P300-Based 3D Brain Painting in Virtual Reality

Willie McClinton
University of South Florida
Tampa, FL 33620, USA
wmcclinton@mail.usf.edu

Derek Caprio
University of South Florida
Tampa, FL 33620, USA
derekc1@mail.usf.edu

Denis Laesker
University of South Florida
Tampa, FL 33620, USA
dlaesker@mail.usf.edu

Blanche Pinto
University of South Florida
Tampa, FL 33620, USA
bjpinto@mail.usf.edu

Sarah Garcia
University of South Florida
Tampa, FL 33620, USA
sarahgarcia@mail.usf.edu

Marvin Andujar
University of South Florida
Tampa, FL 33620, USA
andujar1@usf.edu

ABSTRACT

Brain Painting is a brain-computer interface (BCI) application that gives users the ability to paint on a virtual canvas without requiring physical movement [1-2]. Brain Painting has shown to improve the Quality of Life (QOL) of patients with Amyotrophic lateral sclerosis (ALS), by giving patients a way to express themselves and affect society through their art [1]. Although there is currently no known cure for ALS, through such outlets we can help mitigate the physical and psychological impairments of those living with ALS. This paper discusses the development and

CHI'19 Extended Abstracts, May 4-9, 2019, Glasgow, Scotland, UK.

ACM ISBN 978-1-4503-5971-9/19/05
DOI: 10.1145/3290607.3312968

testing of an immersive Brain Painting application using a Google brush-like tool in a 3D Environment, for able-bodied users. It also discusses how it can help provide a more immersive medium for users to express themselves creatively. In addition, we also discuss feedback received from a preliminary study on how the brush and application can be improved to better allow users to paint in VR using their brain.

KEYWORDS
Electroencephalography (EEG); P300; Brain-Computer Interface; Brain Painting; Event-related potentials (ERP); Virtual Reality (VR)

1 INTRODUCTION

The interaction of humans and machines is an exciting and emerging territory in computer science, especially in the field of BCI. Bringing aspects of Human-centered computing into this arena, especially where BCI is used as a mechanism for control, adds a novel dimension to research. In this study, we demonstrate the first group of able-bodied users painting with their brains in an immersive 3D VR environment.

The art of creative expression is considered to be, until this day, a purely human ability and skill. Art has taken many forms like sculpting, painting, etc. and we are introducing a new mechanism for creating art using only the brain. Brain Painting has shown to improve the quality of life(QOL) of patients with ALS, by giving the patients ways of expressing themselves and affecting society through art exhibitions [1]. Although there is currently no known cure for ALS, through such outlets, we can help mitigate the physical and psychological impairments of those living with ALS. We propose that P300-based Brain Painting using a Google brush-like application will help provide a more immersive medium for participants to express themselves creatively, by introducing a 3D environment. In order to understand if our novel 3D Brain Painting application elicits a more positive experience, we tested our system on participants without ALS. This allowed us to validate, as well as find improvements on our system before running trials directly with the ALS community. Although further research is needed to fully validate one's findings during the healthy patient trials, these trials accelerate the research process, due to the larger participant pool, and lead to more insights into aspects of user experience that both populations share. If the user experience and its usability is good, it is expected that the participants will be able to express themselves naturally through their brain paintings. In this research, we introduce our initial prototype of the 3D VR Brain Painting Application. Moreover, we also present the results from a conducted user study aimed at obtaining feedback on the applications' usability and further improvements.

2 RELATED WORK

The world's first Brain–computer interfaces (BCIs) that enabled creative expression in paralyzed patients were first introduced by a group at the University of Tübingen [1]. They investigated the efficacy and user-friendliness of P300-based Brain Painting, which is an application developed to paint pictures using brain activity only. The application used two screens for the painter: one screen displays the P300 matrix while another screen showed the painting canvas. The standard P300 speller matrix, proposed by Donchin et al, was adapted to contain symbols indicating different colors, objects, grid sizes, object sizes, transparency, zoom and cursor movement. They

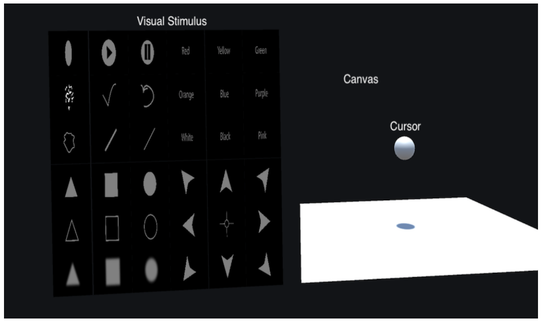

Figure 1: Brain Painting 3D Interface – On the left side, the 2D panel used for visual stimuli is shown. On the right side, the 3D Canvas and Cursor are shown.

Figure 2: User Device – A user wearing the G. Tec Nautilus EEG headset and Oculus Rift VR Headset using 3D BrainPainting.

showed the usability of P300s in painting applications and the qualitative results of peoples' experiences. Their 3 ALS subject user-oriented study got an accuracy of 70% and bit transfer rate of 4.41 bits/min during the brain painting trials, which reflects the accuracies and transfer rates in modern P300 applications.

This study was followed by an extended version of the first Brain Painting with a much greater selection and longer study [2]. They conducted a more extensive user study of 2 ALS patients during 27 home use days over 3.5 months to demonstrate how P300-based Brain Painting could be integrated into their everyday life to promote their QOL. Since their results are based on only 2 end-users, they could not be generalized to the population of potential users, but their achievement of high satisfaction with their participants demonstrates the benefit of adopting user-centered design in BCI development. Although Brain Painting in Virtual Reality has not been explored yet, there have been many other attempts to bring BCI into virtual reality through conventional methods like Motor Imagery, P300, SSVEP, and even Hybrid P300/SSVEP with much success [4] [5] [6] [7]. They have been used in applications for navigation [7], object control [6], and even movement [5] due to recent technological advancement in VR headsets and the design of BCI devices. Surprisingly, none of the new advancements have been utilized in the Brain Painting space, but in this research, we will explore the first glimpse of P300 Brain Painting in Virtual Reality.

3 SYSTEM DESIGN

For our brain-painting control interface, we use 16 dry-electrode channels with the G Tec Nautilus EEG device. We chose this device because it is lightweight, wireless, does not require electrode gel, and can collect high quality EEG data. These features allow for easy integration with the Oculus Rift head mounted display, which is used to project the canvas and brush to the user while painting. Electrodes will be placed at positions Cz, CPz, P1, P3, P5, P7, Pz, P2, P4, P6, P8, PO3, PO7, POz, PO6, and PO4 according to the 10-20 international system. These positions are located on the parietal lobe which is the most prominent for P300 [8].

3.1 User Interface

Our P300-based brain-computer interface for abstract painting in a 3D VR environment was developed using the Unity Game Engine (See Figure 1). The 3D environment is divided into two components comprising the total field of view seen on the Oculus Rift VR headset. The first component is used to incorporate the visual stimulus. This is done by displaying a 6 by 6 grid containing symbols that represent actions in a painting utility (i.e. movement, changing color, or switching brushes). The second component consists of a canvas where the painting takes place. A cursor, placed on the canvas, responds to a selected option from the Visual Stimulus panel. These include moving in ten directions (up, down, left, right, in, out, and all diagonals) in order to draw lines connecting the cursor's current position to its next position on the canvas. Other features of the application allow for printing shapes on the canvas, changing the color of the lines and shapes, size of brush, and rotating the object around the central axis (See Figure 3).

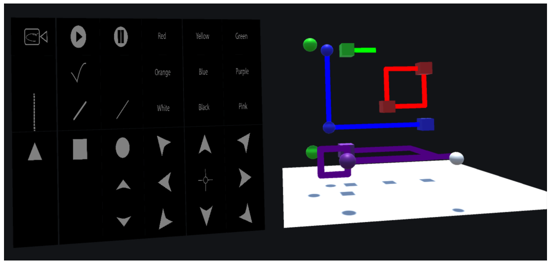

Figure 3: Brain Painting 3D Interface During Live Session– Options not yet implemented are left blank to let alert the user not to try selecting them.

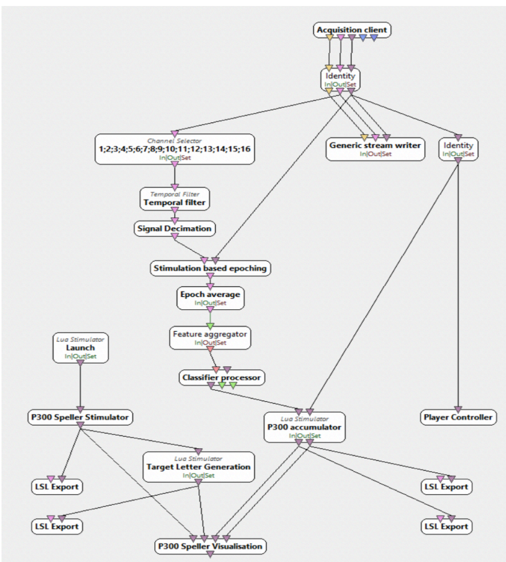

Figure 4: OpenVibe Online Task Scenario – This contains the coding blocks used to gather and classify data during the 3D Brain painting online task.

3.2 Control Interface

The control interface of our application was achieved via the use of OpenVibe, a software platform used to design and test brain-computer interfaces. We used OpenVibe as a mechanism to acquire and classify EEG data coming from the G.Tec Nautilus, as well as an application driver to manage the synchronization between our user interface in Unity and data acquisition from the G.Tec. As a base for the acquisition, training and the online task of our application, we used the already built-in P300 Speller within OpenVibe. We extended the application by creating a virtual environment in Unity on top of the existing OpenVibe application and established a communication link between our user interface and OpenVibe via the LabStreamingLayer (LSL).

Shown (See Figure 4) is the OpenVibe online task scenario. Identical to the filtering process done when training the LDA classifier, the online task reads and filters data coming from the Acquisition client using channels 1-16 (in the 1–20 Hz frequency band with a fourth-order digital Butterworth filter). The data is then decimated by a factor of 5 and cut into signal segments, averaging over the epochs. After the data is preprocessed, it is passed into the classifier trained from the acquisition step. The result of the classification is passed to Unity along with the interface variables via the LSL Blocks. The interface variables include information about the state of the P300 Speller. Our user interface in Unity, using the LSL4Unity library (https://github.com/xfleckx/LSL4Unity), receives the LSL data and then mirrors the instance of the P300 Speller on OpenVibe.

4 METHODOLOGY

This study consists of a pre-experiment survey which asks questions regarding demographics, experience with brain-computer interface devices, and the current affective state of the participant. Eight participants (five males and three females) participated in this study with an age range from 18 - 31. Approximately 75% of the participants had used BCI before, however, only 25% participants had previously interacted with the P300 Speller. Approximately 75% of participants reported being sleepy prior to taking the study with only 60% agreeing to being able to pay attention really well.

Affective state was determined using a PANAS survey [9]. The second part of the study consists of a training session where the participant is then asked to mount the G.Tec Nautilus device and Oculus Rift. After mounting the devices, the first step is to train the P300 using a Linear Discriminant Analysis (LDA) classifier. After 10 series of 12 flashes, the times when the elements containing the chosen symbols were flashed, P300 event-related potentials (ERP) will be elicited in the user. These ERPs are then detected by the trained LDA classifier, which is then transferred into commands to the paint utility. After training is complete, the participant goes through a short familiarization session in which they are asked to make five selections from the painting interface using P300. After the participant is familiarized with how to control the application, they can begin making their painting in a session of 10 or more commands. Moreover, although we have included a total of thirty-six options on the Visual Stimulus panel during the training session, we did not include some during the painting task. We did this for better integration with our control interface.

PANAS Survey Results

User ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Pre-Task PANAS Positive Score	31	30	36	17	33	27	50	33
Pre-Task PANAS Negative Score	17	15	10	10	13	16	11	11
Post-Task PANAS Positive Score	28	28	23	20	31	26	46	32
Post-Task PANAS Negative Score	29	14	11	10	11	17	11	10

Table 1: PANAS survey results after tasks for each user.

Therefore, we exclude the options that are not yet implemented whenever the task is being performed (Figure 3). The final part of the study is a post-survey. When finished with their painting, the participants are asked to answer a series of questions given by our team designed to gauge how intuitive they found our application and what improvements they would suggest for future development of the application.

5 RESULTS & DISCUSSION

Table. 1 represents the change in PANAS results of our preliminary study taken before and after using the application. The drop in the score is probably due to the long training times, participants stated that their alertness was hard to manage throughout the study. Further improvements on shortening the training time would be a good direction for remedying this issue. Furthermore, participants also provided feedback through a set of open-ended questions included within the post-survey. Six out of eight participants felt discomfort from wearing the combination of the G.Tec Nautilus and Oculus Rift. Five mentioned they would use the application recreationally. Multiple participants had similar responses, stating that the application was "relatively intuitive", the "menu options were simple and clear", and that they "enjoyed the concept of painting with [their] brain, it is an interesting way to practice self-expression in a new form". Therefore, such responses indicate positive attitudes toward using this application and its potential. On the other hand, when asked what improvements can be made to the application three of the eight participants mentioned improving the accuracy. Although accuracy was not strictly measured during the free drawing session the users self-reported their accuracies and were often reported as underperforming less than 60%. Accuracy for the classifier on training data was calculated via 10 way cross-validation and were in the ranges of 50%-80% for all participants. A reason for the poor accuracy on testing can be due to the selection speed at which the next action has to be taken and the constant shifting of attention between the commands and the canvas. Other participants mentioned training times, the device's comfortability, and the dark lighting of the environment as places for improvement. All which should be addressed in future iterations of 3D Brain Painting.

In this paper, we have mentioned how brain painting has shown potential to improve the QOL of those considered "locked-in". We sought to build on that promise by improving traditional brain painting applications. However, the feedback we obtained from our preliminary study shows us improvements we need to make to better meet this promise. For instance, we should explore ways of shortening the training process in order to more effectively hold users' attention as most participants mentioned a decrease in their alertness and attentiveness. Additionally, decreasing the time and possibly developing the application for the Oculus Go instead of the Rift, may also make wearing the combination of the G.Tec and VR Headset more bearable as many participants reported an increased level of irritability and mentioned discomfort from the equipment. Some participants also expressed how the dark color scheme of the environment made them feel "sleepy" and lose focus, which is why we intend on using a lighter color palette in future prototypes. In spite of the improvements that remain to be made, participants provided mostly positive feedback. The majority stated that controlling the brush and canvas was intuitive and natural. Participants also expressed an overall enjoyment using our prototype and most stated that they would use it recreationally.

6 CONCLUSION/FUTURE WORK

In this paper, we have described our application for 3D brain-painting in VR. Although the use of VR in BCI applications is not new idea and neither is P300-based Brain Painting, the combination of the two creates and immersive medium where users have a novel experience painting. We have stressed how this application would be beneficial to people with ALS as a means to express themselves creatively, therefore improving their QOL. We have also explained how the user and control interfaces communicate between each other and achieve our desired functionality. In addition, by conducting a user study, we have received feedback on how to improve our application including: improving comfortability, using a brighter user interface, and find mechanisms to hold attention better during play. The next step is to improve on the system based on the comments given through the user study and run a larger study strictly comparing the benefits of our 3D interface over the traditional 2D interface.

REFERENCES

[1] Münßinger, J. I., Halder, S., Kleih, S. C., Furdea, A., Raco, V., Hösle, A., & Kübler, A. (2010). Brain Painting: First Evaluation of a New Brain–Computer Interface Application with ALS-Patients and Healthy Volunteers. Frontiers in Neuroscience, 4. doi:10.3389/fnins.2010.00182.

[2] Botrel, L., Holz, E., & Kübler, A. (2015). Brain Painting V2: Evaluation of P300-based brain-computer interface for creative expression by an end-user following the user-centered design. Brain-Computer Interfaces, 2(2-3), 135-149. doi:10.1080/2326263x.2015.1100038.

[3] Study protocol for the World Health Organization project to develop a Quality of Life assessment instrument (WHOQOL). (1993). Quality of Life Research, 2(2), 153-159. doi:10.1007/bf00435734.

[4] Koo, B., & Choi, S. (2015). SSVEP response on Oculus Rift. The 3rd International Winter Conference on Brain-Computer Interface. doi:10.1109/iww-bci.2015.7073028.

[5] Koo, B., Lee, H., Nam, Y., & Choi, S. (2015). Immersive BCI with SSVEP in VR head-mounted display. 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). doi:10.1109/embc.2015.7318558.

[6] Chun, J., Bae, B., & Jo, S. (2016). BCI based hybrid interface for 3D object control in virtual reality. 2016 4th International Winter Conference on Brain-Computer Interface (BCI). doi:10.1109/iww-bci.2016.7457461

[7] Bevilacqua, V., Tattoli, G., Buongiorno, D., Loconsole, C., Leonardis, D., Barsotti, M., . . . Bergamasco, M. (2014). A novel BCI-SSVEP based approach for control of walking in Virtual Environment using a Convolutional Neural Network. 2014 International Joint Conference on Neural Networks (IJCNN). doi:10.1109/ijcnn.2014.6889955

[8] Manyakov, N. V., Chumerin, N., Combaz, A., & Hulle, M. M. (2011). Comparison of Classification Methods for P300 Brain-Computer Interface on Disabled Subjects. Computational Intelligence and Neuroscience, 2011, 1-12. doi:10.1155/2011/519868

[9] Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. Journal of personality and social psychology, 54(6), 1063.