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Testing of a Consumer-Grade EEG Device for Computer Control

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by
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Abstract

Brain-computer interfaces (BCI) offer the ability to control a computer with just the power of thought; electroencephalography (EEG) is the main method for recording such thoughts. Emotiv Inc. is a technology company which sells consumer-grade EEG devices, promising accessible BCI for general use. This study had participants use the Emotiv Insight, the lower-end EEG device, to play a video game, and compared the results against the Emotiv EPOC+, the more reliable but expensive EEG device. Results showed that the Insight performed probably worse than the EPOC; combining the results with previous literature point towards avenues of improvement for the Insight, including software, training, and comfort.

Contents

Dedication

I would like to dedicate this my parents, who have always been a guiding light to me, Teddy McKrell for always being there for me, and my therapist, who understands my thoughts and actions even better than myself at times.

Acknowledgments

I would like to acknowledge my senior project advisor Bob McGrail for advising me through various stages of the project. I would also like to acknowledge the other computer science faculty at Simon's Rock and Bard College for kindling, guiding, and deepening my own interest in computer science, without whom this project would not exist. Finally, I owe all my data to my peers who participated in my experiment.

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1
Introduction

Using the human mind to control the technology around us has long been a dream. Being able to control a pair of robotic arms with just a thought, or control a computer without raising a finger, is compelling. This area of research is called Brain Computer Interface (BCI), and focuses on computer systems which can read and react to users' thoughts. The most fruitful research uses electroencephalography (EEG) to read brain waves and machine learning to transform those brain waves into commands a computer can interpret. This research has been most pertinent to people with physical impairments that prevent them from effectively using traditional computer control schemes, like mouse and keyboard. However, as the technology becomes cheaper, more powerful, and better understood, BCI's are becoming increasingly in reach for the average consumer. One day, BCIs might be just another way to use a computer.

Until then, we will have to test and refine our current technology. In this experiment, I intend to test the effectiveness of the Emotiv Insight, a consumer-grade EEG device available for general purchase, and compare it to another device from the same company, the Emotiv EPOC+. To do this, I will have participants play BrainBlocks, a Tetris-style game which allows for keyboard and brain control.

2
Theory and Literature

2.1   Theory

For a computer and user to communicate through a BCI, the users' intentions must be derived from their brain signals. This process begins with the user engaging in some cognitive task, sometimes with stimuli. Brain activity is recorded by the EEG device, which is sent to the computer for pre-processing to remove noise. This pre-processed data is then sent to a machine learning program which extracts relevant features. Based on those features, a prediction is made about the user's intentions. This prediction is displayed to the user, often visually but sometimes through auditory feedback. The user is then free to make a judgement about that prediction, and adjust their cognitive task accordingly. This cycle then repeats, both the system and the user learning how best to communicate. In this way, both ends of the cycle can adapt and improve performance of the BCI. Figure 2.1.1 is a digram of this cycle [3].

The brain signals interpreted by the BCI must be voluntarily controlled by the user. There are only a few voluntary brain signals researchers understand well enough to make predictions about - the brain as a whole is still a largely unsolved phenomenon. Of those signals, there are four main brain signals that are currently being used in BCI research. The one I will have participants use will be the sensorimotor rhythm (SMR). SMR comprise the mu and beta brain waves, which range from 7-13hz for the mu band and 13-30hz for the beta band. The sensorimotor rhythm is
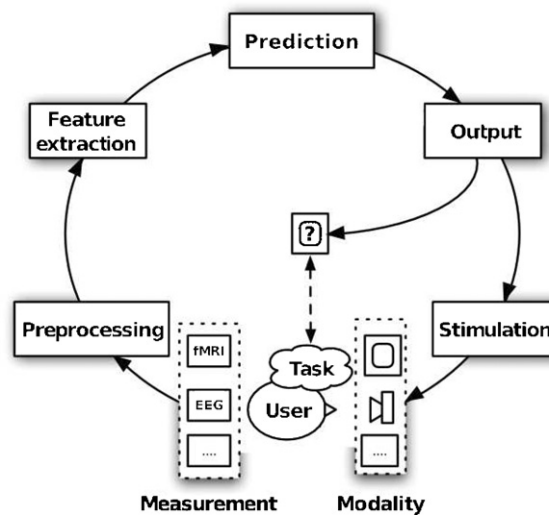
Figure 2.1.1. Diagram of BCI cycle [3]

affected by motor activity and motor imagery - the act of imagining some motor activity. Thus, clenching one's fist will affect the sensorimotor rhythm, but so will the act of imagining clenching one's fist. In this way, users can voluntarily modulate the SMR through their thoughts, and thus use those thoughts to control a computer. [6]

I chose motor imagery as the control paradigm for three other reasons. For one, The Emotiv Insight operates in the 0.5-43hz range, which the SMR fits neatly into [2]. In addition, users can self-regulate the SMR. In other brain signals used for BCI, the signals are recorded in response to stimuli controlled by the program. Thus, motor imagery is a more natural approach to BCI, where a computer is controlled because the user spontaneously wills it, not as a reaction to some external stimuli [6].

Finally, motor imagery is chosen since all of my participants are able-bodied, and thus familiar with, and significantly, able to imagine themselves moving and performing physical actions. While there has been recent research into music imagery, focusing on and playing back particular musical phrases, and visual imagery, holding an image within the mind, motor imagery is guaranteed to be relevant to all participants.

I believe that motor imagery is the most effective control scheme available in this context. However, participants are allowed and encouraged to find the control scheme which best suits them, to allow the possibility that the Emotiv Insight is a multi-modal device.

2.2 Emotiv Capabilities

The Emotiv software offers a variety of services, falling into 3 categories, called detection suites. The first suite, Mental Commands, offers the ability to train neutral and multiple mental commands. The Facial Expressions suite allows the detection of various facial expressions, including: blinking, winking with the left or right eye, and the expressions of surprise, frowning, smiling, and clenching one's face. Finally, the Performance Metrics suite states that it can track multiple metrics, including: excitement, engagement, relaxation, interest, stress, and focus.

The Emotiv EPOC+, their flagship device, has been found in one analysis performed by Turner et al. to be appropriate for clinical tests due to the satisfactory accuracy of EPOC+ devices, rather than restricting the device to the limited scope of BCI and interactive multimedia [16]. Thus, while the EPOC+ is more expensive, the device has a greater guarantee of producing useful and accurate EEG data. The EPOC+ is still significantly cheaper compared to other EEG devices, costing less than $799 at time of writing.

The Insight was released in 2015, with comparatively less attention from the research world. Although it has a simpler design and cheaper price, at about 60% cheaper than the EPOC+, this makes it no less of a valuable research topic. The BCI capabilities of the Insight should be fully explored.

2.3 Literature

Most previous work with developing EEG-based BCI have been focused on research-grade EEG devices, which offer a high level of clarity and quality to the brain wave data. However, as costs decrease and the number of channels decrease, the quality of the data also subsequently

decreases. There has been previous research using EEG devices sold by the same company, specifically the EPOC+ model.

Figure 2.3.1. Emotiv EPOC+ Headset Worn by User

Posen conducted an experiment evaluating the immersive potential of BCI's using the EPOC+ [12]. He did this by developing a BCI-controlled video game, called Brain Blocks, and having participants play it and evaluating their immersion via survey. I will be using that same BCI-controlled video game in my own experiment, with minor alterations. Key differences include a different device being used, the Emotiv Insight versus the EPOC+. I will also be evaluating the effectiveness of the Insight for BCI purposes, rather than concentrating on psychological factors surrounding the BCI system itself.

North et. al from Kennesaw State University also used the EPOC+ in a BCI to test drone control [7]. They were evaluating different methods of controlling drones for efficiency, and compared facial and mental commands. Efficiency is needed for drones, which have to be tightly controlled to prevent crashing. They found that there were no significant difference between facial and mental commands, although participants underestimated the difficulty of both. Their research focused on finding ways to utilize the EPOC+, since there is existing research proving the reliability of the EPOC+.

However, similar research into the usability of the Insight is a research gap I am looking to fill. In addition, I will be using facial and mental commands in conjunction with each other,

rather than comparing them. Instead comparison will be between BCI controls among devices. In addition, efficient methods of control are less of a concern, since I will be using a computer program to test control, where time constraints can be tightly controlled.

2.4 User Training Literature

There is continuing research into methods for training users to effectively use BCI. This is quite pertinent, since the BCI cycle involves both the user and the system learning to communicate with one another. Efficient training methods must be found for both ends of this cycle

One study by Hwang et. al. found that a neurofeedback based training system was very effective [5]. The system presented users with a real-time brain activation map, and directed them towards activating the SMR through motor imagery. They found significant differences in the SMR rhythm of users before and after they used the training system, as well as higher classification accuracy for users after motor imagery training. In comparison, users who did not use the training system showed no consistent improvement.

Another possibility is the use of physical systems for BCI training, raised by Orozbakova [9]. In her study, she had two ways participants could learn to use a BCI, either through learning to move a virtual object on a computer screen, or learning to move a robotic vehicle. She found that users were able to learn more control commands when learning via a robotic car than a virtual object. This points to the possibility of using physical training systems as well.

It should be noted that training a BCI system is not intuitive, and there is a certain segment of the population that is BCI "illiterate", meaning they cannot use BCI at all [8]. Whether this is due to insufficient training systems, an actual cognitive deficit, or some currently unknown reason, remain to be seen.

2.5 Emotiv Insight Literature

Research into the Emotiv Insight has been sparse and mixed. Most research does not use the insight as a BCI, instead gauging participants reaction to stimuli using Emotiv's engagement

metrics, i.e. stress, relaxation, etc. An example of this is the study by Zabcikova, where two participants' levels of interest, engagement, stress, relaxation, and stress were measured when exposed to different visual and auditory stimuli [17]. Of the research which tests the Emotiv Insight's capabilities as an EEG device, and implicitly its usability for BCI, only one study by Nils Berg and Peter Aoun used Emotiv's own built in mental command training [1]. They used a case study, and tested 3 participants in their ability to control a cursor along a one-dimensional line, thus using two commands. This is similar to my own study where only two mental commands are trained. They found that participants failed 44/45 of the trials, and along with complaints of headaches and fatigue, concluded that the Insight is not adequate for use in BCI. However, they did point out that the results are not consistent with researcher's own testing with the Emotiv Insight, and with the small sample size, might be too small to draw conclusions. My study would involve a much greater number of participants, and offer a more conclusive assessment of the Emotiv Insight. The rest of the research I found applied their own statistical and machine learning methods on the raw-EEG data obtained from the Emotiv Insight, and found much better results. Pathirana et al. obtained a maximum of 76.6 % accuracy in user intention detection, although they claim that they could only obtain a user intention detection accuracy of about 50% via their own private testing using Emotiv's provided software [10]. Rahma et al. obtained an accuracy of over 95% in detecting between two types of movement (e.g. grasping v. releasing, pinching v. releasing, hand lifting v. releasing) using data obtained from the Insight [13]. However, Stoelinga could not detect the difference between left and right handed motor actions or motor imagery using the Insight, which other research-grade EEG devices are able to do [15]. Finally, Peining et al. compared the Insight to the Muse, another consumer-grade EEG device, using mental concentration as an input modality [11]. They found that both devices served similarly in terms of effectiveness, but ended up preferring the Muse based on accessibility, since the headset is adjustable and provides free raw EEG data.

All of this research highlights both the lack of research into the Insight and the conflicting conclusions based on the Insight. All of the papers tend to acknowledge Insight's shortcomings,

but seem divided on its ability to act in BCI. Their conclusions about the device for BCI usage range from unusable and mostly usable. The Emotiv Insight seemingly has enough power to differentiate between paired mental commands, which would compensate for any inability to differentiate between left and right brain activities. Peining et. al. points to multi-modal BCI's being possible with consumer-grade devices, but more research would be needed into the various other modalities, e.g. music or visual imagery, to truly say whether it is possible. In addition, Emotiv is constantly updating its suite of development tools, making Emotiv headsets easier to develop for and presumably more accurate as well. One of the purposes of this study is to continue this research into consumer-grade EEG devices for use in BCI.

While they are also testing the Emotiv Insight, I will focus on BCI application with participants using Emotiv's own tools, rather than testing for maximum accuracy with a single user.

3
Materials

Figure 3.0.1. Emotiv Insight Headset

3.1 Emotiv Devices

The experiment utilized the Emotiv Insight, the lowest end system available from Emotiv (Figure 3.0.1). It records on 5 channels: AF3, AF4, T7, T8, Pz, with one reference node, and uses a hydrophilic semi-dry polymer as leads for the electrodes. Glycerine was used as a conductive gel for the leads. It's currently available for \$299, and can connect wirelessly via bluetooth to most computers. In addition, owing to its design, it is easy to fit onto one's own head, without

any outside assistance. In concert with the readily available BCI software Emotiv provides, it is a very accessible EEG device. This together potentially provides a quick and easy BCI usage to even the most inexperienced of users. For its accessibility and cost, it was chosen for this study.

The Emotiv EPOC+, the device more widely used in research and development, is a 14 channel system using saline soaked felt pads as electrodes. It is also designed as a single piece with fixed electrode positions, but is significantly more difficult to put on one's own head.
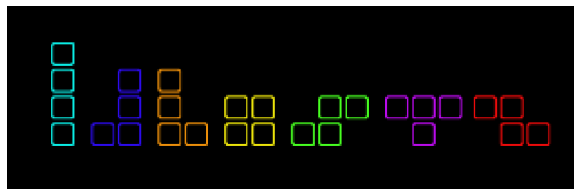

Figure 3.1.1. Selection of Blocks in BrainBlocks

3.2   Brain Blocks

Brain Blocks (Figure 3.2.1) is a version of Tetris, with alterations to accommodate BCI controls.

In Tetris players control tetriminoes, shapes composed of four smaller squares. Tetris is played on a grid, where each square in the grid is the same size as a square which makes up the tetrimino block. The blocks appear at the top of the play-space, where the game is played, and systematically move down until the contact the ground or another block - at which point the block stops moving and another block appears at the top of the screen, ready to be controlled. While the blocks are moving downwards, they can be rotated in 90° increments, or move left and right along the grid in one square increments.

When the stopped blocks at the bottom of the play-space align such that their individual squares form a solid horizontal line across the play-space, a set number of points are scored. Then the horizontal line disappears and all blocks above the line move down one grid space. If multiple horizontal lines are formed, all lines disappear together and the blocks above fall down

one grid space for each line that disappeared. The game ends when a block is stopped above the play space, usually signifying that the play space is filled up.
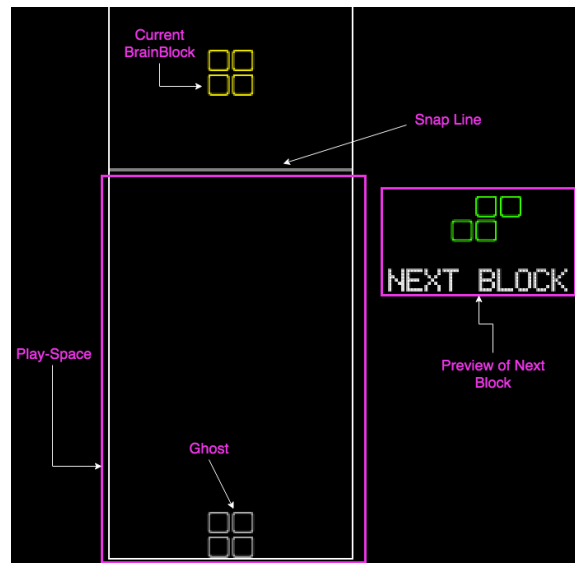

Figure 3.2.1. Labeled View of Brain Blocks

Brain Blocks has two control modes, keyboard and BCI mode. In BCI mode, blinks are used to rotate the block, and trained mental commands (Left and Right) are used to move the block left and right in the play space. Blinks are chosen since they are both universal and easy to perform. In addition, limiting the mental commands to just two paired commands makes it feasible to have participants successfully train those commands in one session. Increasing that number to three makes it much more difficult.

Special accommodations were built into the game to facilitate playing with brain controls and to make the game reasonable for playing with current BCI technology. During a normal game of Tetris, the constant downward movement of the blocks creates a limit on the amount of time players are able to rotate the block or move it left and right. Thus this requires the player to quickly and accurately assess where they want the block to land. Due to the imprecise nature of current BCI technology, and lack of training on the part of the players, this time limit can be frustrating. Thus, in BrainBlocks, the blocks appear statically above the Snap Line, and allow the player to rotate and move the block at will without a time limit. When the player is satisfied

with the position of the blocks, they can then cause the block to fall into place. In addition, a "ghost" image is placed to allow the player to see where the tetrimino will fall while it is being manipulated.

Since blinks were chosen as the command for block rotation, it becomes unreasonable to have the participant not blink when moving the block left and right. As blinks aren't entirely in the players control, accidental rotations due to inevitable blinks would have artificially increased the difficulty of the game. Thus, block manipulation is split into two different modes, Rotation and Navigation modes. In Rotation Mode, the only recognized action is rotation, whereas in Navigation Mode, the only recognized action is left and right movement. Thus, blinks during Navigation Mode are ignored, increasing usability.

4
Methods

4.1 Mental Command Training

For the brain control, the mental commands must be trained in order to play. To train a mental command, the player must hold in their mind a specific thought for eight seconds. The thoughts which work best will be motor imagery, where the player will imagine themselves performing some physical action. The first mental command to be trained is always neutral, which all other commands will be compared against. Neutral is trained by letting the mind be blank, being mentally and physically calm. After neutral is trained, either left or right will be trained, to be decided randomly for each participant. This is to prevent any bias in the training. After training a command, the player must then demonstrate the ability to use that command in a short trial. After the trial, the remaining mental commands will be trained. Figure 4.1.1 shows a user who started with and completed training the right mental command and is currently training the left mental command. At anytime during the training, if the player is not satisfied with their mental command, they can erase the current training on their mental commands and try again.

Once both left and right mental commands are trained, then an additional set of trials will be performed, called familiarization trials, testing if the participant can effectively use both commands at will. Once the player has demonstrated sufficient control over the commands, they are ready to be do freeplay, where the objective is to reach as high of a score as possible.
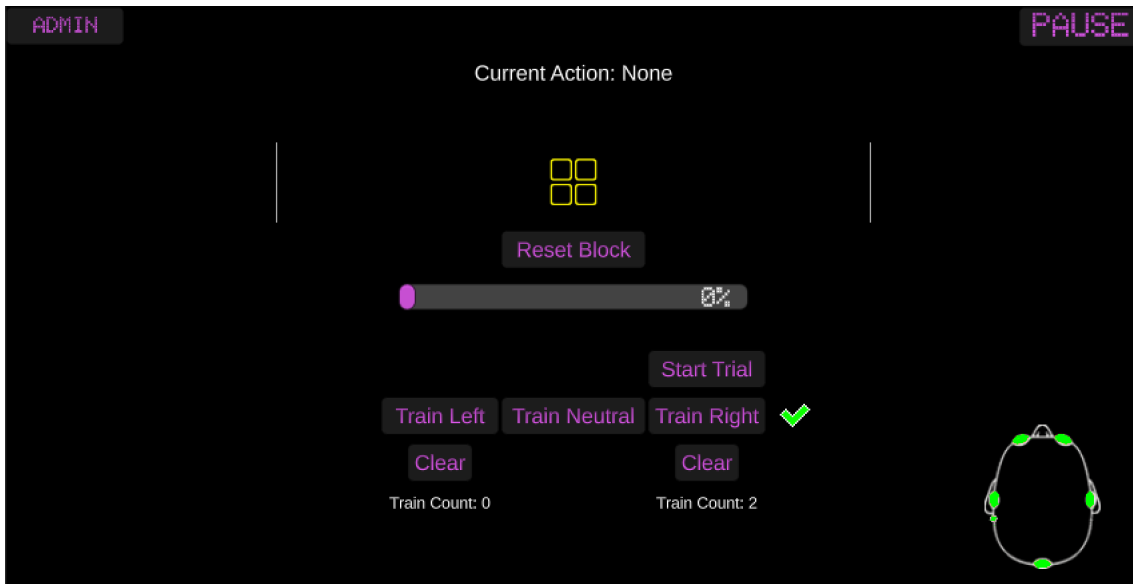
Figure 4.1.1. User Currently Training Mental Commands in Brain Blocks

4.2   Good vs Bad Data

I used all the data I acquired. This includes when the Insight could not establish a good connection with the participant. When a bad connection occurs, this was logged as a failure to pass the trials. Since I will be modeling my data as a binomial distribution, I can still count bad connection as failure.

A good connection occurs when all electrodes are consistently green. Thus, a bad connection is characterized by the electrodes frequently finding, then losing, connection with the scalp. This usually manifests as the electrodes of the Insight blinking between red, a bad connection, and green, a good connection, once or twice a second.

Posen decided to exclude participants who could not sustain a good connection with the EPOC+ from his final analysis. This analysis compared the following three metrics between the keyboard controls and BCI controls: score, speed, and correctness of commands. Thus if a connection was not able to be established, there would be no data generated for BCI controls. In addition, if participants did not complete all the trials, Posen did not use the data generated in final analysis of immersion, a problem which I will not have. Fortunately, he did make available all of the data, which allows me to use it in my own analysis.

4.3   What I provided Participants

All materials provided to the participants will be available in the appendix. This is comprised of the consent form (Appendix A), the mental command training tip sheet (Appendix D), and brain blocks controls (Appendix C). In addition, a paper copy of the questionnaires (Appendix E,F), which were given online, are provided here

5
Experiment

The experiment and all questionnaires have been approved by the IRB.

5.1   Experimental Procedure

Prior to starting the training, the participant is asked to fill out a pre-experiment questionnaire, designed to ascertain their previous experience with BCIs and computer games. Then, the participant will play the game with keyboard controls, as a control and to familiarize them with BrainBlocks. Afterwards the researcher will correctly place the Emotiv Insight on the participants' head, applying glycerin to the electrode leads as needed to ensure a proper connection. If the participant is unable to secure a good connection, the experiment will be terminated at this point. If the participant established a good connection, then the process of training commands will commence.

In some of the trials, the tester will use a sterile chin-rest to limit movement that could disrupt the signal quality. The rest is adjusted to ensure a comfortable fit and to make sure the participant is not clenching their jaw.

The process of training individual commands starts with training the neutral command. Once the "Neutral" brain state is trained, training can begin on the first mental command, either right or left. Training consists of holding in mind a visualization of an action for 8 seconds, which

will then be mapped to left or right. Once two trainings have taken place, the participant is tested on that command by being tasked with moving a training block over a prompt using the trained the trained mental command. The training is then repeated for the second command. Participants could clear their trained data at any time and restart the training process. The training stage concluded once participants were able to demonstrate an ability to issue both trained commands.

If after 30 minutes the participant was unable pass the test for both mental commands, the experiment was terminated.

Next comes the familiarization mode, where participants are tasked with using both the left and right mental commands to match the orientation of the block on screen to the prompt. There are 6 familiarization trials, each one with a time limit of 5 minutes. Following this trial, comes the free gameplay mode, where participants are able to freely play the game, with the only goal being to achieve the highest score. This mode will be 8 minutes with a break in between to prevent fatigue.

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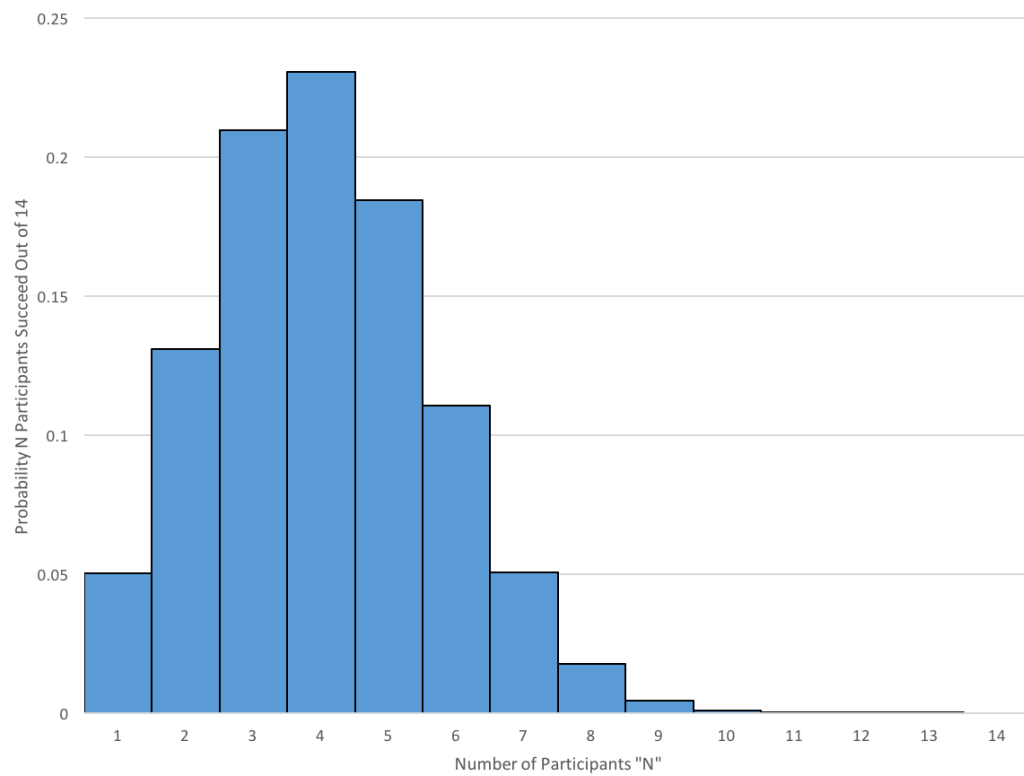# Analysis

6.1 Binomial Distribution

Figure 6.1.1. Binomial Distribution From This Study

A total of 14 undergraduate students at Bard College participated in my experiment, with 4 able to pass all the trials in the allotted time. Of the remaining 10 participants, one was unable to establish a sufficient connection with the Emotiv Insight, two were unable to pass the training stage, and the remaining seven were unable to pass the familiarization phase.

This can be modeled as a binomial distribution, where success is the chance of completing all trials, and failure is the chance of not completing all the trials. The probability of success $P(S) = p = 0.31$, and the probability of failure $P(F) = q = 0.69$, with a mean of 4 and standard deviation of 1.69 (Figure 6.1.1).

I will use Posen's results from his study, since our experimental procedures are comparable. In his experiment using the Emotiv EPOC+, 27 undergraduate students at Bard were tested, with 20 completing all experimental trials in the allotted time. Modeled as a binomial distribution, this gives a $P(S) = 0.74$ and a $P(F) = 0.25$, with a mean of 20 and standard deviation of 2.28 (Figure 6.1.2).
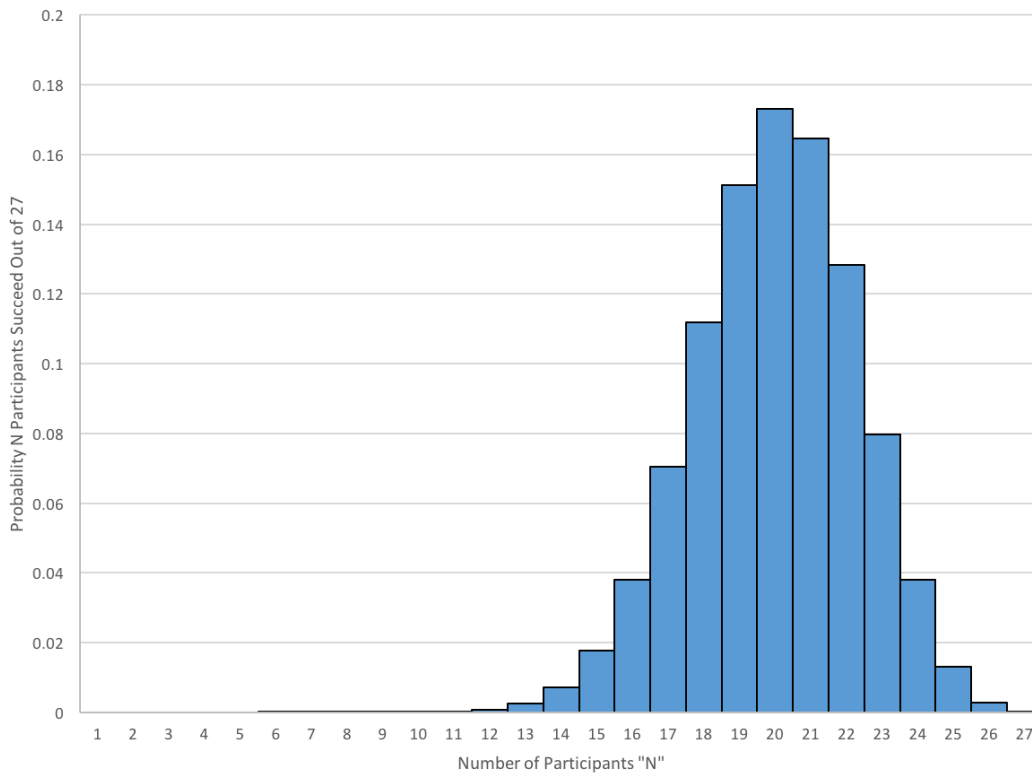

Figure 6.1.2. Binomial Distribution From Posen's Study [12]

In figure 6.1.1 and figure 6.1.2, the graphs display the probability of N participants successfully completing all experimental trial out of the total number of participants. For example, the probability of 7 students successfully completing the experimental trials in my study is 0.05, or 5%.

6.2 Wilcoxon Rank-Sum Test

The Wilcoxon Rank-Sum test is a non-parametric test that determines if the median of two independent samples are significantly different from one another. The null hypothesis is the two samples come from populations with the main medians.

Since the Wilcoxon test is a non-parametric test, the two populations do not have to be normally distributed. While binomial distributions can be approximated as normal distribution, my/the binomial distribution does not satisfy the requirements to be approximated as such.

To perform the rank-sum test, the samples from the two populations must be combined into one large sample. Then each sample is ranked, from 1 to r, where r is the size of the combined sample, based on the value of the sample. In case of a tie, where two samples have the same value, the samples with tied values are assigned a rank **randomly**. The mean of these randomly assigned ranks is assigned to each of the tied samples. For example, let sample a, b, and c have values of 5 and preliminary ranks of 7, 8, and 9 respectively. The final rank of sample a, b, and c would be 8. Note that ties are resolved only after all samples are given a preliminary ranking.

After ties are resolved, the samples are divided back up into their original populations, and the sum of the ranks of each population, R_1 and R_2 are calculated. R_1 and R_2 are compared with the sum of ranks, R, if each population had the same median. This determines if the sum of ranks are significantly different from what would be expected if the null hypothesis were true.

The binomial distribution only has two values, 1 and 0 for success and failure respectively. When combined, all successes and failures are tied in value. Thus, all success are given the same rank and all failures are given the same rank.

In this case, it was found that R_1 and R_2, the sum of ranks for my and Posen's data, were significantly different with $z = -2.2$, at $\alpha = 0.05$. Thus I reject the null-hypothesis that these two samples come from populations with the same median.

7
Conclusion

From the Wilcoxon test, we can see that the Emotiv Insight probably performs much worse than the Emotiv EPOC+ when used for BCI. Specifically, users of the Insight were significantly less likely to successfully complete all experimental trials than users of the EPOC+. The experimental trials mainly focused on the ability to train and use the left and right mental commands, qualities essential to successful BCI usage.

In the Insight's current iteration, with Emotiv's provided tools, I would not recommend the Insight for BCI work. I believe the Insight has potential to be a cheap, accessible, and useful device for BCI. In this moment, multiple improvements have to be made to bring the Insight to this point.

7.1 Software

Current research shows that the Insight produces useful data for BCI. With data processing methods and machine learning models tailored to the Insight, researchers were able to accurately predict user intention and differentiate between paired motor images [10] [13]. Thus, I currently believe that Emotiv's software must improve to make the Insight a viable device for BCI work.

Some might argue that since the Emotiv software works well with the EPOC+, that its detection suites are sufficient. However, it is well known that general machine learning models

are difficult to produce; models that might work for one device or one set of data are not guaranteed to work with another. The EPOC and the original software came out in 2009, with the EPOC+ released in 2013. The Insight came out afterwards, in 2015. It is not surprising that software made for the EPOC and EPOC+ would perform worse when used for the Insight. When custom methods were made for the Insight, the device performed satisfactorily.

Thus I propose Emotiv make the mental command training systems different between the EPOC+ and the Insight, to utilize the full potential of the Insight.

7.2   Training

Most participants found it much more difficult to use the mental commands than to train them. Thus, while the Emotiv software is able to use the Insight's data for training, the users are essentially guessing as to what features the Emotiv is actually using. They do not understand exactly what the Insight is learning, and thus do not understand how to effectively replicate the cognitive actions they trained the device on.

Thus I propose that a more robust training program is needed to more teach users how to effectively use BCI. This training program should clearly show which cognitive tasks the device learned. In real time, it should show the distance between the user's current cognitive task and the device's learned cognitive task. A brain map showing activations is one possible method for this type of teaching program, based off of Hwang's past work [5]. Another possibility for a training system is through robotic control, which is inherently real-time and facilitate user concentration, rather than staring intently at a computer screen [9].

Currently, Emotiv does have a program which details how far apart multiple mental commands are from each other, but this is insufficient. The program plots the "location" of the trained mental commands on a polar graph, with distance detailing how different the mental commands are. However, this is an abstract representation, and has no feedback about how the device is interpreting the user's current cognitive task. In addition, this program is only available through

Emotiv's desktop application, and not available for 3rd party developers, and is such inaccessible to a program like BrainBlocks.

7.3   Comfort

Finally, users complained about physical discomfort after using the Insight for a period of time. The cited cause of this was the rigidity of the Emotiv Insight, which does not allow any ability to adjust its size. Thus for many participants, the Insight tightly pressed against the temples and skull. This discomfort impairs concentration and promotes involuntary fidgeting to relieve the discomfort, both of which impairs the ability of the device to accurately read brain signals. Adding adjustability into the design of the Insight would only increase its usability for BCI.

7.4   Future Work

While my research increases the probability that the Insight with current Emotiv software is less effective than the EPOC+ under similar conditions, a larger study using non-parametric analysis techniques is needed to conclusively state this. With a larger data set, it becomes possible to use the various metrics collected, such as score and correctness, to compare the degree to which they are different.

Since the majority of my participants were unable to pass familiarization, a future topic of study is more effective training methods. I could research the best union of current training methods, combining brain maps with mental command distance and physical real world interaction. With research, such a training method might be able to let users who are BCI illiterate learn to use BCI's.

Appendix A
Consent Form

Project Title: Testing of a consumer grade EEG device for computer control

Researcher: Malcolm Au Gilbert

Faculty Advisor: Robert McGrail

Consent Form

I am a student at Bard College and I am conducting research for my Senior Project. I am studying the use of an electroencephalography (EEG) device to control a computer program and its effectiveness in regards to standard input controls.

During this study you will be asked to complete a number of tasks. These include playing BrainBlocks, a Tetris-like game that has been modified for brain computer interface (BCI) control, and completing a number of questionnaires. You will be tasked with training the BCI system to recognize mental commands, and use these commands to play the game. This experiment will take place in an empty lab at Bard, and is estimated to last 60 minutes, but will take no longer than 90 minutes.

Potential risks to the participant include minor eye strain caused by lengthy computer use. Minor hand strain may also occur from repeated keyboard action and there is a possibility of minor mental fatigue that accompanies elongated BCI interactions. There are no direct benefits to the participant, yet you will be allowed to use relatively new form computer interaction which

you may have not experienced before and will gain experience in the experimental process. For compensation for your time you can be entered into a lottery where a \$50 amazon gift card is available.

At any time you may discontinue the experiment or skip tasks for any reason and without penalty. Please inform the researcher if you choose to withdraw yourself. If you choose to do so you will remain eligible for any aforementioned compensation All responses to questionnaires and data associated with this study will remain confidential. All data and responses will be solely connected to a randomly generated unique participant ID number. There will be no link, digital or otherwise, connecting your name and email to your participant ID. Any information published from this experiment will not make it possible to identify you as a participant.

If you have questions concerning your rights as a participant of this study please contact the Bard College Institutional Review Board (irb@bard.edu). In addition, you can also contact my advisor Robert McGrail (mcgrail@bard.edu) concerning any research- related injury, or contact me (mg3128@bard.edu) for any further questions.

Participant Agreement:

I understand the purpose of this research. My participation in this test is voluntary. If I wish to stop the test for any reason, I may do so without having to give an explanation. The researcher has reviewed benefits and risks of this project with me. I am aware the information will be used in a Senior Project that will be publicly accessible online through the DigitalCommons and at the Stevenson Library of Bard College in Annandale on Hudson, New York.The information gathered in this study is confidential with respect to my personal identity. I understand that complete confidentiality cannot be guaranteed, since the researcher may be required to surrender data if served with a court order. All of my questions have been satisfactorily answered and I have been provided with the relevant contact information should I have any further inquiries. I have read the consent form and agree to be a participant in this study. By signing below, I agree to the participant's agreement and further confirm that I am 18 years of age or older.

Participant's Printed Name: _____

Participant's Signature: _____

Researcher's Signature: _____

Date: _____

Enter your name into a lottery for a $50 amazon giftcard? [   ]

Appendix B
Researcher's Experiment Script

<u>Prior to Consent Form:</u>

Before we can start experimental procedures, please read the Informed Consent Form. If you have any questions about the consent process or any of the items on the consent form, please feel free to ask me.

<u>After Consent Form:</u>

Thank you for agreeing to be a participant in this experiment, if you would like a photocopy of the consent form or an empty copy, please let me know. Here is a listing of your participant id number and your participant group number, as well as the game controls and mental command training tips. You will enter the IDs information at the beginning of each questionnaire and testing session. Please complete the Pre- Experiment Questionnaire open in the internet browser.

<u>After Pre-Experiment Questionnaire:</u>

We are now ready to begin with the first part of the experiment. You will play Brain Blocks, a Tetris variant, using typical keyboard controls. Have you played Tetris before?

Haven't Played: In Tetris, you manipulate colored blocks, all of which are composed of four smaller squares, and manipulate them such that the colored blocks form a solid horizontal line. You are given one block at a time, which starts at the top of the screen, which you can rotate

and move left and right, before it drops onto the ground. Once it drops, manipulation of the block is over, and the next block is available to move. When the blocks form a solid horizontal line, a point is scored, the horizontal line disappears, and all blocks above move down one row. The blocks can be rotated in quarter turns and moved left and right one block on the grid.

Have Played: In BrainBlocks, the blocks don't fall down, they stay at the top of the screen. The blocks start in rotation mode, where you press space bar to rotate them. Then you can press the down arrow to move to navigation mode, where you can move the blocks left and right. When you're satisfied with the position of the block, you can press down arrow to drop the block.

Begin: Please enter your participant ID and group ID, select normal mode and click start. This will begin the familiarization trial, then freeplay. Please click pause during the stage before you ask any questions or if you feel like taking a break. This will take about 8 minutes.

After Normal Mode:

I will now prepare the Emotiv Insight. While I am doing so please review the BrainBlocks control sheet and let me know if you have any questions.

Insight Ready: I will now place the Emotiv on your scalp and establish connection with the computer.

Bad connection: Unfortunately I was not able to establish the required signal connection for this experiment. This means this is the end of the experiment, your name will still be entered into the lottery if you marked the appropriate box on the consent form. Thank you for your time. **END**

Good Connection: Connection has now been established

Pre-Session:

Before BCI Control: I would like to take this moment to give you some tips on how best to train and use the Emotiv Insight. Everything I say is summarized on your mental command training tip sheet. Prior to starting the experimental trials, you will first be asked to train your

unique mental commands of Left, Right, and Neutral. This process will start by training neutral, this will form the baseline to which other mental commands are compared. Each training period takes 8 seconds.

Neutral: When training neutral it is important that you stay mentally and physically calm for the entirety of the training period. Limiting eye movement and blinks is also useful in not polluting the training data. Having good posture, with your back straight helps with this. Once neutral is successfully trained you will be prompted to train your first mental command. Key to this stage is to visualize the command to be trained without tensing your muscles, clenching your jaw, or blinking excessively. For example imagine gripping the bars of a cage. When training left, imagine pulling the bars of the cage farther apart. When training right, imagine pushing the bars closer together Another visualization you may want to try is visualizing clenching your left hand when training left and visualizing clenching your right hand when training right. These are just examples, feel free to use your own visualization however it is best to keep them simple like the examples.

Tips: Successful training requires consistent visualization throughout the entire 8 seconds. Successful use of the trained command requires the ability to recreate the visualization used for training. Once you have trained your first action twice you must pass a trial before being allowed to train your next command. You may clear the training data of your commands if you feel like your mind wandered during the training period, or if you moved (cough, shift in chair), or if you are unable to pass the trial. To restart the training process clear the neutral training data. You will be given 30 minutes to attempt to pass this stage; you will be notified when you have 10 minutes remaining. The BCI Training Tips summarizes what I have just told you. Do you have any questions about the training or the trials? (Answer Questions)

After Training Speech: We are now ready to begin. Enter your participant ID and group ID and select Brain Mode and click start. Be sure not to clench your jaw and to move as little as possible during the session. Please click pause during the stage before you ask any questions or if you feel like taking a break.

<u>During Session</u>: (Answer any questions participants have, be sure they are in a pause when this occurs)

BrainBlocks TimeOut: You have exceeded the allotted time for this stage of the experiment. This means this is the end of the experiment, your name will still be entered into the lottery if you marked the appropriate box on the consent form. I will now remove the headset, and then please fill out post-experiment questionnaire.

<u>Post-Session:</u>

Session Done: This concludes the gameplay component of the experiment. Please again fill out the post-session questionnaire in the open internet browser.

Section Session Questionnaire Finished: This is the end of the experimental procedures. The winners of the raffle will be notified by email at the end of the semester. Thank you again for your participation in this study. **END**

Appendix C

Brain Blocks Control Sheet

Normal Mode	BCI Mode
<u>Orientation Mode</u>	<u>Orientation Mode</u>
Spacebar: Rotate Block	*Blink:* Rotate Block
Down Arrow: Switch to Navigation Mode	*Down Arrow:* Switch to Navigation Mode
<u>Navigation Mode</u>	<u>Navigation Mode</u>
Up Arrow: Switch to Orientation Mode	*Up Arrow:* Switch to Orientation Mode
Left Arrow: Move Block Left	*Left Mental Command:* Move Block Left
Right Arrow: Move Block Right	*Right Mental Command:* Move Block Right
Down Arrow: Drop Block	*Down Arrow:* Drop Block

Preview Block:

The grey preview block shows you where your block would drop given the current position and orientation. The preview block changes shade when you switch between orientation and navigation mode. It is darker in orientation mode and lighter in navigation mode.

Appendix D
Mental Command Training Tip Sheet

<u>General:</u>

- Each training period takes 8 seconds to complete.

- If you have any questions please pause the game before asking

<u>Rules of Training Stage:</u>

- Neutral must be trained first, this data becomes the baseline to which all mental commands are compared.

- You must train each command (not including neutral) twice before starting the mental command trial.

- Training data for left and right can be cleared. If this is done you must retrain twice before being allowed to attempt the trial again.

- Clear neutral training data to start again. (This will also clear all previously trained data for left and right).

- When to clear:

    - Mind wanders during the training period.

   – Physical movements during training period (e.g. cough, shifting in chair).

   – Inability to pass mental command trial

- After a test is passed, the mental command that was being tested can no longer be trained.

- You are given 30 minutes to pass this stage

Training Neutral:

- Remain mentally and physically relaxed throughout the duration of the training.

- Limit blinking or do not blink at all.

- Breath steadily and normally.

Training Left and Right:

- Do NOT tense your muscles during training, this will pollute the training data.

- Maintain your chosen mental command thought consistently over the entire training period.

- Some visualization examples to get you started

   – Example 1: Imagine gripping the bars of a cage. When training left, imagine pulling the bars of the farther apart. When training right, imagine pushing the bars closer together

   – Example 2: When training left, imagine clenching your left fist. When training right, imagine clenching your right fist.

   – Example 3: Imagine a ball of fluid in a cage hovering in front of your eyes. When training left, imagine that ball squeezing through the left side of the cage.

- If you like, you can also imagine a musical phrase or passage

- Successful training requires consistency and focus, the ability to replicate these visualization will assist BCI in classifying your mental commands more accurately.

Appendix E
Pre-Experiment Questionnaire

(circle one or fill in the blank)

Participant ID: _____

1. Gender: _____

2. Handedness

   Left/Right/Ambidextrous

3. Age: _____

4. Have you ever used a Brain-Computer Interface (BCI) before?

   Yes/No

5. If yes, how successful were you in controlling a computer through the BCI?

   (Not Successful) 1 2 3 4 5 (Very Successful)

6. Do you play video games?

   Yes No

7. If yes, approximately how many hours a week do you play video games?

Appendix F
Post-Experiment Questionnaire

(circle one or fill in the blank)

Participant ID: _____

1. How difficult did you find training the mental commands?

   (Not Difficult) 1 2 3 4 5 (Very Difficult)

2. How difficult did you find using the mental commands?

   (Not Difficult) 1 2 3 4 5 (Very Difficult)

3. What visualization did you use to successfully train the left and right mental commands?

   Left: _____

   Right: _____

Bibliography

[1] Nils Berg and Peter Aoun, *Moving an on-screen cursor with the Emotiv Insight EEG headset:An evaluation through case studies*, 2018, Blekinge Institute of Technology Bachelor Thesis.

[2] Emotiv (2019), *Insight User Manual*, https://emotiv.gitbook.io/insight-manual/.

[3] Marcel van Gerven, Jason Farquhar, Rebecca Schaefer, Rutger Vlek, Jeroen Geuze, Anton Nijholt, Nick Ramsey, Pim Haselager, Louis Vuurpijl, Stan Gielen, and Peter Desain, *The brain-computer interface cycle*, Journal of Neural Engineering **6** (2009), 041001.

[4] S. Halder, D. Agorastos, R. Veit, E.M. Hammer, S. Lee, B. Varkuti, M. Bogdan, W. Rosenstiel, N. Birbaumer, and A Kübler, *Neural mechanisms of brain-computer interface control*, NeuroImage **55** (2011), 1779–1790.

[5] Han-Jeong Hwang, Kiwoon Kwon, and Chang-Hwang Im, *Neurofeedback-based motor imagery training for brain-computer interface (BCI)*, Journal of Neuroscience Methods **179** (2009), no. 1, 150 - 156.

[6] Luis Fernando Nicolas-Alonso and Jaime Gomez-Gil, *Brain Computer Interfaces, a Review*, Sensors **12** (2012), no. 2, 1211-1279.

[7] Sarah North, Adnan Rashied, Jason Walters, Ahmad Alissa, Josh Cooper, Eric Rawls, Cheyenne Sancho, Utku "Victor" Sahin, Kate Randell, and Heather Rego, *Performance Analysis of Brain-computer Interfaces in Aerial Drone*, Proceedings of the ACMSE 2018 Conference, ACMSE '18, ACM, New York, NY, USA, 2018.

[8] Minkyu Ahn and Sung Chan Jun, *Performance variation in motor imagery braincomputer interface: A brief review*, Journal of Neuroscience Methods **243** (2015), 103 - 110.

[9] Aiganysh Orozbakova, *Control of Robot Through Brain Computer Interface*, American University of Central Asia, 2019, Bachelor's Thesis.

[10] S. Pathirana, D. Asirvatham, and G. Johar, *A Critical Evaluation on Low-Cost Consumer-Grade Electroencephalographic Devices*, 2018 2nd International Conference on BioSignal Analysis, Processing and Systems (ICBAPS), ACMSE '18, ACM, New York, NY, USA, 2018, pp. 160-165.

[11] Pan Peining, Gary Tan, Aung Aung, and Aung aung Phyo wai, *Evaluation of Consumer-Grade EEG Headsets for BCI Drone Control*, 2017.

[12] Elias Posen, *Is there Joy Beyond the Joystick?: Immersive Potential of Brain-Computer Interfaces*, Bard, Annandale-on-Hudson, 2018, Bard Senior Project.

[13] Osmalina Rahma, Rimuljo Hendradi, and Fadli Ama, *Classifying Imaginary Hand Movement through Electroencephalograph Signal for Neuro-rehabilitation*, Walailak Journal of Science and Technology (WJST) **16** (2018), no. 12, 943-953.

[14] Erik K. St. Louis and Lauren C. Frey, *Electroencephalography (EEG): An Introductory Text and Atlas of Normal and Abnormal Findings in Adults, Children, and Infants*, American Epilepsy Society, Chicago, 2016.

[15] E. Stoelinga, *Exploring the possibilities of the Emotiv Insight: discriminating between left- and right-handed responses*, 2018, Bachelor's Thesis.

[16] Matthew Turner, Darryl Burnet, and Jessica Turner, *Expanding EEG research into the clinic and classroom with consumer EEG systems* (2017).

[17] Martina Zabcikova, *Visual and Auditory Stimuli Response, Measured by Emotiv Insight Headset*, MATEC Web Conf. **292** (2019), 01024.