PsychNology Journal, 2008
Volume 6, Number 1, 99-108

Task and Stimulation Paradigm Effects in a P300 Brain Computer Interface Exploitable in a Virtual Environment: A Pilot Study

Francesco Piccione *♦, Konstantinos Priftis ♣, Paolo Tonin ♦, Denis Vidale ♥, Roberto Furlan ♥, Marianna Cavinato ♦, Antonio Merico ♦ and Lamberto Piron ♦

♦ IRCCS San Camillo Hospital, Lido di Venezia (Italy)

♣ Dept. of General Psychology, University of Padova (Italy)

♥ Khymeia S.R.L., Padova (Italy)

ABSTRACT

The aim of the present study is to compare different visual elicitation paradigms exploitable in a Virtual Environment in order to establish whether the BCI is affected by the structure of the elicitation paradigm, the modalities of stimulus presentation, and the complexity of stimulus recognition and semantic processing.
We have developed a device which can control the motion of a cursor on a computer graphical interface, using ERPs (Piccione et al., 2006). Subsequently, we tested different visual elicitation paradigms which evoked P300 waves to control the movement of an object in a virtual environment. Visual stimuli, consisting of four arrows (forward, right, back, left), were randomly presented in peripheral positions of a virtual environment. Users were instructed to recognize only the stimulus related to the preferred object movement direction (target). The sum of the absolute differences between target and non-target traces (ra index) was compared in the different elicitation paradigms. Results showed a significant reduction of ra index with the use of more semantically complex paradigms. Therefore, the P300 BCI system seems to be affected by the structure of the elicitation paradigm, the modalities of stimulus presentation, and the complexity of stimulus recognition and semantic processing.

Keywords*: BCI, ERP, P300, Visual Paradigms, Virtual Environment.*

Paper Received 10/10/2007; received in revised form 02/04/2008; accepted 10/02/2008.

1. Introduction

Brain Computer Interface (BCI) systems have been developed for people with severe disabilities in order to improve their quality of life (Lulè, Gramm, Kurt, Kassubek, Diekman, & Birbaumer, in press; Murase, Duque, Mazzocchio, & Cohen,2004; Allison

Cite as:
Piccione, F., Priftis, K., Tonin, P., Vidale, D., Furlan, R., Cavinato, M., Merico, A., & Piron, L. (2008). Effects of Task and Stimulation Paradigm Modifications in a P300 Brain Interface Exploitable in a Virtual Environment: a Pilot Study. *PsychNology Journal, 6*(1), 101 – 110. Retrieved [month] [day], [year], from www.psychnology.org.

* Corresponding author:
Piccione Francesco
IRCCS San Camillo Hospital,via Alberoni 70, Lido di Venezia, 30126 Venezia, Italy.
E-mail: piccioneparrinello@aliceposta.it

& Pineda, 2003; Donchin, Spencer, & Wijesinghe, 2000; Farwell & Donchin, 1988). Recently, BCI systems have been also used in other research areas, such as in the field of virtual environment (Bayliss, 2003; Leeb, Scherer, Lee, Bischof, & Pfurtscheller, 2004). Different strategies are used for the control of a BCI. A P300-based BCI (P300 BCI) system has the advantage to not need any specific or time consuming training, given that the P300 is an endogenous response to specific events (Farwell & Donchin, 1988). However, a P300 BCI system needs the elicitation of well distinct target and non-target signals, in order to achieve both a discrete classification accuracy and a communication speed (McFarland, D.J, Sarnacki, W.A., & Wolpaw, J.R., 2003). Furthermore, in the P300 paradigm, focused processing of the targets requires access to limited spatial and sustained attention resources and this could be a limiting factor (Nobre, 2001). To tackle this problem in a virtual environment, both the elicitation paradigm and stimuli presentation should be considered.

This pilot study compares different visual elicitation paradigms exploitable in a Virtual Environment in order to establish whether the BCI is affected by the structure of the elicitation paradigm, the modalities of stimulus presentation, and the complexity of stimulus recognition and semantic processing.

2. Methods

2.1 P300 BCI

The P300 BCI (Piccione et al., 2006) used the P300 wave to control the movement of a cursor (i.e., a blue point on a computer's screen) in order to reach a goal (i.e., a red cross; see Figure 1). There were four possible directions for the movement of the cursor, each one indicated by four flashed arrows (i.e., forward, right, left, and back), that were randomly presented in peripheral positions on the monitor. Users were instructed to pay attention only to the flashed arrow which indicated the required direction of the cursor's movement. Each flashed arrow occurred with a probability of 0.25 and it was considered as a target only when it indicated the required direction of the cursor's movement towards the goal point (i.e., the red cross). Otherwise, the flashed arrow was considered a non-target. Each target stimulus elicited the P300. Every time that the P300 was detected during the trial, the cursor should have moved on the graphical interface according to the direction of the flashed arrow. On the contrary, if the P300 was not detected, then the cursor should have remained still. The classifier previously described by Piccione et al. (2006) assessed the presence of the P300 wave, in a single sweep after each stimulus, by performing on-line data processing procedure consisting of an Independent Component Analysis (ICA) decomposition, followed by feature extraction and neural network classification. If the P300 was detected (network output node value 0), the ball moved on the graphical interface according to the last submitted arrow. In all other cases the ball remained still.

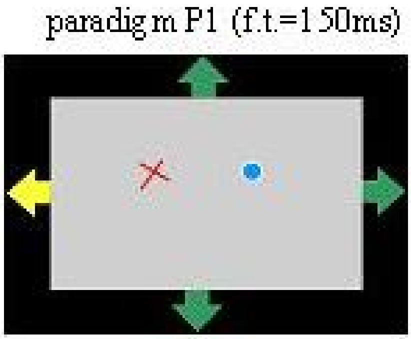

Figure 1. P300 Brain Computer Interface Paradigm (P1) (Piccione et al., 2006).

2.2 P300 BCI in Virtual Environment

The Virtual Environment was developed using MS Visual Studio.NET and the DirectX library by Khymeia S.R.L., Padova, Italy. It consisted of a 3D-view projection display with a resolution of 800x600 pixel placed three meters from the subject. The virtual environment represented a room in which the "virtual user" sat on a wheelchair (i.e. Figure 2). Along the room walls there were four doors, on the four directions of the virtual environment, indicated by flashed arrows (i.e., forward, right, left and back). The arrows flashed randomly. The four doors gave access to other different rooms representing the user needs. They were marked with a food icon indicating hungry/thirsty being; a picture of a toilet to indicate washing or physiological needs; a red cross on white, for health related needs; a “return” sign to indicate that some rest is needed. When the user decision was detected, the target door opened and the virtual wheelchair crossed it, entering in the related room.

In successive developments, each new room will represent four further doors, each of them with an arrow lighting up in sequence, one to come back to the previous room, the others to get more specific choices.

In Virtual Environment users are asked to control the movement of the virtual wheelchair from a starting point to a goal-point, through a virtual path. Forward, right, left, and back arrows were randomly flashed in peripheral positions of the virtual environment. Each arrow indicated one of four possible directions concerning the movement of the virtual wheelchair. Users had to pay attention to the arrow indicating the correct direction (i.e. target arrow; probability of occurrence: 0.25), but ignore the arrows indicating the wrong directions (i.e. distracting arrows; probability of occurrence: 0.75). We hypothesized that every target arrow should elicit a P300 wave.

Each trial comprised the flashing of an arrow for 70-150ms, followed by data processing necessary for P300 recognition and, finally, the generation of the feedback concerning the movement of the virtual wheelchair. The interval between the presentation of two arrows (inter-trial interval: ITI) was fixed to 2.5s in order to achieve optimal off-line data processing. A session was defined as the sequence of trials sufficient to permit the reaching of the goal-point.

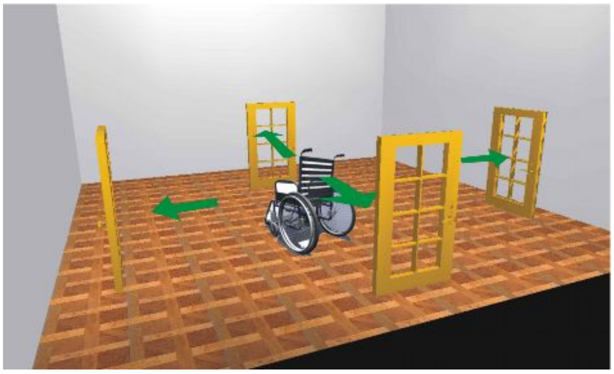

Figure 2. Virtual environment.

2.3 P300 Acquisition and Analysis

Cup silver-chloride electrodes were placed according to the international 10-20 system at Fz, Cz, Pz and Oz. All the electrodes were referenced to bilateral (joined) earlobes. Ground was placed in Fpz. The Electrooculogram (EOG) was recorded from a pair of electrodes below and laterally to the right eye. The EOG registration was useful to differentiate eye movement or blinking from P300 component. The four Electroencephalogram (EEG) channels and the single EOG channel were amplified by SynAmps (NeuroSoft Inc.), band-pass filtered between 0.15 Hz and 30 Hz, and digitised (with a 16-bit resolution) at a 200 Hz sample rate. The five channels recorded single epochs of 1500ms length and 300 sampled point per channel were available. The data were processed on-line through a three-step-sequence that included: ICA decomposition, features extraction and neural network classification (Piccione et al., 2006) (Figure 3).

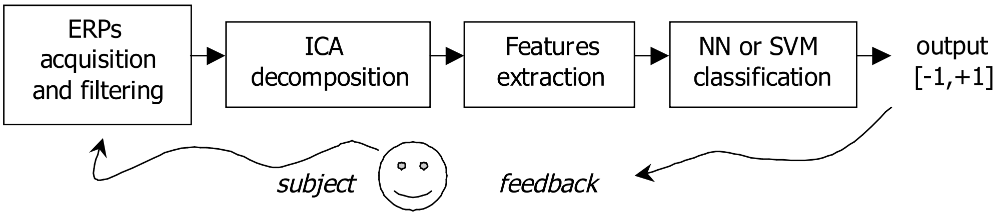

Figure 3. Real time classification of P300.

2.4 Subjects and Experimental Setup

The experiment was performed with the approval of the local ethical committee and the written informed consent of the volunteers.

3 healthy subjects voluntarily participated to the study (1 female and 2 males, mean age of 34 years, range 26-40 years). Participants did not present cognitive deficits and had P300 wave parameters within the normative values (American Electrodiagnostic Medicine Guidelines, 1999). One of them wore corrective lens for a low myopia.

P300 BCI paradigm (P1) was compared with graphical variants (S1, S2, S3) in which the position/shape and flash time of the arrows changed (see Figure 4).

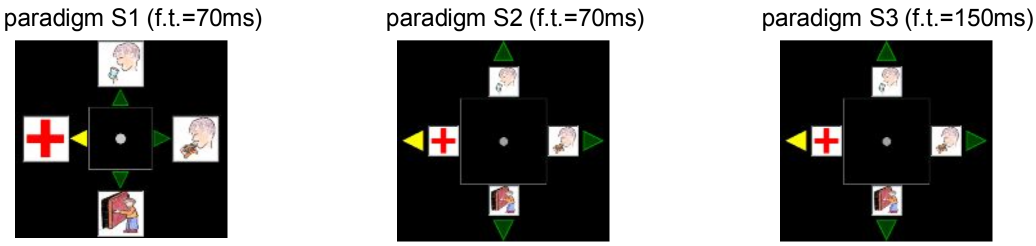

Figure 4. BCI Graphical variants: S1 (field, arrows, targets, flash time 70ms); S2 (field, targets, arrows, flash time 70ms); S3 (field, targets, arrows, flash time 150ms).

System performance (i.e., accuracy in %) and system transfer bit rate expressed in bit/min of the analyzer were computed for the P300 BCI as in the previous work (Piccione et al., 2006). The total error was computed as follows:

$$etot = 1 - \frac{c_1 + c_2}{n_1 + n_2}$$

where:

– n_1 = numbers of non-target stimulus per session;

– n_2 = numbers of target stimulus per session;

– c_1 = numbers of correctly classified non-target data epochs per session;

– c_2 = numbers of correctly classified target data epochs per session.

The performance in % was calculated as follows:

perf = (1 – etot)*100

and the communication speed expressed in bit/min (Transfer Bit Rate, tbr) was computed as follows:

$$tbr = \frac{n_2}{n_1 + n_2} \; \frac{c_2}{n_2} \; \frac{60}{ITI} \; \log_{2(nstim)}$$

where:

– ITI = the Inter-Trial Interval was 2.5 s;

– nstim = numbers of different stimuli used in the interface (4 arrows or directions).

For each paradigm (P1, S1, S2, S3) and subject, 8 sessions were compared; considering a subject and a paradigm, we evaluated the 8 sessions raw traces average of the channel PZ, then the '*ra*' index as follow: the sum of absolute differences between *target* and *non-target* average traces (respectively $avg_2^{PZ}(k)$ and $avg_1^{PZ}(k)$, $k \in [60,160]$) in the interval 200-700ms (1). The core of the P300 and non-P300 patterns classifier was the radial basis kernel function (K).

$$ra = \sum_k \left| avg_2^{PZ}(k) - avg_1^{PZ}(k) \right|, \; k \in [60,160] \qquad (1)$$

An analysis of variance (ANOVA) was applied to compare performance data, P300 latencies and ra index of each subject for the different paradigms (P1, S1, S2, S3). A p-value less than 0.05 was considered statistically significant.

3. Pilot Study Results

Grand-averaged P300 components of the three subjects for the different paradigms are illustrated in Figure 5. No significant impact had the mean latency and amplitude of the P300 components recorded on Pz of paradigms P1 compared to S1, S2 and S3 (P1: P300 latency 447ms, N200–P300 amplitude 401.1mV; S1: P300 latency 386ms, N200–P300 amplitude 84mV; S2: P300 latency 392ms, N200–P300 amplitude 68.9mV; S3: P300 latency 394ms, N200–P300 amplitude 84mV).

P300 BCI average performance of the three healthy subjects was 71.5% (std 7.1), as shown in Table 1. Sessions successfully completed were defined as the sessions where subjects could achieve the target.

Parameters	Measure unit	3 healthy Subjects	
		Mean	**STD**
Performance	%	71.5	7.14
Transfer bit rate	Bit/min	6.62	1.2
Percentage of sessions successfully completed	%	62.52	10.84
Number of trials before first successful session	-	169	129

Table 1. System performance and communication speed (transfer bit rate in bit/min) of the three subjects.

The statistical analysis of variance (ANOVA) shown that the *ra* index appeared to decrease significantly with the use of more semantically complex paradigms. Pilot results of the comparison of the different paradigms are reported in Table 2 and illustrated in Figure 5. Finally, there was no session-by-session improvement in performance or transfer-bit rate.

	P1	**S1**	**S2**	**S3**
subject	**ra (uV)**	**ra (uV)**	**ra (uV)**	**ra (uV)**
1	711	195	241	286
2	471	215	128	159
3	188	151	210	82
mean	457	187*	193 *	176**
Std	262	33	58	103

Table 2. P1, S1, S2 and S3 paradigms comparison (ra). * $p<0.05$; ** $p<0.01$.

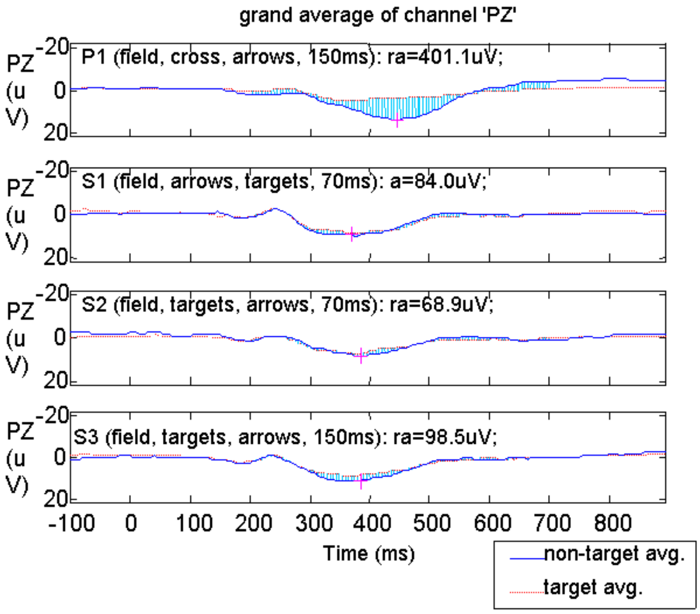

Figure 5. Grand average of raw traces recorded in channel Pz for different paradigms (P1, S1, S2, S3).

4. Discussion

As reported in the literature, the oddball data indicate the ability to attend to the target item, the decision was made to test a system that more nearly approximates a standard oddball sequence, but using three different four-choice paradigms. It was important to utilize more than two stimuli in the sequence because the amplitude of the P300 is affected by the probability of a target stimulus presentation (Allison & Pineda, 2003; Duncan-Johnson & Donchin, 1977). The use of 4 stimuli provides a target probability of 0.25. Furthermore, the P300 wave parameters (latency, amplitude) and its morphology strongly depend on the structure of the elicitation paradigm, the modality of stimulus presentation and the stimulus semantic meaning (Wolpaw, Birbaumer, McFarland, Pfurtscheller, & Vaughan, 2002; Birbaumer, 2006). Our study evaluated the recorded ERPs behavior related to different paradigms in order to check the single-sweep P300 wave recognition capability in virtual environment. The results indicate that although small fluctuations in the classifier accuracy were observed between the differing visual protocols, the relative changes were not statistically significant. However, relevant distinctions among the paradigm P1 and the paradigms S1, S2, and S3 in terms of difference between the P300 amplitudes of target and no-target traces do exist. The different visual elicitation paradigms use the same type and number of stimuli (four arrows) but have differentiations about the global task and the position/shape and flash time of the stimuli. Comparing the different paradigms through the raw averaged traces, we observed that the discrimination between target and non-target signals can deeply change, making the P300 wave recognition task more complex.

5. Conclusion

In this paper, we have analyzed the ERPs response of different paradigms that can be used in a Virtual Environment. Many factors influence the cognitive potential elicitation, modifying the differences between the target and non-target response. Comparing the paradigms, the ERPs behavior changes probably reflect the increment of the task difficulty.

6. References

Allison, B.Z., & Pineda, J.A. (2003). ERPs evoked by different matrix sizes: Implications for a brain computer interface (BCI) system. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 11*, 110-113.

Bayliss, J. D. (2003). Use of the Evoked Potential P3 Component for Control in a Virtual Apartment. *IEEE Trans Neural Sys Rehabil Eng*, *11* (2), 113-116.

Birbaumer, N. (2006). Brain-computer-interface research: Coming of age. *Clin Neurophysiol*, *117* (3), 479–483.

Donchin, E., Spencer, K.M., & Wijesinghe, R. (2000). The mental prosthesis: Assessing the speed of a P300-based brain-computer interface. *IEEE Transactions on Rehabilitation Engineering, 8,* 174-179.

Farwell, L. A., & Donchin, E. (1988). Talking off the top of your head: toward a mental prosthesis utilizing event-related potentials. *Electroencephalogr Clin Neurophysiol*, *70*, 510–523.

Duncan-Johnson, C.C., & Donchin, E. (1977). On quantifying surprise: The variation in event-related potentials with subjective probability. *Psychophysiol, 14*, 456-467.

Leeb, R., Scherer, R., Lee, F., Bischof, H., & Pfurtscheller, G. (2004). Navigation in virtual environments through motor imagery. In *Proceedings of the CVWW'04*, Piran, Slovenia, February, 99–108.

Lulè, D., Gramm, R., Kurt, A., Kassubek, J., Diekmann, V., & Birbaumer, N. (in press). The functional anatomy of motor execution and imagery in amyotrophic lateral sclerosis. *Journal of Neurology*.

McFarland, D.J, Sarnacki, W.A., & Wolpaw, J.R. (2003). Brain-computer interface (BCI) operation: optimizing information transfer rates *Biol Psychol*, *63*, 237-251.

Murase, N., Duque, J., Mazzocchio, R., & Cohen, L. G. (2004). Influence of interhemispheric interactions on motor function in chronic stroke. *Annals of Neurology*, 55, 400–409.

Nobre, A. C. (2001). Orienting attention to instants in time. *Neuropsychologia*, *39*, 1317–1328.

Piccione, F., Giorgi, F., Tonin, P., Priftis, K., Giove, S., Silvoni, S., Palmas, G., & Beverina, F. (2006). P300-based brain computer interface: Reliability and performance in healthy and paralised participants. *Clin Neurophysiol*, *117*(3), 531–537.

Wolpaw, J. R. , Birbaumer, N., McFarland, D. J., Pfurtscheller, G., & Vaughan, T. M. (2002). Brain-computer interfaces for communication and control. *Cl Neurophys*, *113*, 767-91.