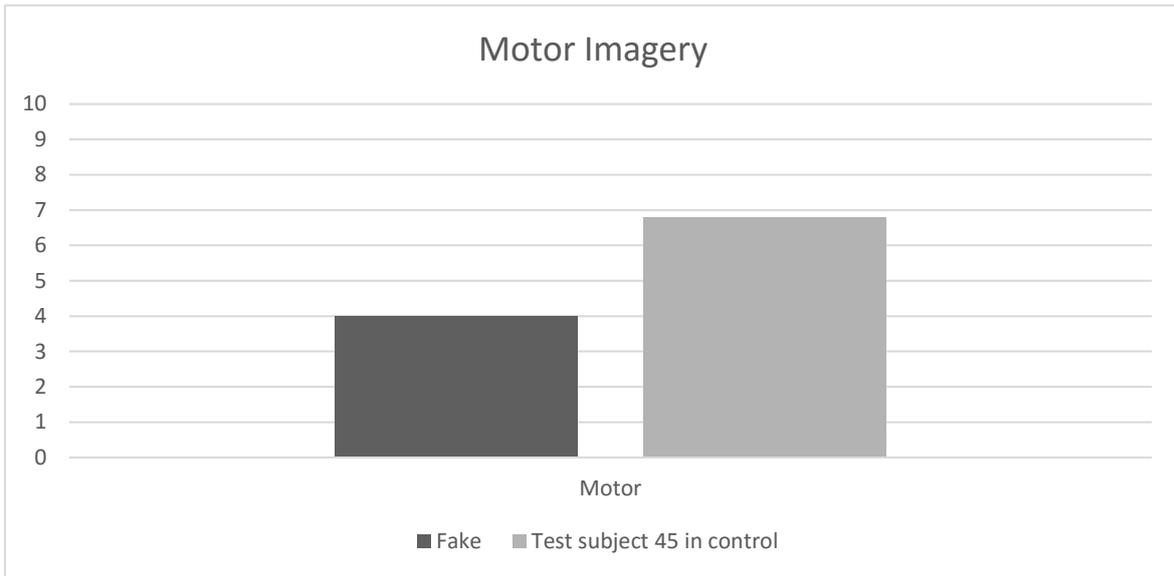


Figure 99 Average motor imagery control scores for test subject 45

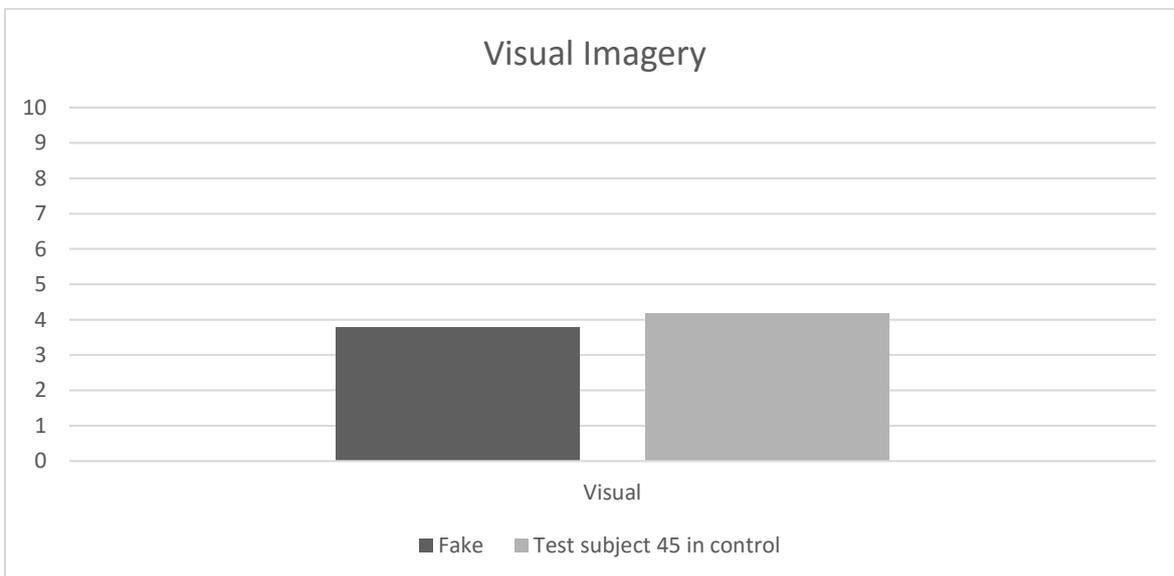


Figure 100 Average visual imagery control scores for test subject 45

14.6.7 Test subject 46

The average control scores from the motor imagery rounds: 3 while in control, 3.4 while not in control. Average scores from the visual imagery rounds: 1 while in control, 1.8 while not in control. Test subject 46 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

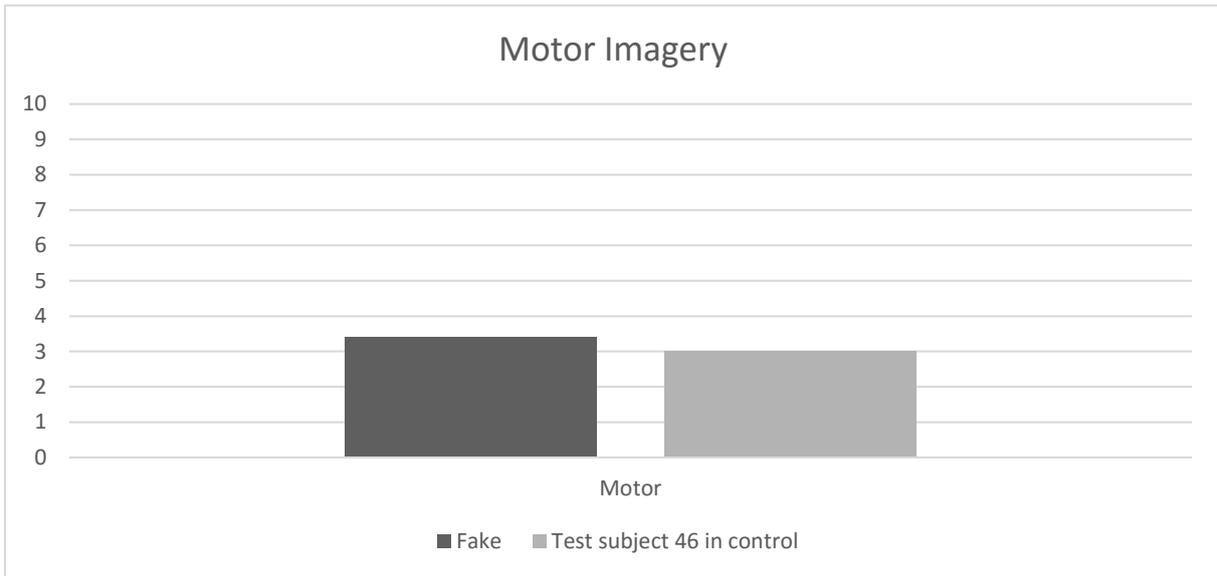


Figure 101 Average motor imagery control scores for test subject 46

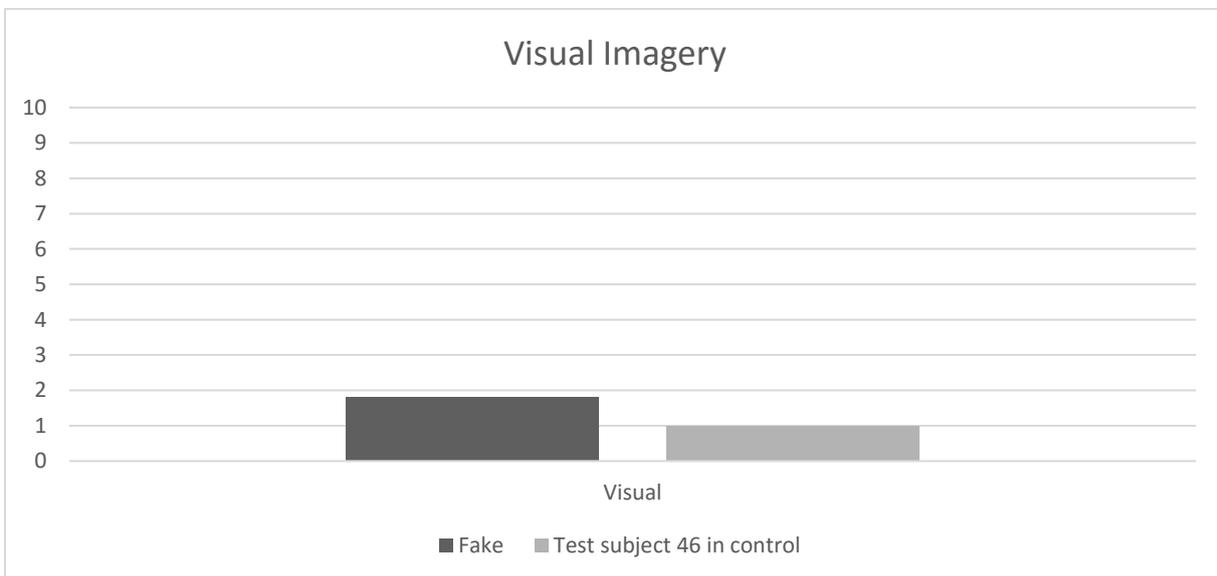


Figure 102 Average visual imagery control scores for test subject 46

14.6.8 Test subject 47

The average control scores from the motor imagery rounds: 1.8 while in control, 1 while not in control. Average scores from the visual imagery rounds: 1 while in control, 1.6 while not in control. Test subject 47 reported higher control scores while in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

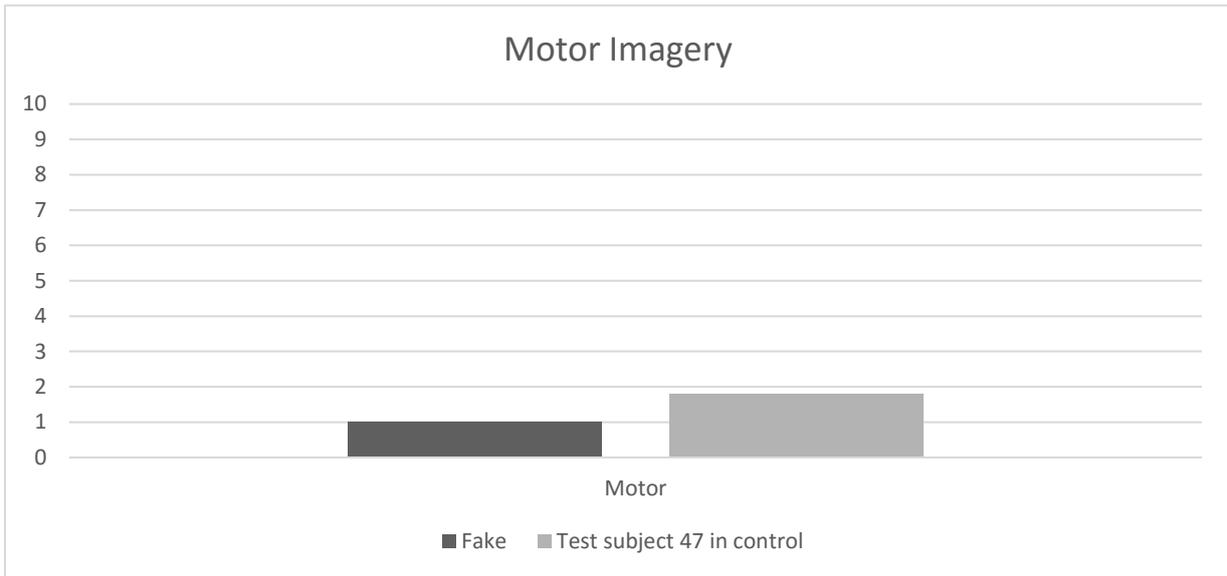


Figure 103 Average motor imagery control scores for test subject 47

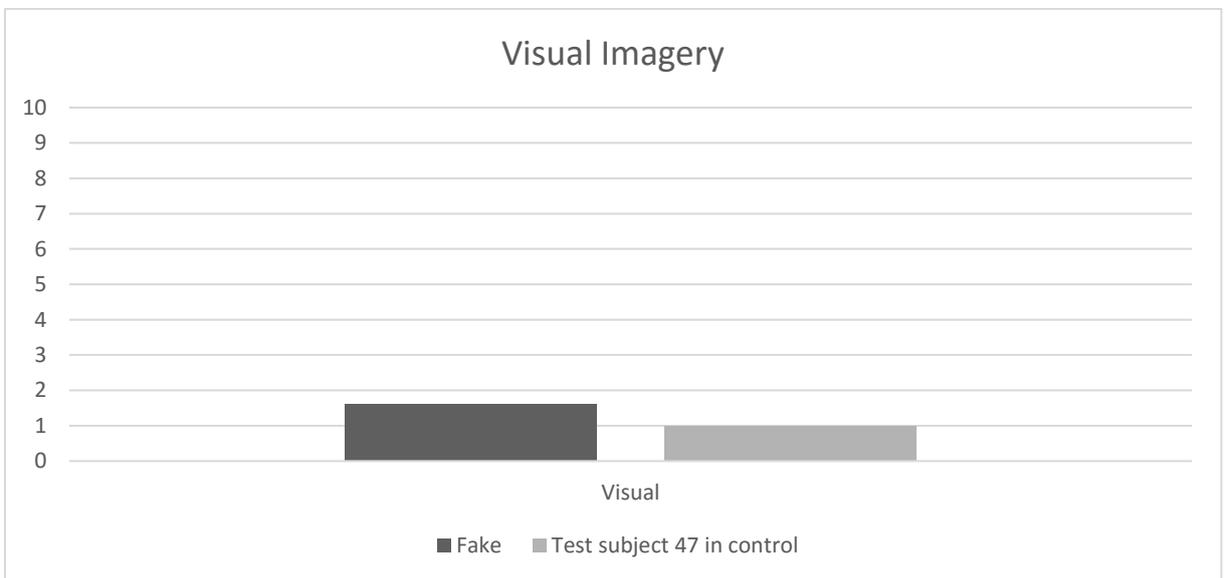


Figure 104 Average visual imagery control scores for test subject 47

14.6.9 Test subject 48

The average control scores from the motor imagery rounds: 5.2 while in control, 5.6 while not in control. Average scores from the visual imagery rounds: 5 while in control, 5.4 while not in control. Test subject 48 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

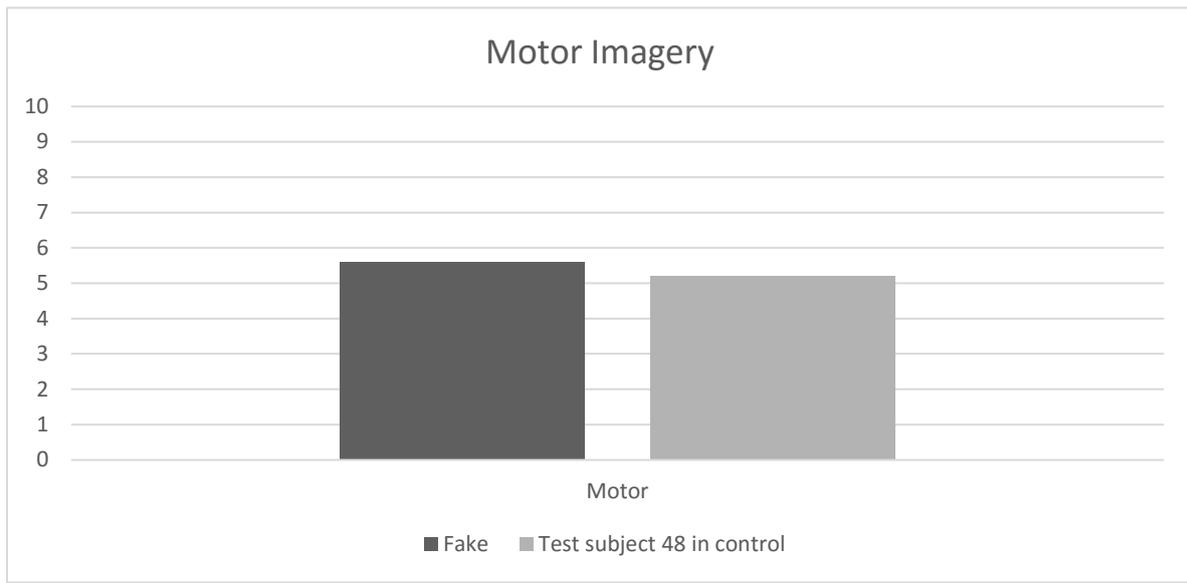


Figure 105 Average motor imagery control scores for test subject 48

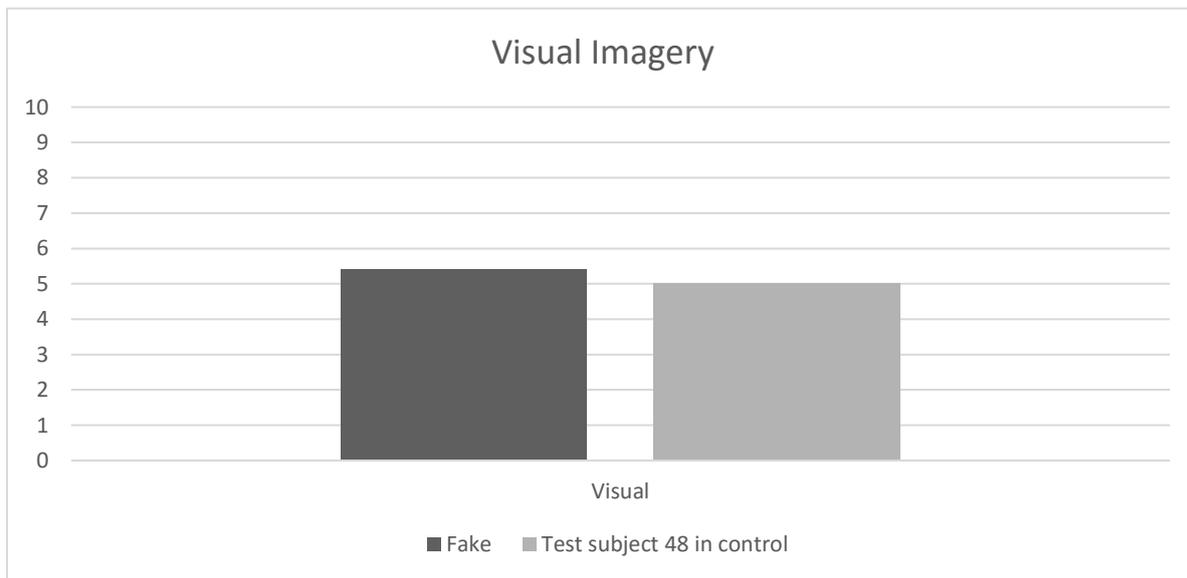


Figure 106 Average visual imagery control scores for test subject 48

14.6.10 Test subject 49

The average control scores from the motor imagery rounds: 3.6 while in control, 3.8 while not in control. Average scores from the visual imagery rounds: 1.2 while in control, 2.8 while not in control. Test subject 49 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

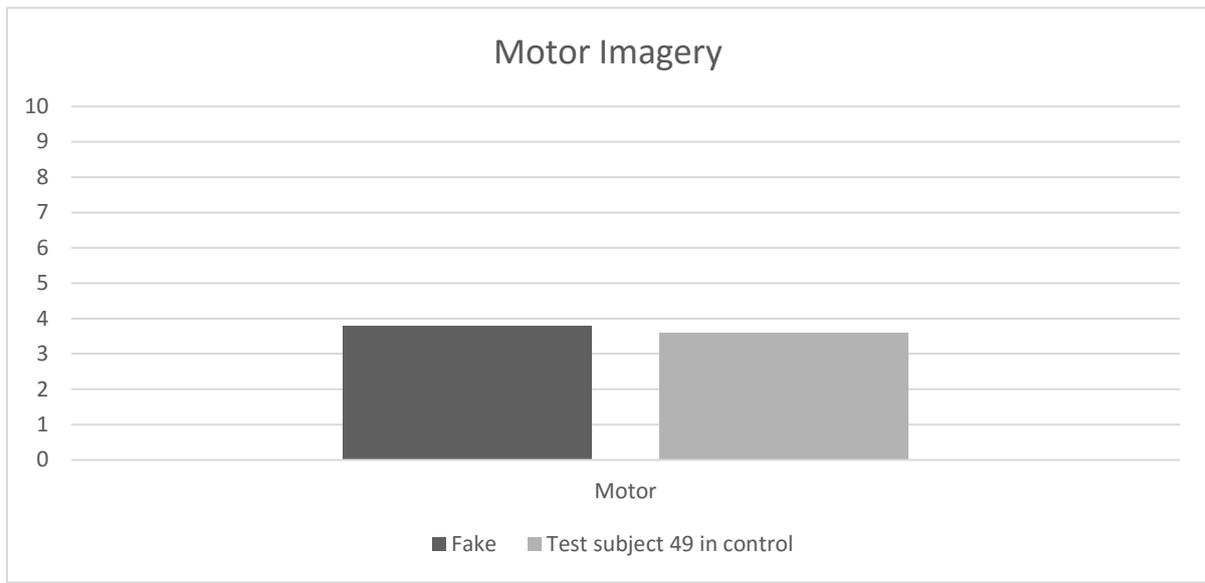


Figure 107 Average motor imagery control scores for test subject 49

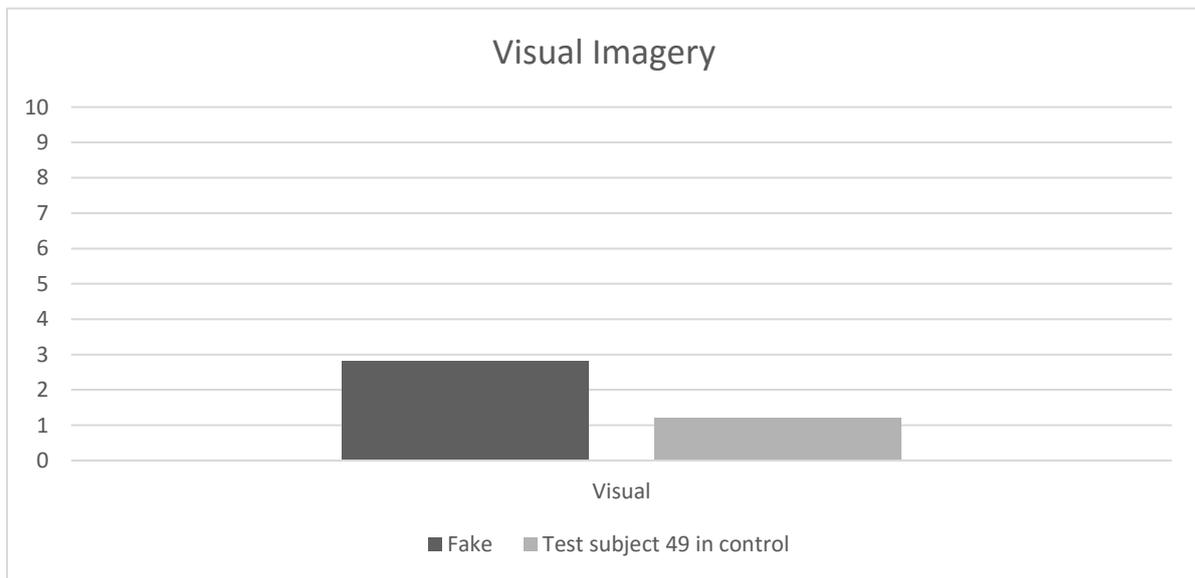


Figure 108 Average visual imagery control scores for test subject 49

14.6.11 Test subject 50

The average control scores from the motor imagery rounds: 1.8 while in control, 4.2 while not in control. Average scores from the visual imagery rounds: 3.8 while in control, 4.6 while not in control. Test subject 50 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

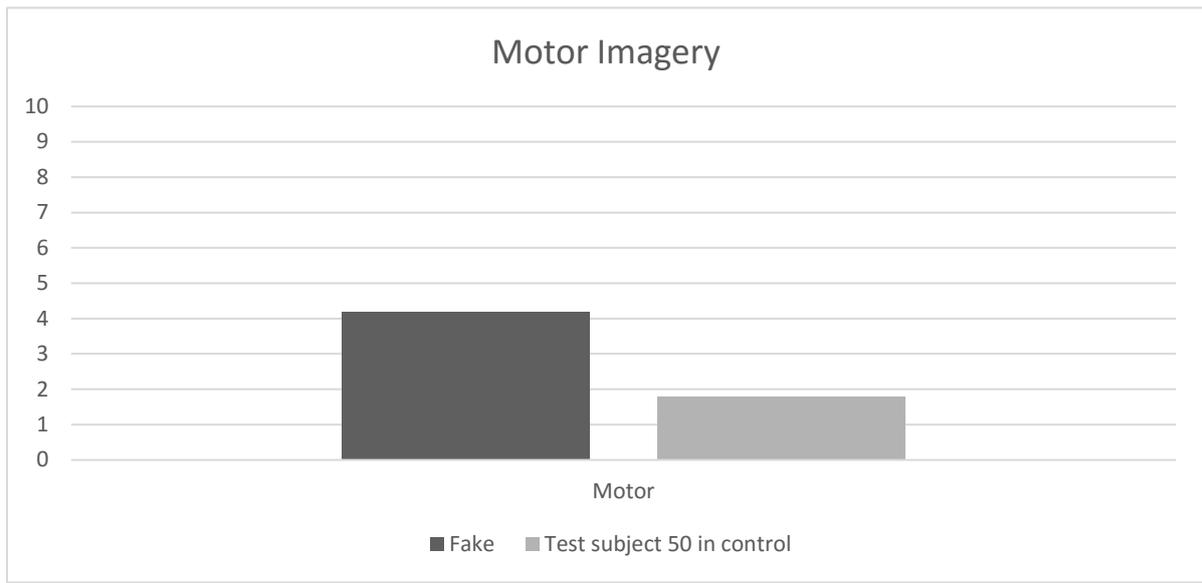


Figure 109 Average motor imagery control scores for test subject 50

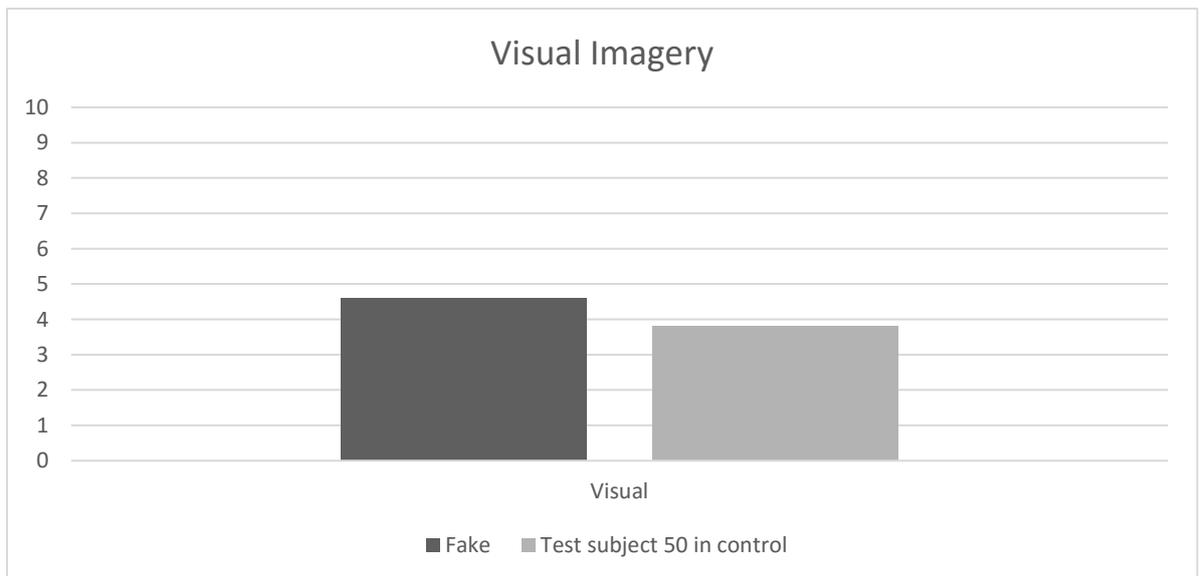


Figure 110 Average visual imagery control scores for test subject 50

14.6.12 Test subject 51

The average control scores from the motor imagery rounds: 5.2 while in control, 2.4 while not in control. Average scores from the visual imagery rounds: 2.4 while in control, 2.4 while not in control. Test subject 51 reported higher control scores while in control during motor imagery rounds, and the same average control scores for when in control and not in control during visual imagery rounds.

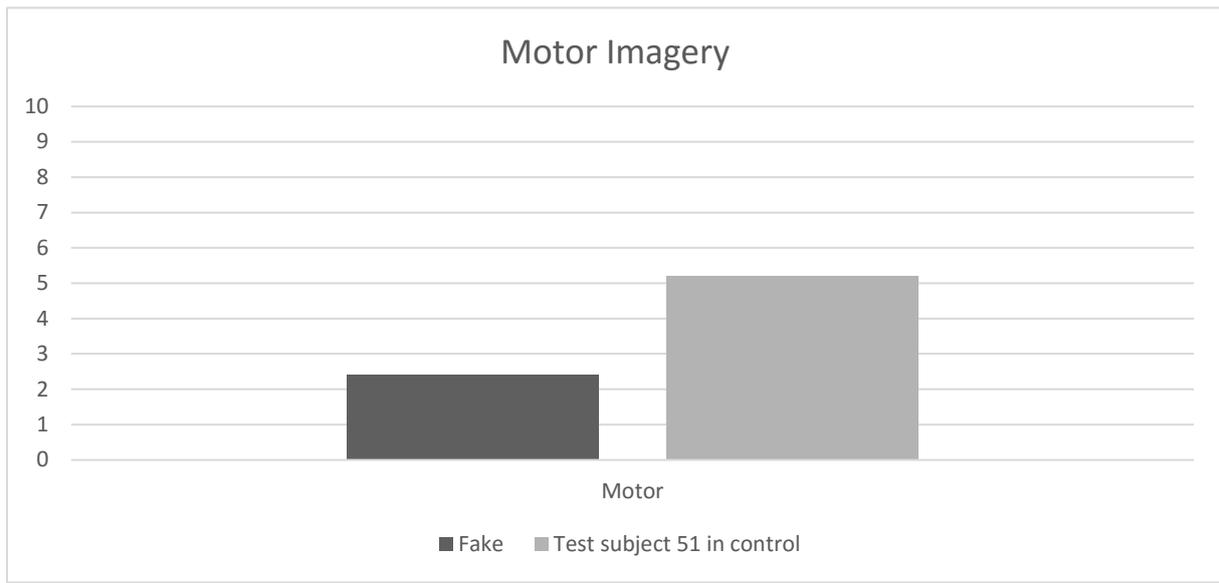


Figure 111 Average motor imagery control scores for test subject 51

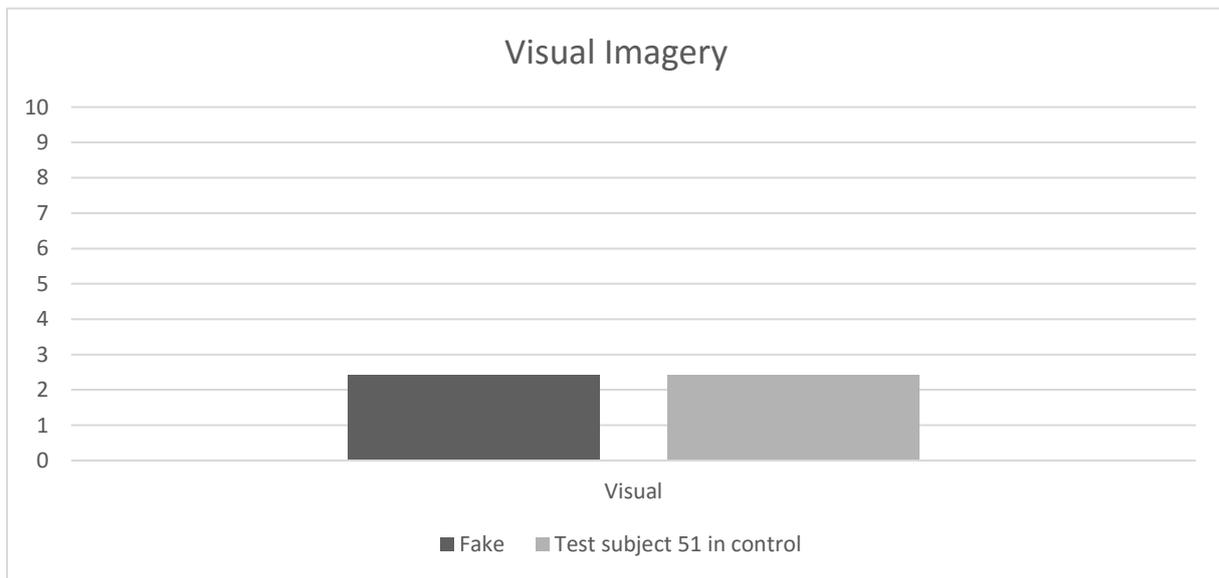


Figure 112 Average visual imagery control scores for test subject 51

14.6.13 Test subject 52

The average control scores from the motor imagery rounds: 2.4 while in control, 2.4 while not in control. Average scores from the visual imagery rounds: 3.8 while in control, 2.8 while not in control. Test subject 52 reported the same average control scores for when in control and not in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

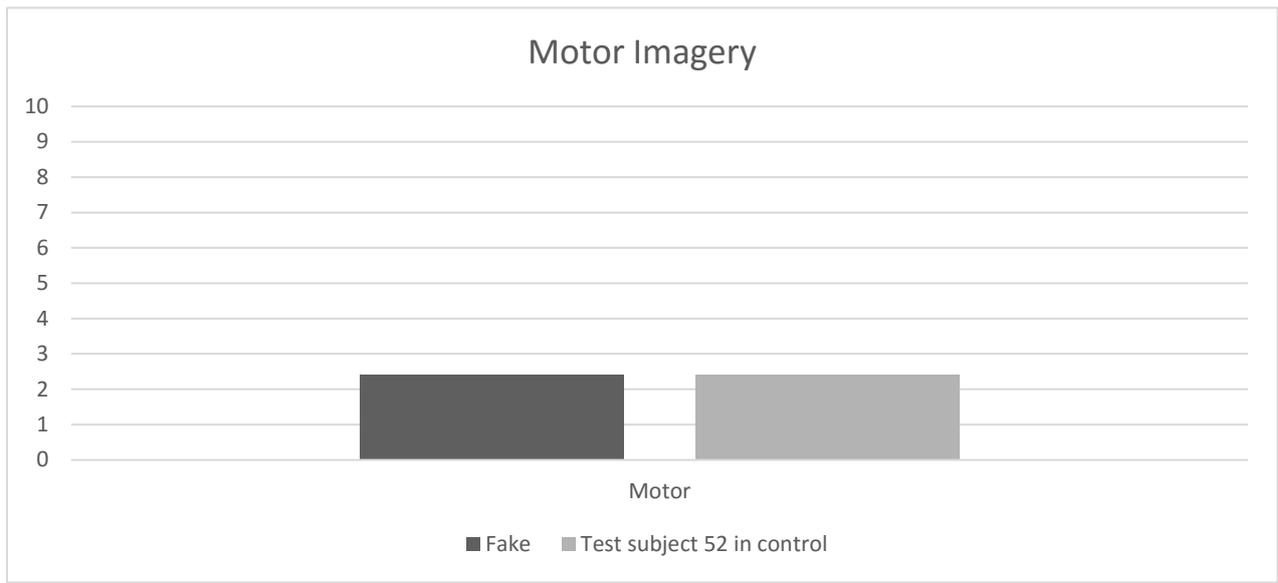


Figure 113 Average motor imagery control scores for test subject 52

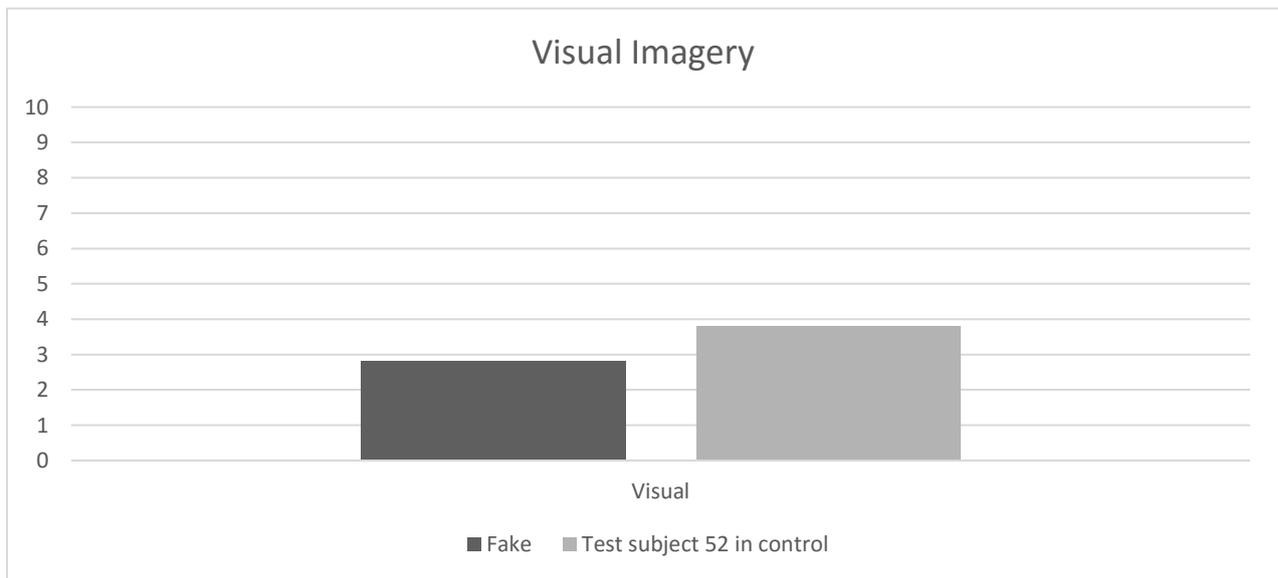


Figure 114 Average visual imagery control scores for test subject 52

14.6.14 Test subject 53

The average control scores from the motor imagery rounds: 6.6 while in control, 3.2 while not in control. Average scores from the visual imagery rounds: 4.6 while in control, 2.8 while not in control. Test subject 53 reported higher control scores while in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

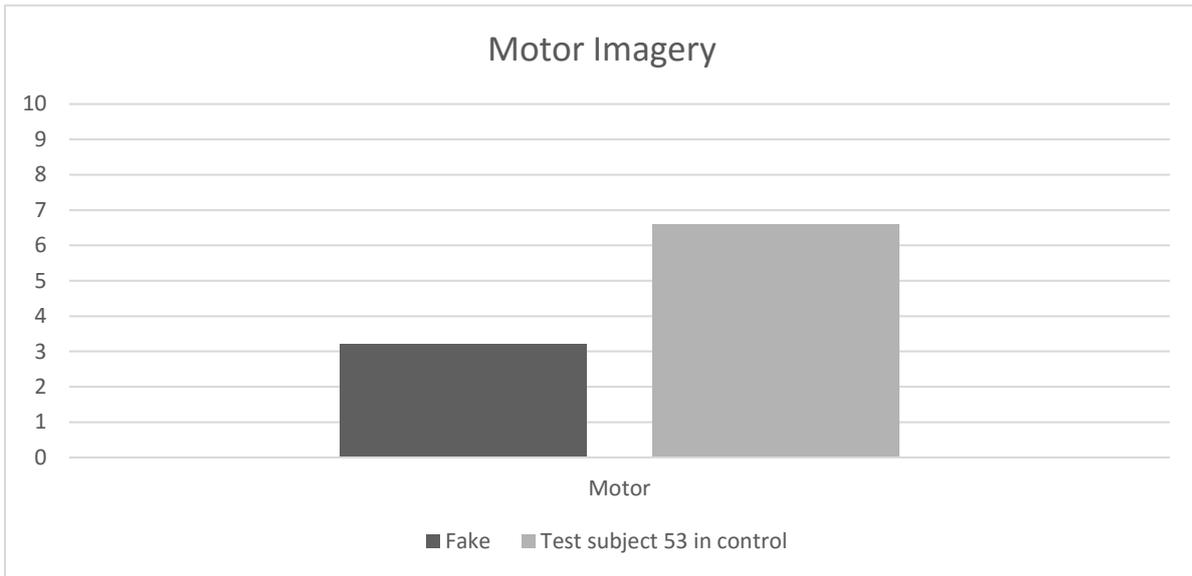


Figure 115 Average motor imagery control scores for test subject 53

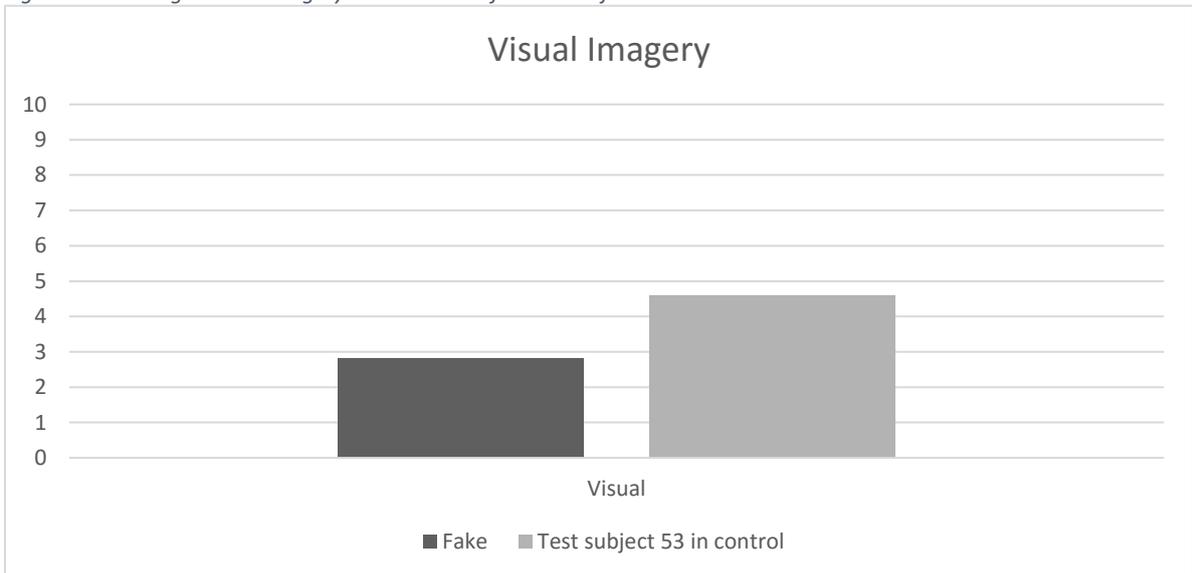


Figure 116 Average visual imagery control scores for test subject 53

14.6.15 Test subject 54

The average control scores from the motor imagery rounds: 6.8 while in control, 4 while not in control. Average scores from the visual imagery rounds: 3.4 while in control, 2.6 while not in control. Test subject 54 reported higher control scores while in control during motor imagery rounds, and higher control scores while in control during visual imagery rounds.

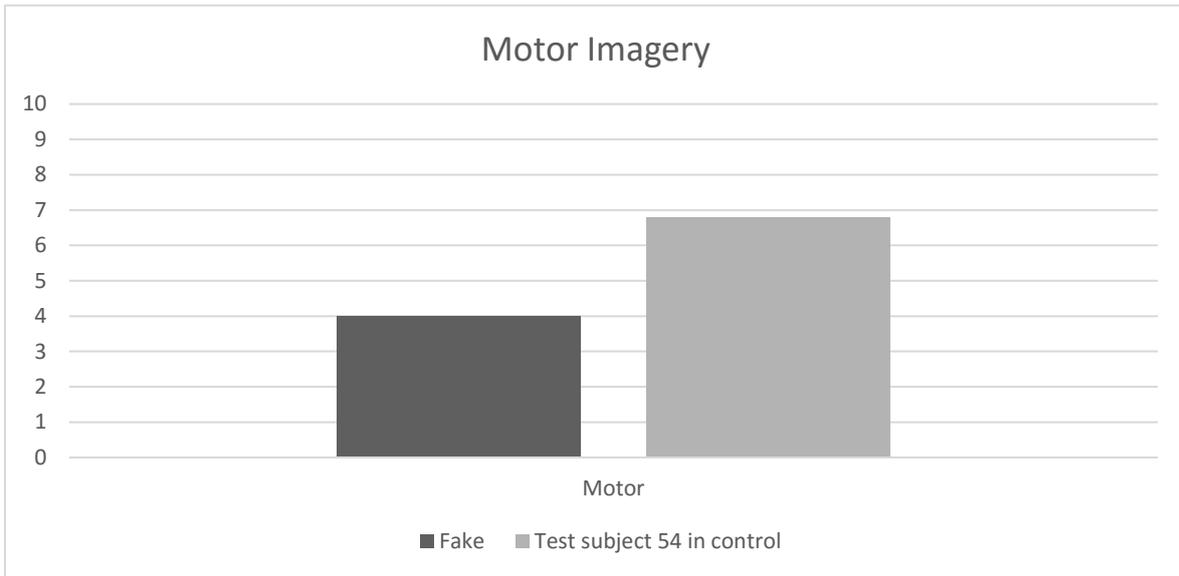


Figure 117 Average motor imagery control scores for test subject 54

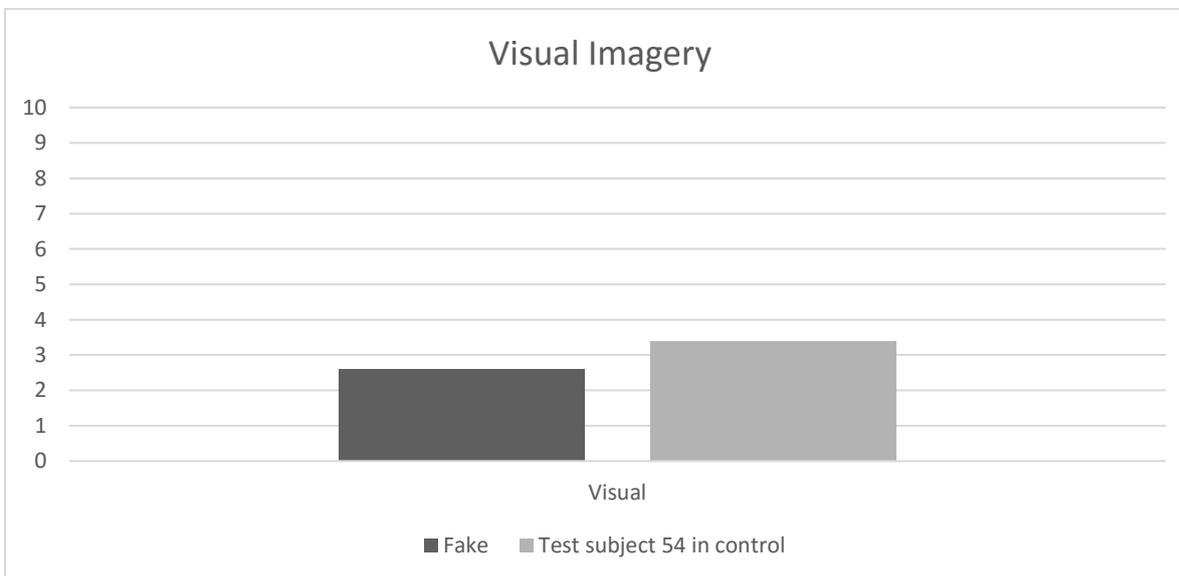


Figure 118 Average visual imagery control scores for test subject 54

14.6.16 Test subject 55

The average control scores from the motor imagery rounds: 3.2 while in control, 3.4 while not in control. Average scores from the visual imagery rounds: 3.2 while in control, 3.8 while not in control. Test subject 55 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

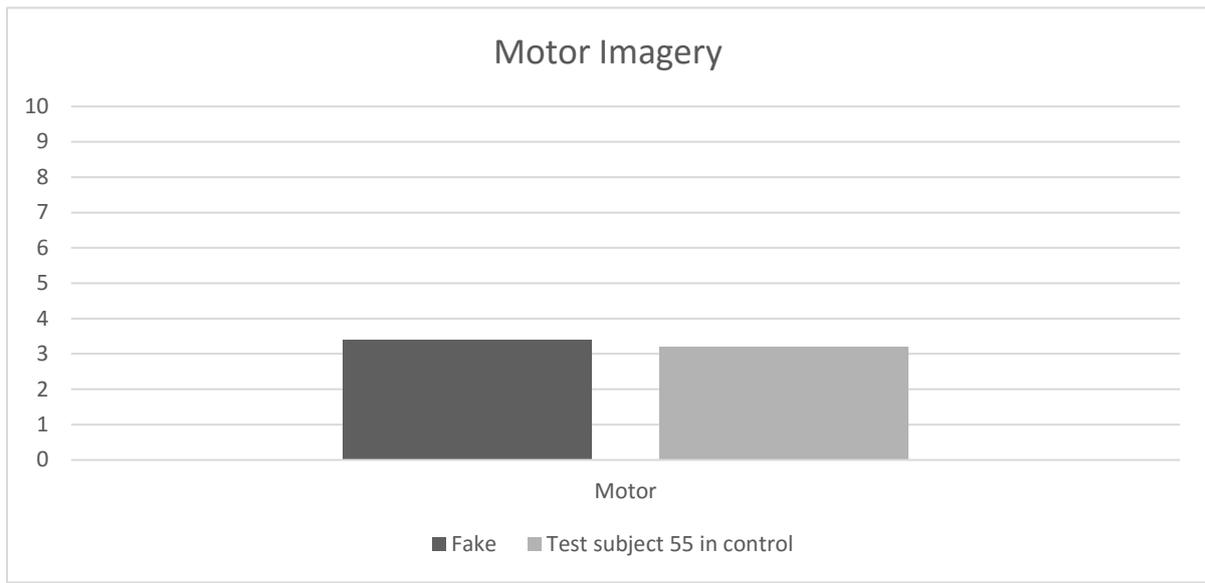


Figure 119 Average motor imagery control scores for test subject 55

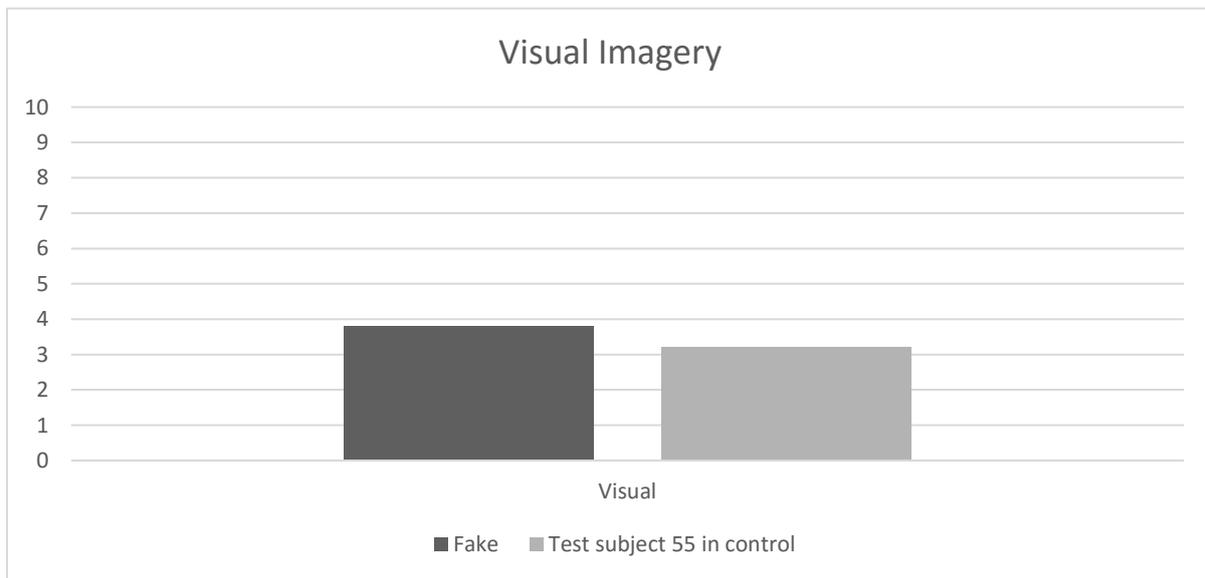


Figure 120 Average visual imagery control scores for test subject 55

14.6.17 Test subject 56

The average control scores from the motor imagery rounds: 4.6 while in control, 4.8 while not in control. Average scores from the visual imagery rounds: 3 while in control, 5.6 while not in control. Test subject 56 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

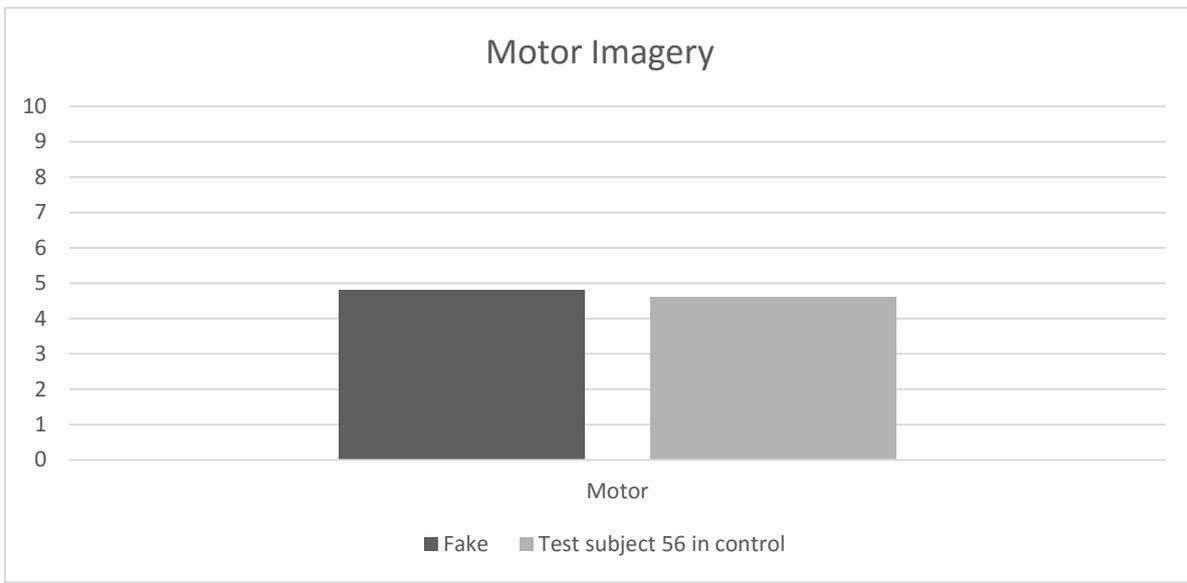


Figure 121 Average motor imagery control scores for test subject 56

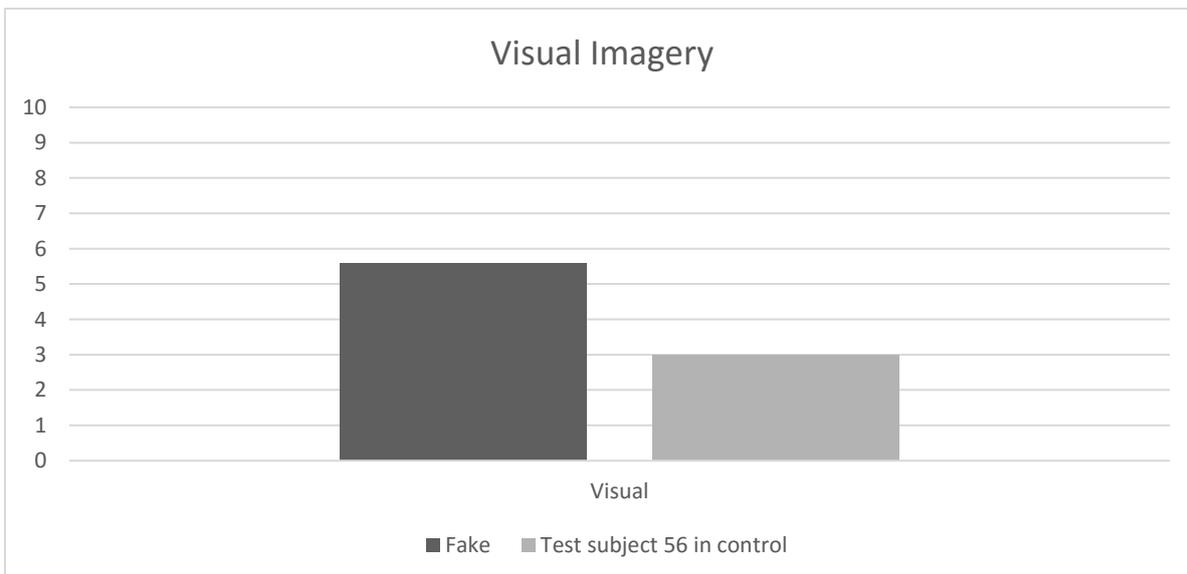


Figure 122 Average visual imagery control scores for test subject 56

14.6.18 Test subject 57

The average control scores from the motor imagery rounds: 4.8 while in control, 5.6 while not in control. Average scores from the visual imagery rounds: 2.8 while in control, 3.4 while not in control. Test subject 57 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

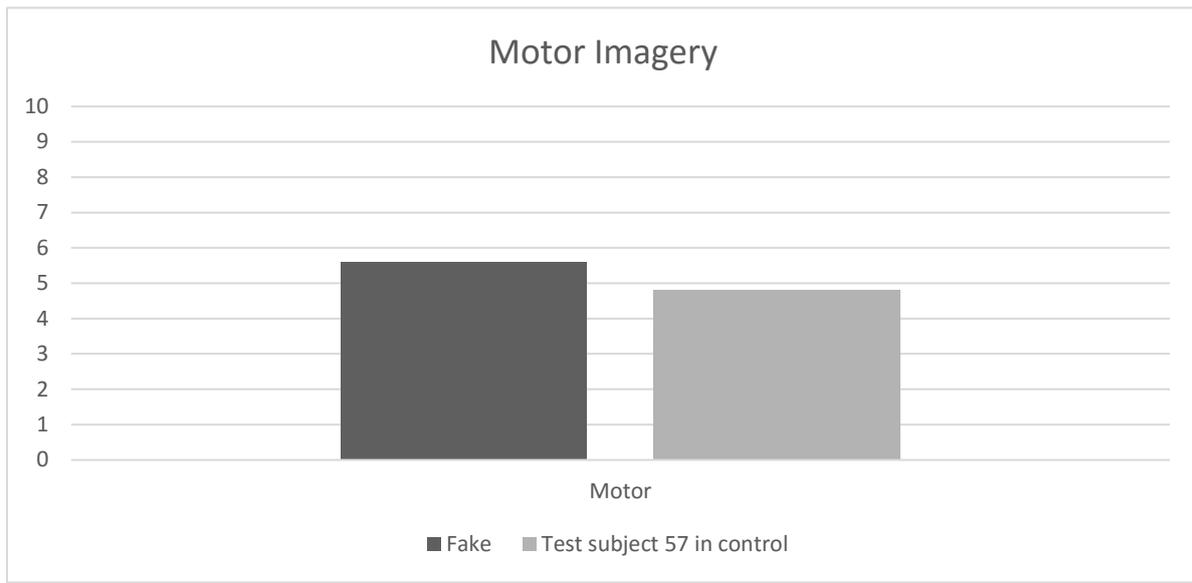


Figure 123 Average motor imagery control scores for test subject 57

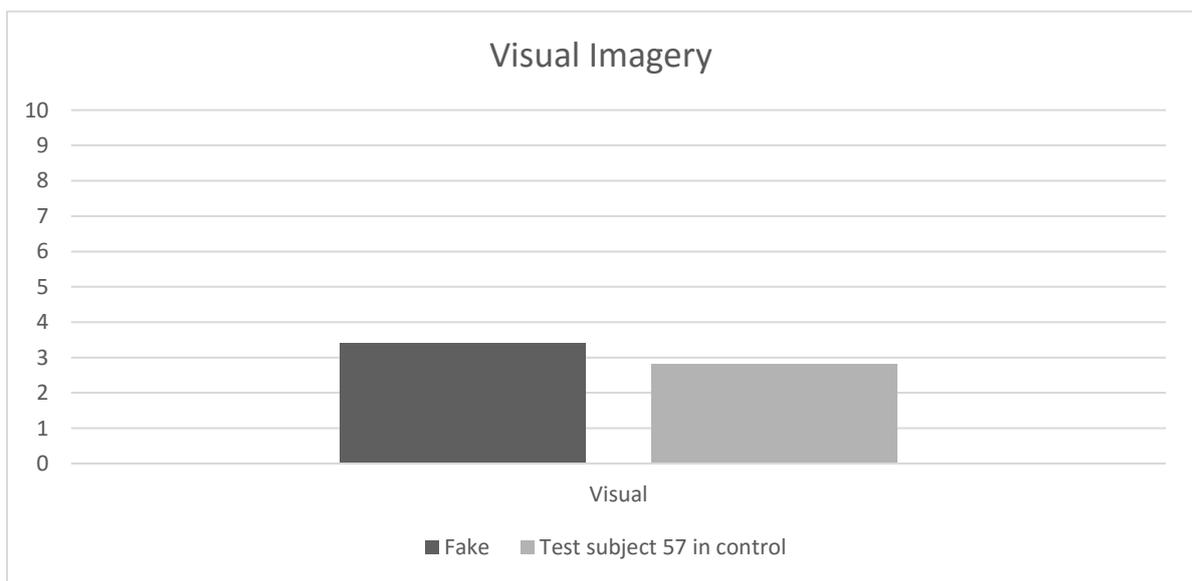


Figure 124 Average visual imagery control scores for test subject 57

14.6.19 Test subject 58

The average control scores from the motor imagery rounds: 4.8 while in control, 4.2 while not in control. Average scores from the visual imagery rounds: 2.6 while in control, 3.8 while not in control. Test subject 58 reported higher control scores while in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

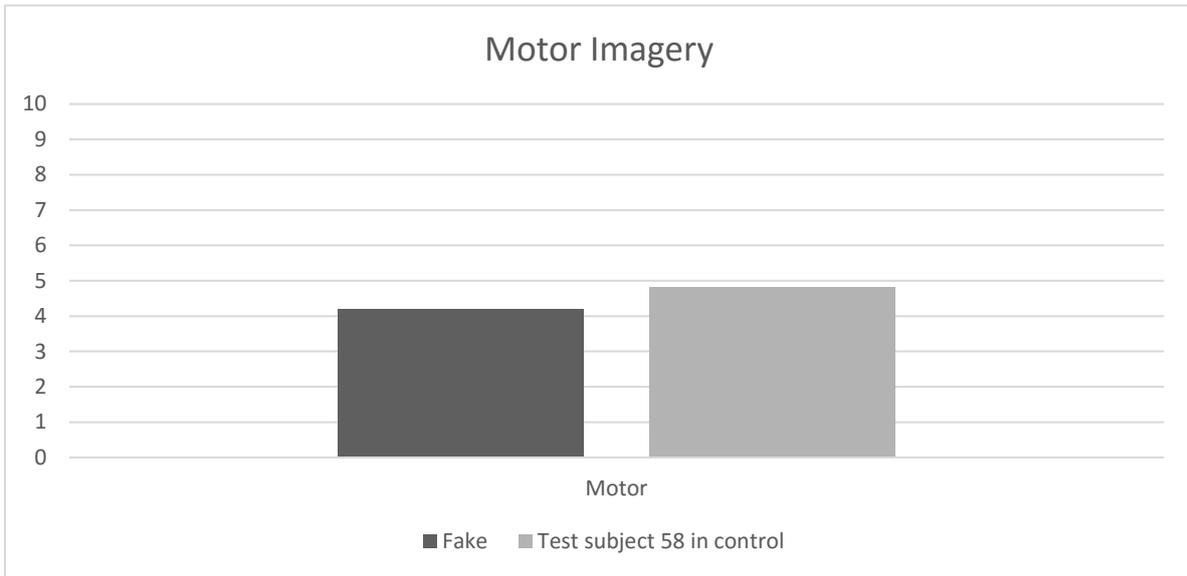


Figure 125 Average motor imagery control scores for test subject 58

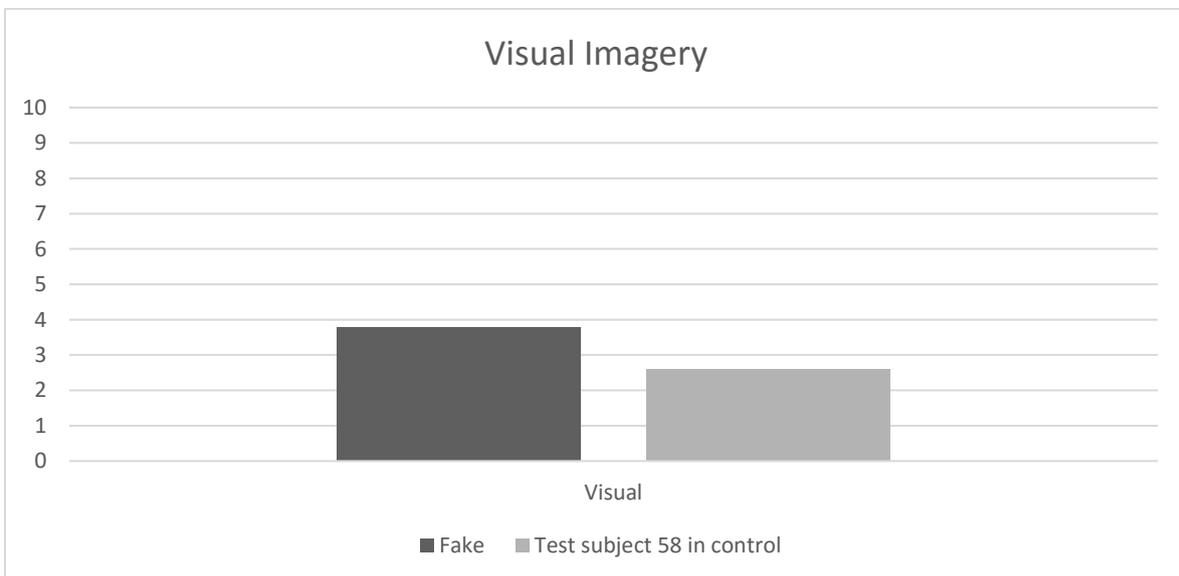


Figure 126 Average visual imagery control scores for test subject 58

14.6.20 Test subject 59

The average control scores from the motor imagery rounds: 7.2 while in control, 6 while not in control. Average scores from the visual imagery rounds: 1.4 while in control, 5.2 while not in control. Test subject 59 reported higher control scores while in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

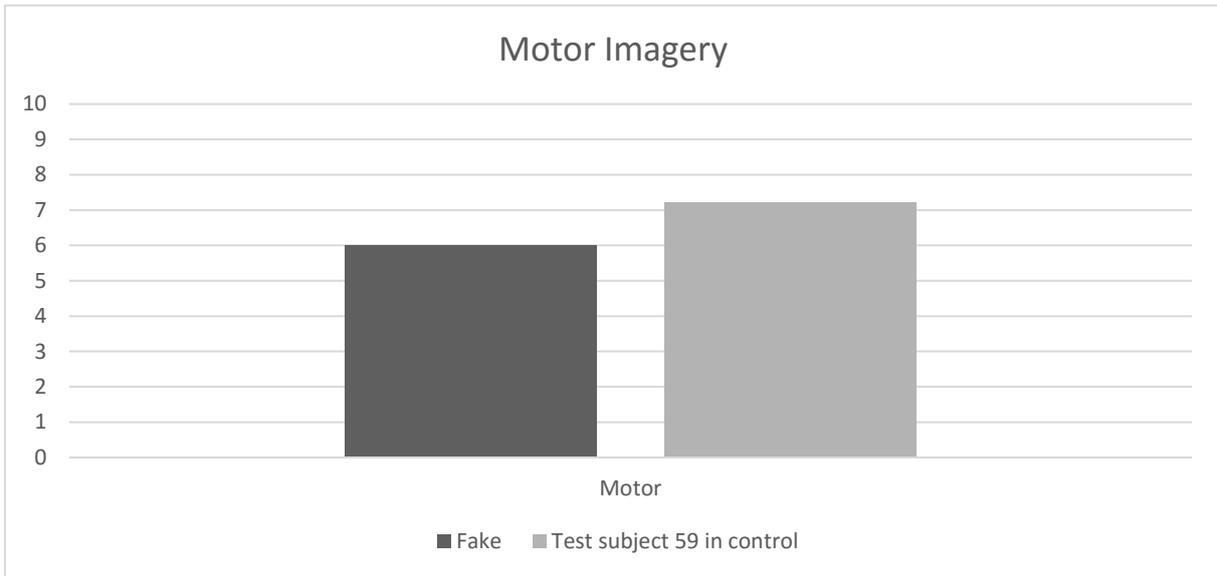


Figure 127 Average motor imagery control scores for test subject 59

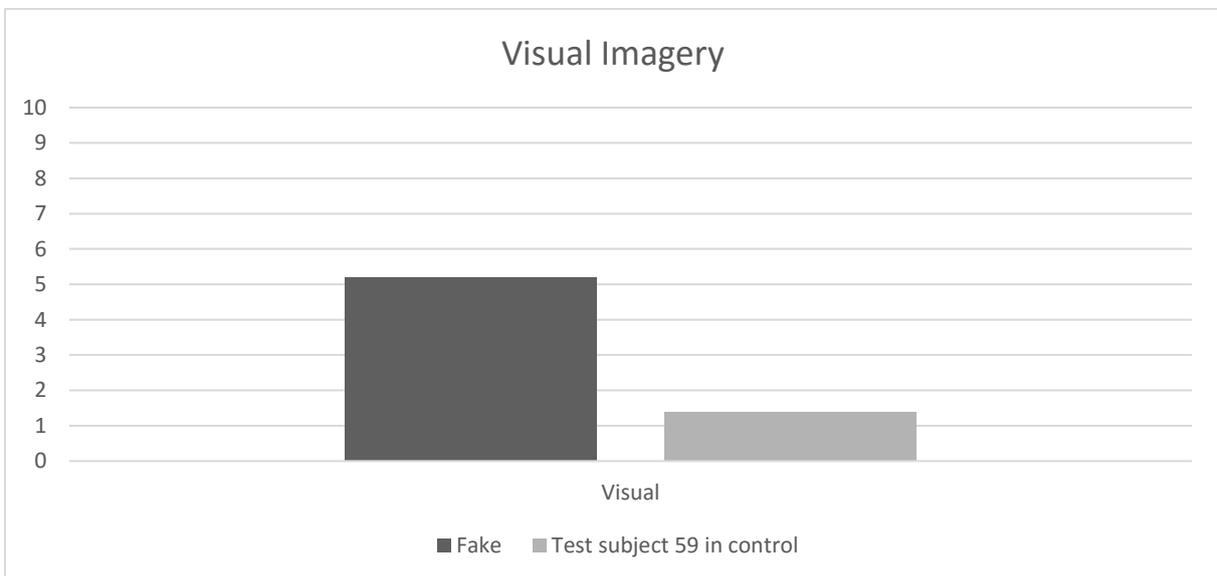


Figure 128 Average visual imagery control scores for test subject 59

14.6.21 Test subject 60

The average control scores from the motor imagery rounds: 5 while in control, 6.2 while not in control. Average scores from the visual imagery rounds: 3.6 while in control, 5.4 while not in control. Test subject 60 reported higher control scores while not in control during motor imagery rounds, and higher control scores while not in control during visual imagery rounds.

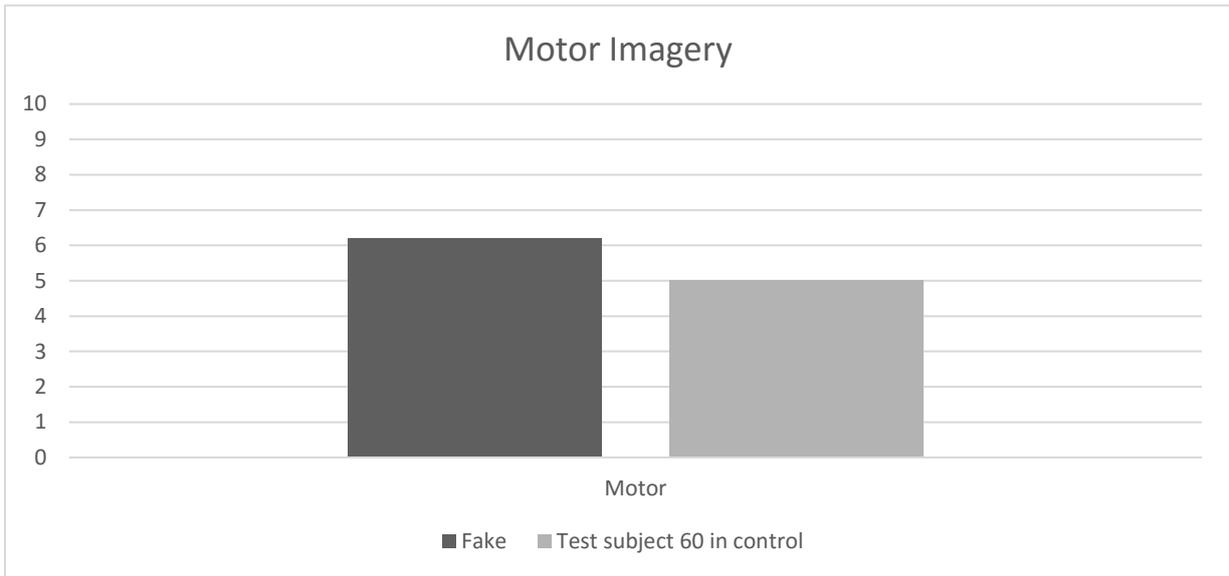


Figure 129 Average motor imagery control scores for test subject 60

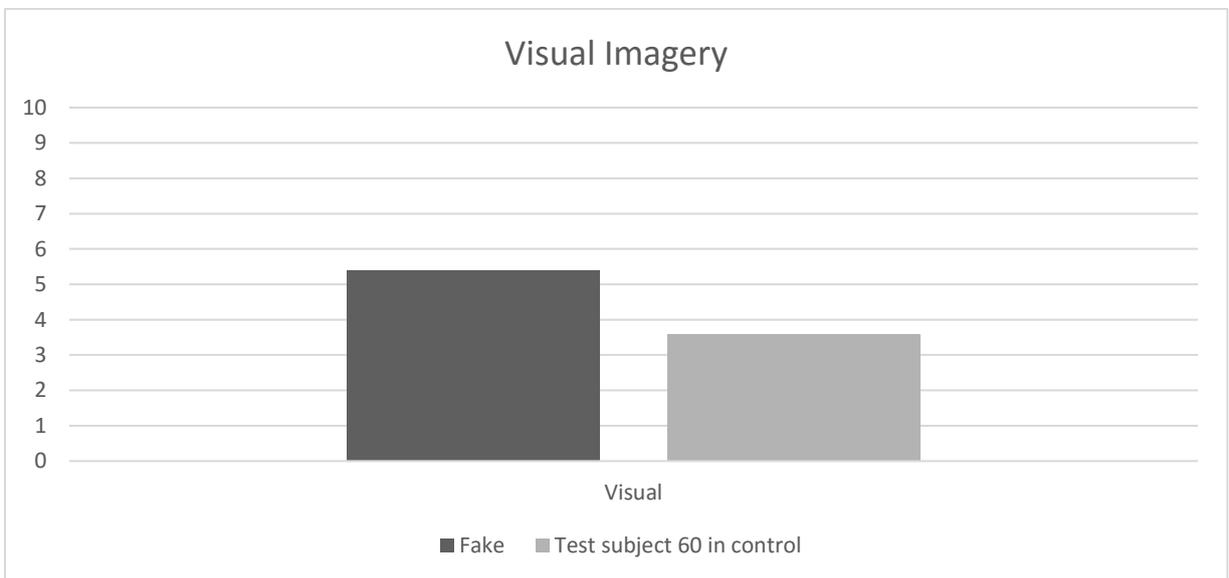


Figure 130 Average visual imagery control scores for test subject 60

15. Discussion

The results I ended up with after the final experiment has given me more questions than answers. I anticipated to see a clear difference between motor and visual imagery but ended up with finding no significant difference. The only exception was in the pilot test where the P-value for visual imagery was 0,005 (statistically significant). It could be argued that this was because the pilot test was the only test performed in an audibly quiet office with few wireless devices that could disturb the wireless signal with wireless noise.

The Emotiv product page states that the headset is quote: “Designed for everyday use, Insight boasts advanced electronics that are fully optimized to produce clean, robust signals anytime, anywhere.” (Emotiv Inc., 2017).

I could have tested in a lab environment for all my experiments but I decided to continue to do my experiments at the LAN parties because I wanted to test the EEG headsets in the conditions it has been advertised to work in: “Anywhere”.

Further experiments should be done to see if testing in a lab environment makes a significant difference when comparing motor and visual imagery using the methods I used.

It could also be that the setting of the office where I did the pilot test was so different from the LAN party that the participants were in a completely different mind frame. Perhaps the setting was a bigger factor than the audible/wireless noise.

The setting could also change how the participants approach the task, where the serious office setting puts the participants in a different mind frame than the fun LAN party.

It could also be argued that motivation between people makes a difference on how they approach the task. Some participants could also be more susceptible to participant expectation effect where they do what they think the experimenter wants them to do.

If a participant thinks the experimenter expects them to fail some tasks and succeed in others during the experiments, it could be a factor in the results.

If I had more time I would look at the results from each participant individually as a case study to see if there is a pattern that would suggest that the individual is more of a “motor imagery person” or a “visual imagery person”. But I have not found a method yet to analyse the results I have from the tests in this manner. If I were to do this kind of categorizing I should have used some kind of personality test like the Vividness of Visual Imagery Questionnaire (VVIQ) (Marks & Isaac, 1995) before testing.

By changing the presentation of “FlappyBrain” as a “game” where the test participants compete against each other, to a “calibration tool” where their scores will not be compared to other participants we theorized that it could result in a significant difference in the results (compared to previous tests). If the test subjects did not think of “FlappyBrain” as a game where they had to perform, but a “calibration” where the performance did not matter, it could make the participants more relaxed during testing.

If this change in presentation could result in a significant difference between motor and visual imagery, then it might be important to consider how a BCI test is presented to participants.

The participants might report different control scores if I was using a game other than FlappyBrain during the tests that does not have a “points” counter. Some participants might be reporting more accurately if they did not have a point counter to “help” them decide how much control they had.

One of the “mental commands” that the Emotiv Control Panel has, and which is considered to be one of the more difficult to use, is the “disappear” command where you imagine that the orange cube used in the motor imagery training disappears. If I did a test where I compared the “disappear” command to a visual imagery of for example the arrow pointing up, I might find difference bigger than in my current results.

It could also be interesting to see if it is possible to combine motor and visual imagery into one command if possible. For example, with two different symbols for visual imagery and four different movements (up, down, left, right) for motor imagery. A hybrid solution would be interesting, because it can potentially use motor imagery as “modifiers” for visual imagery rather than using another visual imagery and speed up the usage.

In order to test a hybrid method I would need more time with each test subject than I had in this project.

16. Conclusion

According to the data collected in the four tests where the test subjects reported their feeling of control there is no statistically significant difference between motor imagery and visual imagery ($p > 0.05$).

24 of 47 test subjects reported higher control when not in control for motor and 25 of 47 test subjects reported higher control when not in control for visual.

The conclusion I draw from the results of my tests is that more testing must be done before either motor imagery or visual imagery can be recommended as the best alternative for a universally designed EEG system. I was not able to disprove my null hypothesis (H_0).

If future tests cannot find any significant difference and thus recommend motor or visual imagery as the superior alternative, EEG systems of the future should have both motor and visual (and possibly more) imagery available for their users to pick from.

16.1 Possible explanations:

I could not find a significant difference between motor and visual imagery with the testing methods I used. The methods I used might not be accurate enough because I did not record enough EEG samples or because I only tested 10 rounds of motor and visual imagery rather than more than 10 due to time constraints.

It could also be because I only tested one command with motor and one command with visual imagery on each test subject due to time constraints, and I should test with more than one motor and visual imagery command to get more data.

If I tested again using the same test subjects over longer periods of time, I would perhaps see a change in the performance in each test subject for both motor and visual imagery. It is also possible that there is a difference between motor and visual imagery that can be measured using my existing methods, but it is too small to be picked up using the consumer grade Emotiv EEG headset I have available. I might have to do more testing using a medical grade EEG headset to find the difference.

The environments I tested in were noisy both in terms of wireless noise from various devices using Bluetooth and audible noise from people close to the test-area.

The 21 participants in my final test might not be a large enough sample size to find a significant difference between motor and visual imagery and I might have to do another test on a larger sample size to see if there is a significant difference.

One of the more interesting possibilities is that people think differently, and approximately half of the population are more in control and able to recognize when they are in control using motor imagery and the other half is more in control and able to recognize when they are in control using visual imagery. It might be that around half of the population prefers motor over visual regardless of control. In the paper I mentioned earlier where they used the Vividness of Visual Imagery Questionnaire (VVIQ) (Marks & Isaac, 1995) the researchers filtered out 12 test subjects from 60 potential test subjects based who had the 6 lowest and 6 highest scores in the VVIQ.

17. Future work

I want to continue my research on motor and visual imagery with EEG based BCI headsets, and there are a few “paths” which I want to explore.

17.1 Path 1: Testing in a lab

The tests I did was done at LAN parties where people use multiple wireless devices and that had audible noise from other people at the LAN party and/or music. This was done because the Emotiv product page states that the headset is quote: “Designed for everyday use, Insight boasts advanced electronics that are fully optimized to produce clean, robust signals anytime, anywhere.” (Emotiv Inc., 2017). And I decided to test the hardware in the conditions it was advertised to work in: “anywhere”.

I want to re-test in a lab-environment that has less confounding variables such as wireless and audible noise. If I conduct a re-test in a lab environment isolated from audible noise with a faraday cage to block out wireless noise, I might find a difference between motor and visual imagery using the same procedure. If there’s a difference between tests done in a noisy environment and noise-free environment, then the Emotiv EEG headsets might not be as robust as the product page claims. I won’t know for sure until I have tried.

I will also include some kind of personality test such as the Vividness of Visual Imagery Questionnaire (VVIQ) (Marks & Isaac, 1995) to see if there is a correlation between VVIQ scores and motor/visual imagery.

17.2 Path 2: Long term testing

I want to re-test on the same participants multiple times over longer periods of time.

By testing the same participants multiple times over longer periods of time I may find a significant difference between motor and visual imagery that I might not be able to find using only one test per participant. If I decide to use long term testing with more than just one mental command active, I can check if test subjects prefer to use only motor imagery or only visual imagery or a combination of both for controlling the buttons in a game.

I could also check if the test subjects preference for using motor or visual imagery to control a button in a game changes over time.

A long term study might reveal if the test subjects are less susceptible to confirmation bias after playing the same game over longer periods of time. It would be interesting to see if the test subjects can more accurately detect fake feedback from the game when using either motor or visual imagery over longer periods of time.

A long term study could perhaps find that test subjects who use motor imagery to control the game over longer periods of time are more likely to detect when they are not in control of the game compared to test subjects who use visual imagery (or vice versa).

If I get the opportunity to do a long-term test I want to incorporate the Vividness of Visual Imagery Questionnaire (VVIQ) (Marks & Isaac, 1995) to see if there is a correlation in the VVIQ scores and if the participants prefer to use motor or visual imagery. And I would like to ask the participants to take the VVIQ regularly to see if their personality changes during the testing.

17.3 Path 3: Equipment upgrade

I want to do a re-test with both consumer grade EEG headsets from Emotiv and medical grade EEG headsets that can detect both motor and visual imagery to see if medical grade headset makes a significant difference in the results.

It would be interesting to see if a medical grade EEG headset can help the participants to identify when they are genuinely in control more accurately than with consumer grade headsets such as the Emotiv headsets.

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