BrainBrush, a Multimodal Application for Creative Expressivity

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***Abstract*—We combined the new developments of multimodal Brain-Computer Interfaces (BCI) and wireless EEG headsets with art by creating BrainBrush. Users can paint on a virtual canvas by moving their heads, blinking their eyes and performing selections using a P300 BCI. A qualitative evaluation (n=13) was done. A questionnaire was administered and structured interviews were conducted to assess the usability and user experience of the system. Most participants were able to achieve good control over the modalities and able to express themselves creatively. The user experience of the modalities varied. The use of head movement was considered most positive with the use of eye blinks coming in second. Users were less positive about the use of the BCI because of the low reliability and higher relative cost of an error. Even though the reliability of the BCI was low, the BCI was considered to have an added value: the use of BCI was considered to be fun and interesting.**

***Keywords*-Creative Expression, Brain-Computer Interface, Multimodal Interaction, P300**

I. Introduction

The act of creative expression is considered by many to be a purely human ability and skill [1]. Creative expression allows humans to express their identity and it can take multiple forms: for instance making music, dancing, painting, writing or acting. Apart from these more traditional forms of art, new art forms have emerged, such as computer art, motion graphics and the use of virtual reality environments for art.

In recent years, a neurorevolution has taken place in which neurotechnology is a hot topic. For instance, research has been done on improving task performance using neurotechnology. Some athletes now use neurofeedback training to enhance their performance by managing the stress of training and competition [2]. Furthermore, Ros et al. have shown that the microsurgical skills of ophthalmic microsurgeons can be improved significantly with neurofeedback training [3]. Neurotechnology has even been applied to the field of economics, creating the science of neuroeconomics: combining neuroscience, economics and psychology to explain the human decision making process [4]. In neuromarketing, neurotechnology is used to research why consumers make certain choices: for instance, why consumers prefer either Pepsi or Coca Cola [5]

Brain-Computer Interfaces (BCIs) are another example of research in the field of neuroscience are. A BCI provides a direct interface between a human brain and a computer, without using peripheral nerves or muscles. For years BCI research has mainly focused on assistive technology for people with disabilities. For instance, patients with the motor neuron disease Amyotropic Lateral Sclerosis (ALS) can now benefit from BCIs like the P300 speller [6], brain-controlled wheelchairs [7] or BCIs to control their environment [8].

In recent years, BCI research has also focused on applications for healthy people. One example is the ‘NeuroPhone’ system developed by Campbell et al. which allows neural signals to drive mobile phone applications on an iPhone using a wireless EEG headset, for instance to dial a phone number using the same principles as the P300 speller [9].

Furthermore, research is being done on incorporating BCI technology in games. Plass-Oude Bos et al. developed AlphaWoW, incorporating BCI in the game ‘World of Warcraft®’ [10]. They used alpha waves in the EEG for automatic adaptation of the avatar shape from bear to elf and vice versa. Gürkök et al. used SSVEP for sheep herding in the game ‘Mind the Sheep!’ [11].

BCIs can also provide a unique link between the source of creativity, the brain, and art. Christoph De Boeck created a responsive environment, Staalhemel (http://www.staalhemel.com), where 80 steel segments are suspended in a room, above the visitor’s head. The visitors wear a portable EEG headset and as they walk through the room, tiny hammers are activated by their brainwaves, tapping rhythmical patterns on the steel segments.

Other examples of the use of Brain-Computer Interfaces for art include the ‘Brain-Computer-Music Interface’ which enables a disabled person to create music [12], and the ‘Câmara Neuronal’, a performance where the brain signals of the performer are translated into audio and visual compositions (http://projects.jmartinho.net/3486412/Camara-Neuronal-Video-Teaser).

The German artist Adi Hösle, in cooperation with the Institute of Medical Psychology and Behavioural Neurobiology at the University of Tübingen, designed the application ‘Brain Painting’, a painting application which is controlled using a BCI and enables paralyzed patients to express themselves creatively. In ‘Brain Painting’, all actions are

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performed using the P300 paradigm. The system uses two screens for the painter: one screen displays the P300 matrix while another, larger, screen shows the painting canvas. The standard P300 speller matrix, containing characters and numbers, was adapted to contain symbols indicating different colors, objects, grid sizes, object sizes, transparency, zoom and cursor movement. By repeatedly making selections using this P300 speller matrix, users can paint pictures on the virtual canvas. In the first evaluation of the 'Brain Painting' application, with 3 ALS-patients and 10 healthy subjects, both the ALS-patients and the healthy subjects were able to use the application with high accuracies: during a copy-painting task, the ALS patients achieved an average copy-painting accuracy of 70.18% while the healthy subjects scored an average accuracy of 80.53% [13]. One participant in the 'Brain Painting' study, who was severely disabled due to ALS, described her experience with the system: *"I am deeply moved to tears. I have not been able to paint for more than 5 years. Today I again had butterflies in my stomach, a feeling that I have missed for so much, so much* [sic]. *I was so sad, I was plagued by fears of loss, I was in shock because I could not paint. For me the picture I have created is so typical for me, no other paints in my style, and despite five years of absence, I am simply an artist again; I'm back to life!"*. Even though this feedback is very positive, the artistic freedom of the painter is limited due to the fact the cursor cannot be moved freely; the cursor can only be moved in a predetermined grid.

In continuation of the 'Brain Painting' research, Holz et al. developed the 'Brain Drawing' application to overcome the cursor movement limitation of the 'Brain Painting' system. In the 'Brain Drawing' application, imagined movement is used to control the cursor when drawing. During the first evaluation with 1 subject, the subject performed a Copy Drawing task in which he was instructed to draw a simple object (circle, ellipse or rectangle) on a virtual canvas. Holz et al. considered 4 out of 36 copied drawings to be succesful by visual inspection and the subject found it very difficult to draw. The subject had to focus his attention for a long period because he continuously had to imagine movement, which resulted in high workload [14].

Todd et al. used two different BCIs in their research on how creativity can be supported and assessed using a BCI [15]. With their first BCI, users could only control a drawing cursor in horizontal and vertical directions by looking at one of four LEDs placed at the top, bottom, left and right of the screen. The cursor would move in the direction of the LED the user looked at, and continue drawing in that direction until the user looked at another LED. For the second application, the four LEDs were mapped onto four shapes (circle, star, square and line). After choosing a shape, the shape would be drawn on the canvas. Users did not have any control over the position, size or color of the shapes. Todd et al. concluded that relying completely on the efficiency of a BCI for image production is not practical as BCI technology is not yet mature enough for 100% reliability. A possible solution they suggest is to create a hybrid, or multimodal, BCI by combining a BCI with other input modalities such as an eye-tracker.

These examples show that the focus in BCI research should shift from reliability to usability and user experience as is also reported by the FutureBNCI roadmap [1]. This shift in focus is necessary in order for BCIs to migrate out of the lab and into society. Healthy persons can choose from various alternative input modalities. For healthy persons to choose for BCI, the user experience and usability must be adequate. Most people have never used a BCI and the novelty of this new technology can be a reason for people to decide to use a BCI instead of alternative input modalities, even if a BCI is less reliable and slower. However, if the user experience and usability are not good, people are expected to choose a different input modality which provides a better user experience and usability. Due to the fact that the focus in BCI research has mainly been on the reliability, no standardized methods to assess the user experience for BCIs exist yet. Gürkök et al., Plass-Oude Bos et al. and Van de Laar et al. addressed the need for standardized methods to assess the user experience for BCIs [16], [17], [18]. Van de Laar et al. proposed a questionnaire consisting of a core containing general questions and modules for the different kinds of mental tasks and ways of interacting with the BCI [19].

In this study, we combined the new developments of multimodal BCIs and wireless EEG headsets with art by creating a multimodal interactive system (called BrainBrush) which allows healthy persons, but possibly also patients, to express themselves creatively. We evaluated this system to explore how the different modalities contribute to the user experience and whether BCI has an added value for this system.

II. Methods

First we will describe how BrainBrush was developed and how the design choices were made. Second we will outline how we set up our experiment to evaluate the system.

A. Development of BrainBrush

BrainBrush (see figure 1) was developed in a two step iterative process. The outcome of the first evaluation and how this influenced our design choices is however beyond the scope of this paper. For a more in-depth description see the work by Brugman [20].

We aimed to design the BrainBrush system in such a way that it would be appealing to healthy persons and would also be usable for patients who had lost control from their neck down (e.g. due to spinal cord injury). We expected healthy persons would find it appealing to be able to operate the BrainBrush system using only head movement, eyeblinks

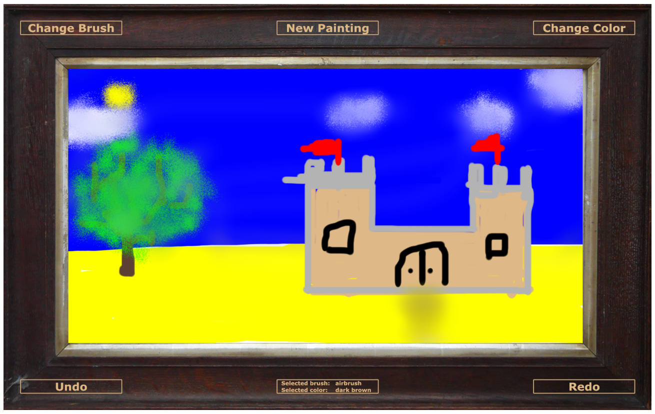

Figure 1. User interface in Painting mode with the 'New Painting' menu option at the top and the 'Undo' and 'Redo' menu options at the bottom

Figure 2. User interface during brush selection showing the 11 available brushes and the eraser

and brain activity because it is completely different to how healthy people normally use a computer. For patients who do not have control over their limbs, it is a necessity to be able to operate the system using nothing else than the described modalities.

Head movement, the P300 speller and eyeblinks were used as the input modalities for the BrainBrush system. Head movement has been used successfully in the past as an input modality, for instance to control a cursor [21]. Furthermore, the P300 speller has proven to be a robust BCI paradigm [22] and has been used in many BCI systems. The P300 signal is a positive deflection in the ongoing EEG signal observed roughly 300ms post stimulus over the centro-parietal area of the skull [6]. Finally, eyeblinks have been used for communication systems for ALS patients, such as the system for making selections on a computer screen proposed by Takeshita et al. [23]. However, the eyeblinks are usually detected using a camera and image processing techniques, instead of using an EEG headset. Chambayil et al. have shown promising results for their virtual keyboard BCI which uses eyeblinks to select characters [24]. All three modalities can be captured by one device: the Emotiv EPOC, using the EEG sensors and built-in gyro sensors.

The task of creating a brushstroke requires the system to provide users with a way to signal when they want the paintbrush to be put to the canvas and to signal once again when they want to take the paintbrush off the canvas, thereby ending the brushstroke. This on/off switch for the paintbrush has been implemented by detecting intentional eyeblinks in the EEG data based on an algorithm by Plass-Oude Bos et al. [25]. A template was constructed out of an EEG recording with 40 intentional eye blinks. A threshold is set for the Euclidean distance between the template and the live EEG data over channels AF3 and AF4. Both template and window have a length of 103 samples. When the Euclidean distance is below the threshold on either of the channels the on/off switch is triggered.

Head movement was implemented by using the gyro sensors of the Emotiv EPOC headset. An application called the *Mouse Emulator* is provided with the device and was used to convert head movement into cursor movement in order to move the paintbrush across the virtual canvas.

In BrainBrush, we use P300 speller grids for the selection of brushes and colors because the P300 speller is suitable for making selections from a large set of options in a relatively short period of time [26], compared to other Brain-Computer Interfacing paradigms. In a study performed by Guger et al. with healthy participants, 88.9% of the participants were able to achieve at least 80% accuracy using the P300 speller paradigm [22], showing the robustness of the P300 signal. Although, we suspect a lower accuracy in our system because of the lower signal quality of the EPOC hardware. For BrainBrush, we use the original grid structure, but instead of grids with characters, grids with pictures are used where each picture depicts a certain brush or color (see Figures 2 and 3). The *P3Speller* module of the BCI2000 framework is used for the implementation of the P300 speller grids [27]. The stimulus duration is set to 100ms and the inter-stimulus interval to 175ms. For the selection of a brush or color, 15 sequences of flashes are shown, meaning each row and column flashes 15 times. Therefore, the target is flashed 30 times in total.

Finally, BrainBrush uses the open source MyPaint application to provide us with a virtual canvas (see figure 1). An overview of the complete system can be seen in figure 4.

B. Experimental Design

The BrainBrush system was evaluated on user experience with a qualitative user study. We want to gain an understanding of underlying reasons and motivations for both the positive and negative opinions the participants formed about the user experience with the system and the various input modalities. Participants were asked to fill out an informed consent form and provide their demographic details. They

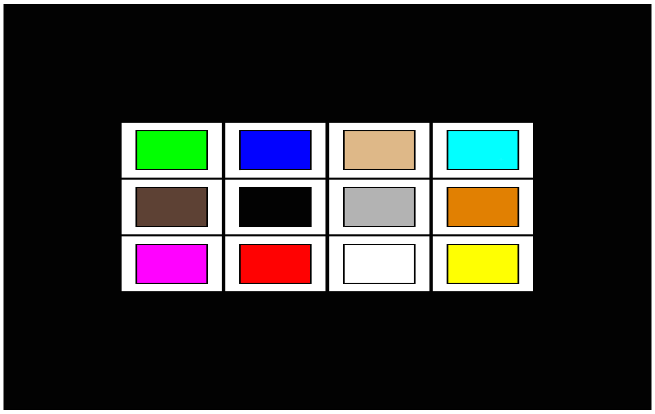

Figure 3. User interface during color selection showing the 12 available colors

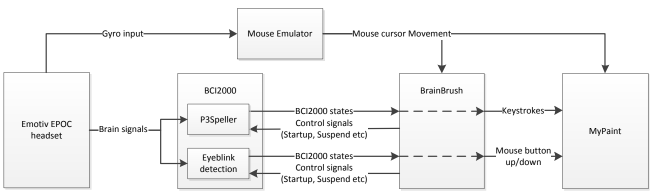

Figure 4. BrainBrush system overview

were given instructions on how to use the P3 Speller. They could try the P300 speller in a practice session, after any questions the experimenter proceeded to record a training session for the P300 classifier [28]. Training data consisted of a 10 letter word ('BRAINPOWER') with 15 sequences utilizing all 14 channels of the Emotiv EPOC. After the training session an online session was carried out in which participants tried to spell the 5 letter word 'PAINT' using the *P3Speller* without feedback so not to bias their expectations. Next, participants were given instructions on using BrainBrush. After 5 minutes of familiarizing themselves the free painting sessions started and the experimenter left the room. Participants could take as long as they wanted, up to 30 minutes. If they wanted to stop painting at an earlier point in time, they would ring a bell to signal the experimenter. After the free painting session, the experimenter would administer the SUS questionnaire [29] followed by an in-depth structured interview.

III. Results

The group of participants for the user study consisted of 8 males (61.5%) and 5 females (38.5%). All participants were aged 20 to 29, the average age was 24.8 (standard deviation: 2.9). 11 participants (84.6%) are right-handed, 2 left-handed (15.4%). All participants had the Dutch nationality.

None of the participants reported relevant medical conditions. Out of 13 participants, 2 participants (15.4%) indicated that they had previously participated in BCI research. Four participants (30.8%) indicated they regularly exercise some

Table I
P300 classification accuracy during copy spelling and free painting

	Copy spelling		BrainBrush
Participant	Result	Accuracy	Accuracy
001	R6INW	40%	Regularly incorrect
002	XAINT	80%	70%
003	PACNZ	60%	80%
004	RHINT	60%	Regularly incorrect
005	R5IZT	40%	Regularly incorrect
006		-	< 50%
007	LAINT	80%	At the beginning: 50% At the end: 100%
008	RAIPT	60%	70%
009	RAINT	80%	21 out of 24 sessions correct (88%)
010	RAINT	80%	70%
011		-	Brush selection: 50-60% Color selection: 90%
012	L5BNN	20%	Choice decided beforehand: 100% Otherwise: lower
013	RGUNC	20%	25-33%
Average		56.4%	

form of creative expression: participant 001 paints, draws and designs daily for study-related purposes; participant 012 paints once a week as a form of recreation; participant 008 regularly uses Photoshop and participant 009 sometimes plays the drawing-game 'Draw Someting' on the iPad.

During the interviews after the free painting session, the participants were asked what accuracy they thought they had been able to achieve with the brush and color selection during the free painting session. These results together with the results from the online session are shown in table I.

During the experiments of participants 006 and 011, the classifier was accidentally not loaded during the online spelling session. Therefore, no copy spelling results are available for these participants. For the other 11 participants, the average accuracy during copy spelling was 56.4% (standard deviation: 23.4%, minimum 20%, maximum 80%).

The average SUS score for all participants was 66.2 (standard deviation: 14.2, minimum: 45, maximum: 87.5). A score of 68 would be average for all systems tested with SUS. During the interviews participants were asked to order the three modalities on pleasantness. An overview of the results can be seen in figure 5.

A summary of all analyzed topics covered in the questionnaire can be seen in table II.

IV. Discussion and Conclusion

In this study, we set out to develop a multimodal interactive system which allows persons to express themselves creatively and included Brain-Computer Interfacing technology. Using this multimodal interactive system, we wanted to research how the different modalities contribute to the user experience and whether BCI has an added value.

We developed the BrainBrush system, which lets users paint on a virtual canvas using their head movement for brush control, eyeblinks to turn the brush on and off, and

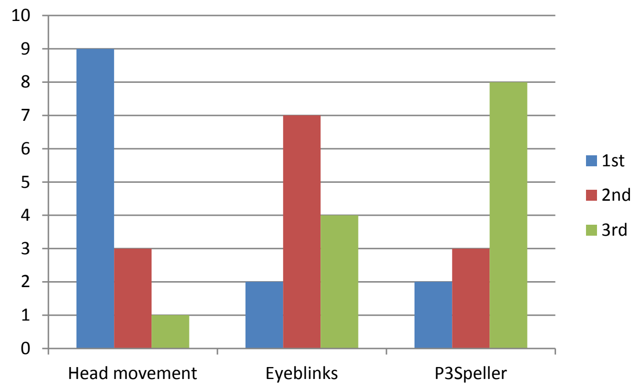

Figure 5. Ordering of pleasantness of modalities: Head movement was most often ranked most pleasant, eyeblinks most often second and the P3Speller (BCI) most often last.

Table II
SUMMARY OF INTERVIEW RESULTS

	+	+/-	-	Total
Expectations	6	7	0	13
Transfer creative ideas	4	3	6	13
Draw picture in mind	3	7	3	13
Time spent painting	4	2	7	13
Purchasing the system	0	4	9	13
Eyeblinks	7	2	4	13
Head movement	7	4	2	13
P3Speller	4	3	6	13
BCI for creative expression	9	2	2	13
Combination of modalities	9	1	3	13
Fun	12	1	0	13

the P300 speller to select different brushes and colors. The presented system is the first of its kind utilizing these modalities.

A user study with thirteen participants showed that the BrainBrush system does not enable all users to express themselves creatively. The group of users who were able to achieve good control over all three input modalities were able to expres themselves creatively and made nice paintings. However, for all users to be able to achieve this, the reliability of the input modalities must be improved.

The head movement modality was considered to be the most pleasant. However, misalignment of the cursor and a lack of smoothness negatively influenced the user experience. Replacing the Emotiv Mouse Emulator program with new software to translate head movement to cursor movement, is expected to improve the user experience.

After the head movement modality, the use of eyeblinks to turn the brush on or off was considered to be the most pleasant. In general, the user experience for this input modality was positive. However, the user experience can be further enhanced by performing more research into the topic of intentional eyeblink detection and improving the detection.

The P300 speller was considered to be the least pleasant input modality. In contrast to the other two input modalities, the user experience was not positive: using the P300 speller was considered to be mentally tiring and it caused physical discomfort and frustration. Participants suggested improvements to the P300 training setup and to the BrainBrush system.

The multimodal aspect of the system was good for the user experience. The combination of the three input modalities within the BrainBrush system was considered to be positive: it was a combination that made sense to most users and the input modalities were well balanced.

Finally, concerning the value of BCI for a multimodal interactive system for creative expression, we can conclude that BCI does have an added value: even though there were some issues due to the BCI modality, the use of BCI was considered to be fun, cool and interesting.

We feel the BrainBrush system in its current state offers a good basis, and with the suggested improvements, the user experience should improve further.

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This manuscript is largely based on Ivo Brugman's Master's thesis [20].

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