Educational Neurogaming: EEG-Controlled Videogames As Interactive Teaching Tools For Introductory Neuroscience

David Schwarz[1], Vivek Subramanian[1], Katie Zhuang[1], Christine Adamczyk[2]

[1] Center for Neuroengineering, Duke University, Durham, NC 27710
[2] Center for Science Education, Duke University, Durham, NC 27710

Abstract

In order to advance the field of neuroscience, we must continue motivating youth to pursue science education. In this report we tested the idea of combining neurogaming with education. We developed a pair of electroencephalography (EEG)-controlled neurogames using inexpensive and/or free tools to teach students about the fundamentals of neuroscience and brain machine interfaces (BMI) through a fun, interactive activity. We report on the particular concepts they allowed us to introduce, the techniques and methods we used, and the effect of the activities on stimulating students' interest in neuroscience, and discuss how to optimize the learning experience. We conclude that educational neurogames could be a key tool for furthering and motivating neuroscience education.

1. Introduction

Neuroscience is exceedingly important as a basic and clinical field of study. International, interdisciplinary scientific endeavors such as the Human Brain Project (Human Brain Project, 2012), the BRAIN initiative (NIH Advisory Committee to the Director, 2013), and the WalkAgain Project (The International Neuroscience Network Foundation, 2007) are examples of its nearly universal public and private support. As we explore more complex problems in the field, generating interest in youth becomes ever more important.

Videogames are commonplace among today's youth, with almost equal gender representation (Electronic Software Association, 2013). Recently, the development of inexpensive brain computer interfaces (BCI) has made neurogaming, the use of brain signals as videogame input, a possibility. Previously, non-invasive BCIs based on electroencephalography (EEG) have showed reliable control performance (Bierbaumer, 2006), but medical-grade EEG technology was and still is prohibitively expensive. While in early stages, inexpensive consumer BCIs such as the Emotiv Insight (Emotiv, 2014) and the Neurosky Mindset (Neurosky, 2014) have potential as tools that enhance the understanding of basic neuroscience principles using novelty and fun, making them a unique platform for education.

Here we propose a position for motivating aspiring neuroscientists in the digital age, exploiting these recent advances by developing simple educational neurogames; interactive experiences coupled with relevant educational concepts. We prototyped two ideas under this concept: a game based on Pong (BrainPong) with motor imagery-controlled paddles, and a game inspired by Geometry Wars (EmoBlaster) with emotionally mediated difficulty and game behavior. These games allow us to embed neuroscience concepts of cortical function, electrophysiology, and neuronal biology into a relatable framework that is relatable with youth, generates interest in continuing scientific careers, and provides opportunities for discussion on the clinical relevance of basic neuroscience, such as neuroprosthetics, feedback therapy, and rehabilitation.

2. Methodology

2.1. EEG headset and setup

Since accessibility was important, we used an inexpensive, commercially available BCI headset for recordings. The Emotiv EPOC is a wireless EEG-recording system that allows for recording of neural activity (128 Hz sampling rate, 16 bit analog-to-digital converter). Fourteen sensors are placed primarily around the prefrontal and frontal regions of the brain. The wireless system allows for freedom of movement, and the built-in gyroscope keeps track of the user's orientation. The sensors are padded with felt, and are considered "wet sensors": a conductive solution, saline, is required for operation. Preparation of the Emotiv headset was the most time consuming step of the activity. Because of this, we enlisted the help of tutors; neuroscience graduate students and advanced undergraduates with neuroscience background who assisted with teaching and setup of the Emotiv headset. A few additional preprocessing steps expedited setup significantly, including preparation of the felt sensors with saline and mounting them on the headset prior to the activity, training the tutors on the Emotiv software suite, and enlisting help of students when necessary. For BrainPong, two headsets per student pair were required per session. For EmoBlaster sessions, only one headset per session was needed. Multiple sessions could be held in parallel as long as there were tutors available. For our group interactions, we acquired ten Emotiv EEG headsets, for a maximum of five concurrent sessions. Since the headsets are wireless, multiple headsets could interfere with each other. To prevent connection issues, students were separated into different rooms.

2.2. Neurogames and educational concepts

The main goal during development was to develop an approach that was easy to interface with the EEG headsets. Both games were developed by the authors with existing game development frameworks and free open source software (FOSS). Both applications are open source, and additional details can be found in the source code.

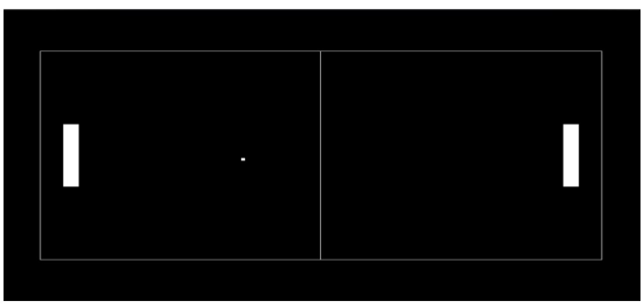

Figure 1. Screenshot of BrainPong game.

2.2.1. BrainPong

The aptly named BrainPong (Fig. 1) was developed on C++ using the cocos2dx framework. It uses two Emotiv headsets for literal head-to-head competition. After setup, the students trained on motor imagery, classifying states with two discrete labels, “Lift” and “Drop”. These actions were then used to raise and lower the Pong paddle. We performed this training using the Emotiv Cognitive processing suite (these use common spatial parameters and linear discriminant analysis for classification). Two students could then play Pong by moving the paddles with these thought evoked actions. The experience was open for questions about the discrepancy between control of the paddle with a keyboard and with trained EEG signals. A tutor guided the students on selecting salient motor commands while simultaneously explaining the role of motor cortex in motor plan generation and the resulting event related desynchronization (ERD) of EEG mu rhythms that are elicited (Pineda, 2005), as well as describing the somatomotor loops of motor action and proprioception (Valbo, et al., 1979).

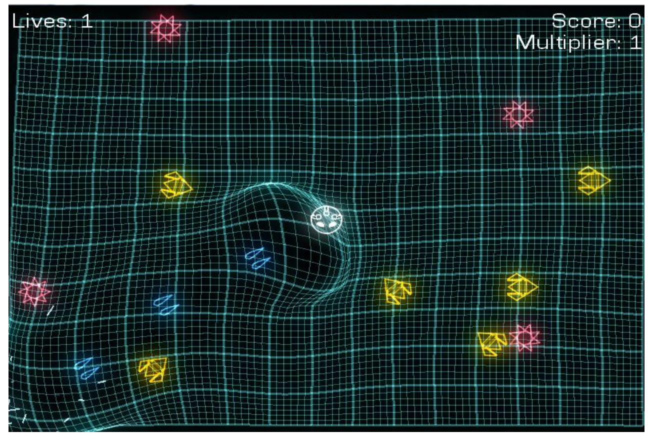

Figure 2. Screenshot of EmoBlaster. The grid in the background ebbs along the RGB color spectrum, dependent on the affective score.

2.2.2. EmoBlaster

Titled for the emotional measurements, EmoBlaster (Fig. 2) was developed on Microsoft’s XNA game framework using C#, with an open source game called ShapeBlaster as base. It is controlled like a traditional twin stick shooter, using a gamepad, with one analog joystick controlling movement of the player ship and another controlling the direction of firing. A single headset and the Emotiv Affective suite rated excitable/affective state by measuring several Z-scaled oscillations, including beta, considered to be associated with active concentration (Lalo, et al., 2007). The score drove a sigmoidal curve of inversely proportional enemy difficulty and health. Difficulty was represented as enemy speed and spawn rate. Feedback for these values was represented on the background grid with an RGB color value. Higher values (representing anxiety, loss of focus, or frustration) increased enemy health while reducing difficulty and red-shifting the background, while lower values (representing active thinking and calmness) inverted the enemy behavior and blue-shifted the grid. The players could also train a motor imagery action to clear the screen of all enemies as a special ability (rewarding good concentration). This posed the complex requirement of players to be mindful of the game and emotional state simultaneously. A tutor guided the player on relaxation techniques, while occasionally disrupting with prodding and jest in order to break focus. This allowed a conversation between the player, the tutor, and the spectators on emotional representation and the relevant brain structures, including prefrontal cortex’s role in decision making and relevant circuits (i.e. mesocorticolimbic circuit), the amygdala, and the hypothalamus, among others.

2.3. Interactive sessions

Most BrainPong sessions were performed during two years at the Duke Summer Science Sleuths Summer Camp, in collaboration with members of the Duke University Department of Biomedical Engineering and camp staff from the Duke Center for Science Education, with additional sessions occurring during scientific outreach activities in the Durham Museum of Life and Sciences. Sixty rising 8th to 10th graders participated in the camp, although only 10th graders participated in the activity. We characterized a session into four distinct phases: Introduction, Setup, Training and Gameplay. A session would start with a brief primer lecture: an introduction on the field of neuroscience, the activity, expectations, and open-ended questions. During setup, the tutors would briefly explain concepts of EEG recording, such as electrical conductance and how neurons generate potential. Next, students were divided and assigned to a corresponding tutor. Tutors would train the students on the activity as previously described, and guide them through the gameplay phase, then answer questions. Altogether, sessions lasted between one and two hours. After the camp, which consisted of two weeks of hands-on, context-based science activities, students were surveyed for their opinion of science and their interest in a science career.

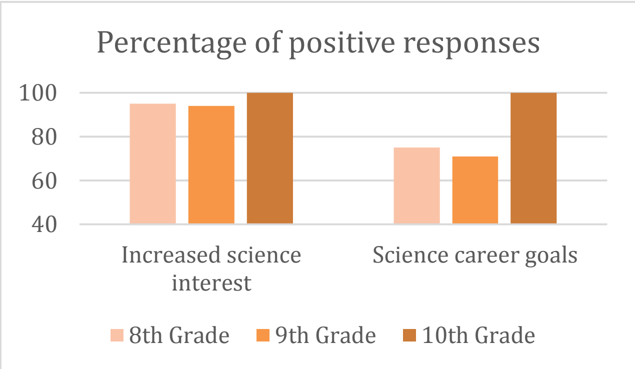

Figure 3. Percentage of positive (yes) responses to key questions in student survey.

3. Preliminary results

Polling showed that the Science Sleuths Camp as a whole has had an overwhelmingly positive effect on science interest in young students. Nearly all students expressed an increase in general science interest (Fig. 3). More interestingly, those who participated in our activity, the group of rising 10th graders, had the highest expression of interest in pursuing a scientific career.

Activity	Concepts
Introduction	Neuroscience as the study of the brain
Setup	Electroencephalography, electrophysiology, the action potential
Training	Basic brain anatomy, EEG oscillations
BrainPong	Motor imagery, role of somatomotor cortex
EmoBlaster	Emotion representation, role of prefrontal cortex, amygdala, hypothalamus

Table 1. Summary of activity- concept pairings.

4. Discussion

In this position paper, we showed a framework that could be used for enhancing neuroscience education in traditional curriculum (Table 1). While the evidence strongly suggests a positive motivational component in the activity, more specific surveying is required to ascertain the utility of neurogaming as a pedagogical tool. We also noted changes based on participant feedback. For example, we found that students had just as many questions during the Setup phase of a session as after the gameplay. This is likely due to the novelty of wearing the EEG device. Thus, we used this phase to continue the introductory lecture, focusing on the nature of BMIs and neural recording techniques. While the appreciation of the activity was overwhelmingly positive, some students expressed frustration at the lack of control. Since sessions allowed relatively short training periods, this was expected. We capitalized on this shortcoming by using it as a point of conversation for illustrating the problems of neuroprosthetics and the complex nature of the human motor system.

With further work, parts of the teaching experience could be built into the games themselves, automating the teaching and requiring less tutor guidance. This would require planning and conversations with more experienced pedagogues in order to design an optimal game/teaching balance. We also believe that additional concepts can be presented with different game designs. Our own designs were based on obvious properties: concepts of motor movement with motor imagery, and concepts of emotional structures with emotional game modulation. We would like to see conversations between game designers and neuroscientists on additional, optimal pairings between design and education. While more work is needed, principally pedagogical testing, we believe our framework has great potential as an educational tool.

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Source Code

Source code for BrainPong can be found at https://code.google.com/p/brainpong/. Source code for EmoBlaster can be found at https://code.google.com/p/emoblaster/. Both are licensed under LGPL.

References

Bierbaumer, N., 2006. Breaking the silence: brain-computer interfaces (BCI) for communication and motor control.. *Psychophysiology,* November, 43(6), pp. 517-532.

Electronic Software Association, 2013. *Sales, Demographic and Usage Data: Essential facts about the computer and videogame industry,* Washington, D.C.: Electronic Software Association.

Emotiv, 2014. *Emotiv EPOC,* San Francisco: Emotiv.

Human Brain Project, 2012. *The Human Brain Project Report,* Lausanne: HBP-Consortium.

Lalo, E. et al., 2007. Phasic increases in cortical beta activity are associated with alterations in sensory processing in the human. *Experimental Brain Research,* February, 177(1), pp. 137-145.

Neurosky, 2014. *Neurosky.* [Online] Available at: http://neurosky.com/ [Accessed 5 July 2014].

NIH Advisory Committee to the Director, 2013. *Brain Research through Advancing Innovative Neurotechnologies (BRAIN),* Bethesda: National Institutes of Health.

Pineda, J. A., 2005. The functional significance of mu rhythms: translating "seeing" and "hearing" into "doing".. *Brain Research. Brain Research Reviews.,* 1 December, 50(1), pp. 57-68.

The International Neuroscience Network Foundation, 2007. *The International Neuroscience Network Foundation.*
[Online] Available at: http://www.innf.net/walk_again.php [Accessed 5 July 2014].

Valbo, A. B., Hagbarth, K. E., Torebjork, H. E. & Wallin, B. G., 1979. Somatosensory, proprioceptive, and sympathetic activity in human peripheral nerves. *Physiological Reviews,* October, 59(4), pp. 919-957.