Evaluation of different spelling layouts for SSVEP based BCIs

Christopher Kick, Ivan Volosyak

Abstract— **Brain-computer interface (BCI) systems enable humans to communicate with their environment by directly using brain signals. This way, body movement is not explicitly required for communication making this technology especially useful for people with limited mobility. In this study, the system performance and well-being of 38 subjects are investigated using two different layouts of graphical user interfaces (GUI) presented on a computer screen. A steady state visual evoked potential (SSVEP) based BCI speller is used. Furthermore, three different predefined stimulus frequency sets are tested. Results show that the system works best for 55 % of the test subjects using visual stimuli in the range of 8.57 Hz - 15 Hz. The majority of subjects (71 %), prefers the graphical user interface layout called Layout 2. Main advantage of this layout is that each desired letter or symbol can be selected with only two commands in contrast to Layout 1, where usually more than two commands are needed to select a desired object.**

I. Introduction

Communication without using classical neuronal pathways and therefore enabling severely disabled users to convey information is one of the primary goals in BCI research. Brain signal acquisition is possible via various invasive and non-invasive techniques. Invasive and neuro-imaging approaches, however, show several disadvantages compared to scalp recorded electroencephalogram (EEG) signals. Major drawbacks are a lack of portability, the need of surgery with corresponding risks and high costs. For this reasons the vast majority of BCI systems, including the BCI speller presented in this paper rely on EEG signals [1]. In contrast to other mental spelling systems using event related P300 signals, the here presented speller is based on steady state visual evoked potentials. The effectiveness of BCI-systems is often measured by means of the information transfer rate (ITR), which is defined by the classification speed, the number of available targets and the obtained task accuracy. SSVEP based BCI speller have shown in various studies to be of practical use, reaching a mean ITR as high as 61.70 $\pm$ 32.67 bit per minute with a mean accuracy of 96.79$\pm$ 7.88% [2]. The use of a computer monitor to represent visual stimuli normally limits the number of usable stimulus frequencies in SSVEP applications [3]. Therefore, the number of commands needed to select a desired object is generally higher compared to using P300 signals [4]. In P300 based BCI-systems often one command is sufficient to select a desired target. The reason for the necessity of a multi-step classification lies in the visual stimuli generation. Commonly, individual stimulus sequences are generated using a frequency modulated approach [3]. In this approach, a frame-based design is used to guarantee a stable flicker frequency. For this reason the number of usable stimulus frequencies is always limited [3]. A recent study by Wang et al. proposed an alternative approximation approach allowing to display a plurality of suitable frequencies independent of the refresh rate of the used monitor [5]. Therefore, a rather small frequency band can be deployed very efficiently, ensuring a high resolution of the input stimulus frequencies. In this manner, various visual stimulus frequencies can be implemented into a SSVEP based GUI layout, permitting an one command target selection. A possible design, resembling a QWERTY-style keyboard, has been proposed by Hwang et al. [4]. The ambition to select a desired target with as few commands as possible was also the reason for the development of the graphical user interface called Layout 2, which is a further improvement of the work published in [6]. Using Layout 2, only two commands are needed to spell any character or symbol. The study aims to make a further comparison of Layout 2 and the graphical user interface layout used for the SSVEP-based Bremen-BCI speller, called "Layout 1", as already introduced in [6]. Main focus is given to BCI performance and subject well-being. Another often discussed problem of brain-computer interfaces is the limitation of effective system control due to subject specific brain signal variations [7]. For this reason, three different stimulus frequency sets were tested for each subject in a familiarization phase prior to the actual experiment.

This research was supported by the German Federal Ministry of Education and Research (BMBF) under Grant 16SV6364.

The authors are with the Faculty of Technology and Bionics, Rhine-Waal University, 47533 Cleve, Germany. Corresponding author is Ivan Volosyak, ivan.volosyak@hochschule-rhein-waal.de

II. Methods and materials

A. Subjects

The study consisted of 38 subjects of 16 nationalities and a mean age of 21.84 $\pm$ 2.86 years (range 18-29). The majority of subjects (71 %) were males, 29 % were females. The subjects were provided with an information sheet and were directed to read and sign a written consent form. Important subject related questions about former seizures, mental or physical disorders or epilepsy had to be stated before the person was accepted as a research subject. The vision of all subjects was normal or corrected-to-normal, respectively. Only five subjects had previous experience with a SSVEP BCI-system. Participation did not entail any financial benefits.

B. Experimental Setup

Each subject was confronted with two different graphical user interface layouts subsequently. Layout 1 resembles an

978-1-4244-7929-0/14/$26.00 ©2014 IEEE

earlier, at the University of Bremen developed GUI layout [6]. This layout consists out of 32 characters including all letters of the English alphabet. The letters are arranged accordingly to their commonness in the English language. Frequently used letters are placed around the center of the virtual keyboard while the less frequently used ones are located at the corners of the keyboard. Layout 1 offers the subject five possible commands to reach and select a desired target. The available commands are represented via flickering boxes surrounding the virtual keyboard. Initially, the virtual cursor is placed over the letter "E" in the center of the keyboard. The subject directs the cursor via the above described commands (left, right, up and down) to the desired letter. After the letter is selected via the select command, the letter is written into the line beneath the actual word to spell on the bottom left of the layout while the cursor jumps back to the center of the keyboard. Audio feedback of the classified command is given after each selection. The flickering boxes are set to a default size of 125 x 125 pixels. The size of the boxes varies during the experiment, as described in [2]. The graphical user interface layout shown in Figure 1 resembles the herein before mentioned GUI layout. However, the letters are arranged in a different manner and the amount of commands is increased. Here, seven commands are available represented by flickering boxes of a default size (125 x 125 pixels). The size of the boxes vary analog to the ones described in Layout 1 and are also framed with a fixed size frame. Initially, the subject faces seven boxes containing "A-F", "G-L", "M-R", "S-X", "Y-_" and "Del" in a first window. The selection of one of the commands leads the subject to a second layout window with one letter or symbol in each of the mentioned boxes according to the previous selected box. Additionally, the box containing "Del" will be replaced by a box containing "back", offering the user to return to window 1 without selecting a letter. For example, if the subject chose the top middle box in window 1 containing the letters "G-L", each of the boxes in window 2 will contain one of the individual letters G-L. This enables the user to select each target with only two commands, which is not always possible in Layout 1. The selection of a command in the second window will add the designated letter to the line beneath the actual word to spell on the bottom left of the layout and instruct the program to return to window 1, respectively. Analog to Layout 1, each command is accompanied by an audio feedback announcing the selection.

C. Procedure

Given the reported problem of BCI-illiterate, three frequency sets were prepared prior to the study to ensure a most effective system control for each individual subject. The provided sets consisted out of seven different frequencies each, including 6.00, 6.31, 6.66, 7.05, 7.50 and 8.00 Hz in the first set (low frequency set), 5.71, 6.66, 7.05, 7.50, 8.00, 8.57, 9.23 and 10.00 Hz in the second set (medium frequency set) and 8.57, 9.23, 10.00, 10.91, 12.00, 13.33 and 15.00 Hz in the third set (high frequency set). At

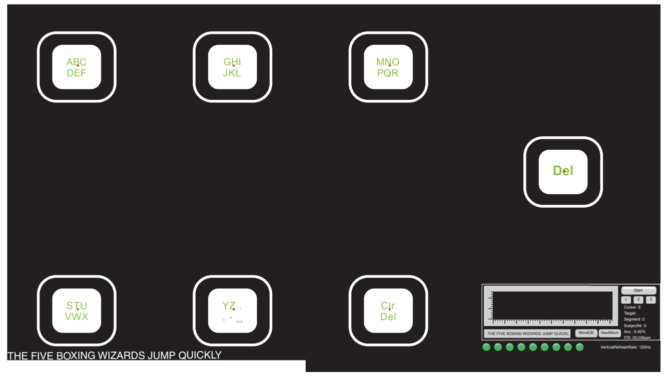

Fig. 1. GUI Layout 2 window 1

the beginning, each participant completed a questionnaire containing questions about well being and demographics while being equipped with an EEG cap of appropriate size and connected to the system. In a short familiarization phase prior to the experiment, all provided frequency sets were presented to the subject. The subject was directed to execute specific, randomly by the experimenter chosen classifications in the starting layout. Individual decisions for the most efficacious set were mutually made between the experimenter and each subject based on effective system control and ease of use. The thresholds for each used frequency in the selected set were also chosen collectively. In this case, the subject was instructed to select all frequencies several times. Each classification border was changed until an optimum between classification speed and accuracy was found. After all mentioned parameters had been adjusted, the subject was directed to spell a word of his/her liking to get accustomed to the faced layout. Subsequently to the familiarization phase, the actual experiment started and the subjects were prompted to spell the words "BCI" and "BRAIN" and the pangram "THE FIVE BOXING WIZARDS JUMP QUICKLY" in the two presented layouts. The order of the presented layouts as well as the spelling tasks were randomized for each subject in order to minimize the risk of adaption. Each spelling phase ended automatically when the presented word was spelled correctly. The experiment was stopped manually in case a subject could not execute a desired classification within a certain time frame, the subject wished to end the experiment or unintentional repeated misclassifications occurred. Spelling errors were corrected via the implemented "Del" and "Clr" buttons. Information needed for the analysis of the test was stored anonymously during the experiment.

D. Hardware and Software

The subjects were seated in front of a LCD screen (BenQ XL2420T, resolution: 1920 x 1080 pixels, vertical refresh rate: 120 Hz) at a distance of about 60 cm. The used computer system operated on Microsoft Windows 7 Enterprise and was based on an Intel processor (Intel Core i7, 3.40 GHz). Standard Ag/AgCl electrodes were used to acquire the signals from the surface of the scalp. The electrodes were placed at predefined locations on the EEG-cap, marked with AF_Z, C_Z, P_Z, PO_3, PO_4, O_1, O_2, O_Z, O_9 and O_{10}. The ground electrode was placed over AF_Z, the reference electrode over C_Z. Standard abrasive electrolytic electrode gel was applied between the electrodes and the scalp which ensured impedances below 5 $k\Omega$ during the experiment. An EEG amplifier g.USBamp (Guger Technologies, Graz, Austria) was utilized. The sampling frequency was set to 128 Hz. During the EEG signal acquisition, an analog band pass filter between 2 and 30 Hz and a notch filter around 50 Hz were applied directly within the amplifier. The internal classifications of the acquired signals were done as published in [2].

E. Result Calculations

BCI performance for each subject was evaluated by calculating the information transfer rate in bit/min, as discussed e.g. in [8]. In case of the here presented layouts, the overall number of possible choices was equal to 5 and 7 for Layout 1 and 2, respectively. The accuracy was calculated based on the number of correct command classifications divided by the total number of classified commands.

III. Results

The overall BCI performance is given in Table I. The provided values for 5 subjects (marked with * in Table I) represent the averaged values of the spelling tasks “BCI” and “BRAIN”. Those subjects were not able to complete the pangram task. All other values refer to the pangram spelling task. Subject 21 and 22 could not finish even the shortest words “BRAIN” and “BCI” in both layouts and are therefore omitted in Table I. Additional study results based on the evaluation of the questionnaires are provided in Table II. The vast majority of subjects (82 %) were able to successfully control the BCI speller for all given tasks after the appropriate frequency set was chosen and the thresholds were adjusted. Only 18 % could not complete the pangram task. The high frequency set (8.57-15.00 Hz) worked best for 21 subjects. The medium (5.71-10.00 Hz) and low (6.00-8.00 Hz) frequency set allowed a most effective system control for 8 and 9 subjects, respectively. ITR values ranged from 8.96 - 65.29 bit/min with a mean of 25.37 $\pm$ 12.34 bit/min in Layout 1 and from 7.16 - 53.40 bit/min with a mean of 21.65 $\pm$ 11.44 bit/min in Layout 2 for the pangram task. Mean accuracies of 84.86 $\pm$ 8.04 % for Layout 1 and 82.28 $\pm$ 10.64 % for Layout 2 could be reached, respectively. Average ITR and accuracy values for the combined spelling task were 16.06 $\pm$ 10.02 bit/min and 83.17 $\pm$ 12.56 % for Layout 1 and 20.49$\pm$ 12.84 bit/min and 84.63 $\pm$ 16.68 % for Layout 2, respectively. EEG preparation and familiarization took about 21 $\pm$ 10 min on average. The average duration of the experiment was about 46 $\pm$ 20 min per person. Participants of this study generally used a computer 30.37 $\pm$ 18.88 hours per week. The average participant slept 6.60 $\pm$ 2.53 h the night before the experiment. Evaluation of the questionnaires assumes that, neither the level of caffeine, alcohol or tiredness had any influence on the subject’s performance. The subjective question about whether the BCI system worked better in case the subject concentrated on the desired object or just gazed at it was answered by 74 % of the subjects in favor of the first mentioned case. Switching attention from one flickering box to another was not considered difficult in neither of the tested layouts. Fatigue level recorded for every subject before and after the experiment show that over half of the subjects (53 %) did not feel more tired after the experiment. The flickering boxes used to display the visual stimuli were in average rated as “moderately annoying”.

TABLE I

ITR, Acc and time results for each subject and each layout. Mean values and range are given at the bottom of the table

	”THE FIVE BOXING WIZARDS JUMP QUICKLY” * = Mean values of ”BCI” & ”BRAIN”					
	Layout 1			**Layout 2**		
Subject	**Time**	**Acc.**	**ITR**	**Time**	**Acc.**	**ITR**
in	sek.	%	bpm	sek.	%	bpm
1	410.31	97.04	40.87	272.19	95.12	43.38
2	559.81	86.93	28.32	760.91	70.33	16.69
3*	60.43	75.18	24.84	59.52	100.00	22.29
4	948.59	71.09	16.29	490.14	72.19	22.84
5	530.56	89.94	31.53	412.55	87.25	28.59
6	1204.02	86.10	13.63	1238.76	66.50	10.19
7	1102.05	70.07	18.86	645.53	98.65	18.36
8	746.99	83.97	26.01	661.38	95.00	17.36
9*	94.91	82.69	15.54	51.70	92.86	26.03
10	645.43	83.14	31.53	238.16	92.94	48.33
11	1103.07	79.05	19.91	1125.82	85.14	7.16
12	815.24	66.53	27.24	407.88	95.18	29.35
13	625.93	91.78	24.46	794.73	95.12	14.86
14	698.85	90.48	21.17	570.68	71.05	14.28
15	268.94	92.64	65.29	227.09	100.00	53.40
16	1166.45	83.65	13.44	505.68	87.00	22.71
17	505.98	92.20	29.61	528.23	86.60	20.85
18	1237.23	80.97	13.58	754.31	77.37	15.81
19	460.48	94.16	33.63	431.54	78.57	23.42
20	949.81	87.89	18.57	913.66	83.19	12.76
23	345.72	92.96	44.69	566.62	68.42	17.57
24	737.04	85.47	20.89	536.05	82.61	21.77
25	1237.03	75.69	12.81	723.94	71.51	17.93
26	1733.98	7500	9.37	1315.74	68.18	10.86
27	437.53	87.57	37.18	369.89	82.50	32.82
28	2387.43	75.67	10.69	986.38	71.86	12.42
29	945.04	86.67	15.60	1272.88	80.51	8.85
30	1755.51	73.98	8.96	1188.89	78.08	10.92
31	515.94	88.31	28.08	442.41	87.38	27.02
32*	144.07	84.09	9.62	222.37	65.69	6.45
33*	79.17	100.00	25.04	36.71	94.44	37.68
34	738.77	90.50	27.27	431.74	80.33	26.85
35	529.65	89.33	32.63	381.47	100.00	31.79
36*	421.54	73.91	5.24	149.09	70.14	9.98
37	395.38	97.08	43.10	416.00	77.31	24.86
38	846.83	84.58	21.13	1789.23	64.89	7.28
Min	268.94	66.53	8.96	227.09	64.89	7.16
Max	2387.43	97.08	65.29	1789.23	100.00	53.40
Mean	**857.60**	**84.86**	**25.37**	**690.34**	**82.28**	**21.65**
SD	**470.08**	**8.04**	**12.34**	**374.69**	**10.64**	**11.44**
Min*	60.43	73.91	5.24	36.71	65.69	6.45
Max*	421.54	100.00	25.04	222.37	100.00	37.68
Mean*	**160.02**	**83.17**	**16.06**	**103.88**	**84.63**	**20.49**
SD*	**152.26**	**12.56**	**10.02**	**81.50**	**16.68**	**12.84**

IV. Discussion

In this study two different layouts of graphical user interfaces were compared. The mean ITR for Layout 1 was 25.37 $\pm$ 12.34 bit/min. A former study with 7 subjects done

TABLE II

EXPERIMENT RESULTS, SUBJECTS DEMOGRAPHICS AND QUESTIONNAIRE ANSWERS OF 38 SUBJECTS

Age	**Gender**		**Vision correction**		**Tiredness before (after) the experiment**					**Computer use per week**	**BCI experience**		**Frequency set**			**Which layout worked best**	
Years	**Male**	**Female**	**Yes**	**No**	**1-"not tired"**	**2-"a little tired"**	**3-"moderately tired"**	**4-"considerably tired"**	**5-"very tired"**	**Hours**	**Yes, SSVEP**	**No**	**Low**	**Middle**	**High**	**Layout 1**	**Layout 2**
25.83±7.84	27	11	17	21	6 (4)	15 (11)	14 (9)	3 (12)	0 (2)	30.37±18.88	5	33	9	8	21	11	27

at the University of Bremen yielded a comparable mean value of 24.64 $\pm$ 9.2 bit/min using different pangrams [6]. Combined averaged results for the spelling tasks "BCI" and "BRAIN" differed substantially. In the study from 2011, higher mean ITR values were reached (32.65 $\pm$ 12.53 bit/min compared to 16.06 $\pm$ 10.02 bit/min). A reason for this could be the fact that the here presented values for the combined spelling task only refer to subjects who were not able to spell the pangram at all. Those subjects had considerable problems gaining effective control over the BCI system. The average times and accuracies underpin this assumption. The mean time was about 4 times higher and the accuracy about 12.6% worse than in the former study. As proposed by Hwang et al. in [4], it should be possible to reach higher information transfer rates for layouts in which a desired target can be classified with as few commands as possible. However this could not been proven in this study. The mean values for both layouts regarding ITR, accuracy and time did not show any substantial difference for any of the tasks. One of the most important features of a brain-computer interface, next to the overall performance of the system, is the ease of use. The layout of the graphical user interface plays a key role in ensuring user friendliness and effective control. Hereby, the arrangement of the visual stimuli and the desired targets as well as the minimum number of commands needed for a selection are crucial. Layout 2 was favored by the majority of subjects for one or more of the following usability reasons: clear structured arrangement of letters and characters, intuitiveness, 2-command classification and the availability of a delete button in the layout window 1 as shown in Figure 1. The delete button provided a very useful correction tool for every subject. Through this, even after a spelling mistake was made, it could be corrected using only one command. An implemented fixed reference point in the center of each box in the layout window 1 was suggested by some subjects in a preliminary study comprised of 6 persons. The fixed reference point should prevent the eye from unfocusing while the box changed in size during the classification. However, most of the subjects stated that it did not ease classification. Some participants even felt slightly irritated by it. Layout 1 was favored by 29% of the participants. Main reasons were the arrangement of letters and flickering boxes. Here, the arrangement of the flickering boxes was similar to the one on a physical keyboard, which made cursor direction intuitive for some subjects. The location of the select button sometimes led to misclassifications when the subject aimed to move the cursor left or up, probably caused by peripheral vision. The frequencies of the high frequency set (8.57-15.00 Hz) seemed to be more effective for the majority of BCI users. Some of the participants were able to use the system with all provided sets, however the SSVEP signal amplitudes were often times higher for fast frequencies. Similar results were observed in a previous study [9]. The representation of visual stimuli on a computer screen still limits the amount of usable frequencies in an appropriate frequency range. Several studies suggest that the BCI performance could be increased by decreasing the amount of commands needed to select a target (usually a letter) [3], [4]. The theoretical potential of high information transfer rates and predominant positive subject feedback for Layout 2 fortify our ambition to further modify the layout.

REFERENCES

[1] S. G. Mason, A. Bashashati, M. Fatourechi, K. F. Navarro, and G. E. Birch, "A Comprehensive Survey of Brain Interface Technology Designs," *Ann. Biomed. Eng.*, vol. 35, no. 2, pp. 137–169, Feb. 2007.

[2] I. Volosyak, "SSVEP-based Bremen-BCI interface – boosting information transfer rates," *J. Neural Eng.*, vol. 8, no. 3, p. 036020, 2011.

[3] M. Nakanishi, Y. Wang, Y.-T. Wang, Y. Mitsukura, and T.-P. Jung, "An approximation approach for rendering visual flickers in SSVEP-based BCI using monitor refresh rate," in *Engineering in Medicine and Biology Society (EMBC), 2013*. IEEE, 2013, pp. 2176–2179.

[4] H.-J. Hwang, J.-H. Lim, Y.-J. Jung, H. Choi, S. W. Lee, and C.-H. Im, "Development of an SSVEP-based BCI spelling system adopting a QWERTY-style LED keyboard," *Journal of neuroscience methods*, vol. 208, no. 1, pp. 59–65, 2012.

[5] Y. Wang, Y.-T. Wang, and T.-P. Jung, "Visual stimulus design for high-rate SSVEP BCI," *Electronics letters*, vol. 46, no. 15, pp. 1057–1058, 2010.

[6] I. Volosyak, A. Moor, and A. Gräser, "A dictionary-driven SSVEP speller with a modified graphical user interface," in *Advances in Computational Intelligence*. Springer, 2011, pp. 353–361.

[7] A. Nijholt and D. Tan, "Brain-computer interfacing for intelligent systems," *Intelligent Systems, IEEE*, vol. 23, no. 3, pp. 72–79, 2008.

[8] J. Wolpaw, N. Birbaumer, D. McFarland, G. Pfurtscheller, and T. Vaughan, "Brain-computer interfaces for communication and control," *Clin. Neurophysiol.*, vol. 113, pp. 767–791, 2002.

[9] I. Volosyak, D. Valbuena, T. Luth, T. Malechka, and A. Graser, "BCI demographics II: How Many (and What Kinds of) People Can Use a High-Frequency SSVEP BCI?" *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, vol. 19, no. 3, pp. 232–239, 2011.