BRAIN-COMPUTER INTERFACE: COMPARISON OF TWO CONTROL MODES TO DRIVE A VIRTUAL ROBOT

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Abstract

A Brain-Computer Interface (BCI) is a system that enables communication and control that is not based on muscular movements, but on brain activity. Some of these systems are based on discrimination of different mental tasks; usually they match the number of mental tasks to the number of control commands. Previous research at the University of Málaga (UMA-BCI) have proposed a BCI system to freely control an external device, letting the subjects choose among several navigation commands using only one active mental task (versus any other mental activity). Although the navigation paradigm proposed in this system has been proved useful for continuous movements, if the user wants to move medium or large distances, he/she needs to keep the effort of the MI task in order to keep the command. In this way, the aim of this work was to test a navigation paradigm based on the brain-switch mode for ‘forward’ command. In this mode, the subjects used the mental task to switch their state on /off: they stopped if they were moving forward and vice versa. Initially, twelve healthy and untrained subjects participated in this study, but due to a lack of control in previous session, only four subjects participated in the experiment, in which they had to control a virtual robot using two paradigms: one based on continuous mode and another based on switch mode. Preliminary results show that both paradigms can be used to navigate through virtual environments, although with the first one the times needed to complete a path were notably lower.

Keywords: Brain-Computer Interface (BCI), virtual robot, switch mode, motor imagery (IM)

Introduction

A brain-computer interface (BCI) is based on the analysis of the brain activity, such as electroencephalographic (EEG) signals, recorded during certain mental activities, in order to control an external device. One of its main uses could be in the field of medicine, especially in rehabilitation. It helps to establish a communication and control channel for people with serious motor function problems but without cognitive function disorder (Wolpaw, Birbaumer, McFarland, Pfurtscheller & Vaughan, 2002). Amyotrophic lateral sclerosis (ALS), brain or spinal cord injury, cerebral palsy and numerous other diseases impair the neural pathways that control muscles or impair the muscles themselves. Some patients suffering this kind of diseases can neither communicate with the outside world nor interact with their environment. In this case, the only option is to provide the brain with a new and non-muscular communication and control channel by means of a BCI.

EEG activity includes a variety of different rhythms that are identified by their frequency and their location. Mu (7-13Hz) and central beta (18-26Hz) rhythms are focused over sensorimotor cortex and recorded from the scalp over central sulcus. Sensorimotor rhythm-based BCIs (SMR-BCI) are based on the changes in mu and beta rhythms, which can be modified by voluntary thoughts through such specific mental tasks as motor imagery (MI), (Kübler & Müller, 2007); i.e. when a person performs a movement (or merely imagines it), it causes a synchronization/desynchronization in the neuron activity (event related synchronization/desynchronization, ERS/ERD) which involves a mu rhythm amplitude change (Neuper & Pfurtscheller, 1999). This relevant characteristic is what makes SMR suitable to be used as input for a BCI.

Many BCI applications based on mental task discrimination allow the user to control simulated (Tsui, Gan & Roberts, 2009) or real mobile robots (Barbosa, Achanccaray, Meggiolaro, 2010), (Millán, Renkens, Mourino, & Gerstner, 2004). The vast majority of BCI system to control external device match the number of commands to the number of mental tasks. Having a higher number of commands implies higher information throughput and makes it easier for the subjects to navigate through the environment, since they have more choices to move. However, some studies proved that the best classification accuracy is achieved when only two classes are discriminated (Kronegg, Chanel, Voloshynovskiy, & Pun, 2007).

One of the main objectives of the BCI research at the University of Málaga (UMA-BCI) is to provide a BCI system to freely control an external device (robot, wheelchair) based in the discrimination of only two classes. To obtain this objective, different paradigms have been proposed. In (Ron-Angevin, Velasco-Álvarez, Sancha-Ros & Da Silva-Sauer, 2011), subjects performed one MI task to extend a rotating bar that pointed to four possible commands in order to select them; two mental tasks are mapped this way into four navigation commands, allowing carry out discrete movements. On a later experiment (Velasco-Álvarez, Ron-Angevin, Da Silva-Sauer & Sancha-Ros, 2010), the same navigation paradigm was used to provide continuous movements: after the selection of a command, the movement was kept while the MI task was above certain threshold. Both paradigms have been used to control a virtual and a real robot (Ron-Angevin, Velasco-Álvarez, Sancha-Ros & Da Silva-Sauer, 2011), (Velasco-Álvarez, Ron-Angevin, da Silva-Sauer & Sancha- Ros, 2013), and a virtual (Velasco-Álvarez, Ron-Angevin, Da Silva-Sauer & Sancha-Ros, 2010) and real wheelchair (Varona-Moya et al., 2015).

Although a wheelchair controlled through a BCI system should provide continuous movements, in some situations this paradigm could have some disadvantages. If the user wants to move forward during a long period in order to cover medium or long distances, he/she needs to keep the effort of the MI task in order to keep the virtual wheelchair moving forward. A smart solution to this problem could be to apply the concept of a *Brain-Switch (*Mason, & Birch, 2000) to this paradigm. A BCI based on a brain-switch offers only an on/off control and only distinguishes between a predefined state and one specific mental task, therefore it fits the paradigm operating mode. In this way, for large distance, instead of keeping the ‘forward’ command active continuously, this one could be activated by a switch control. Once the subject decides to stop the movement, he/she deactivates the ‘forward’ command through another switch control action. This approach has been used by others BCI groups (Solis-Escalante, Müller-Putz, Brunner, Kaiser & Pfurtscheller, 2010), (Müller-Putz, Kaiser, Solis-Escalante & Pfurtscheller, 2010).

The aim of the present study is to check the usefulness of this brain-switch mode for controlling a virtual robot. In order to obtain comparative results, subjects also control the virtual robot in continuous mode.

Methods

Subjects and Data acquisition

Twelve naïve subjects (aged 21.5±2.2 years) participated in the study. As a design criterion, a maximum value of 30% in the error rate was considered to allow an efficient control of the paradigm. In the present study, only subjects who performed under this threshold in the calibration session (see section 2.2) continued with the navigation sessions. Finally, six out of the twelve subjects accomplished this criterion, being the others six subjects discarded due to their lack of control in the training sessions.

The EEG was recorded using gold disc electrodes from two bipolar channels over left and right central areas. Channels were derived from two electrodes placed 2.5cm anterior and posterior to positions C3 and C4 (right and left hand sensorimotor areas, respectively) according to the 10/20 international system. The ground electrode was placed at the FPz position. Signals were amplified by a 16 channel biosignal g.BSamp (Guger Technologies) amplifier and then digitized at 128 Hz by a 12-bit resolution data acquisition NI USB-6210 (National Instruments) card.

Initial training and signal processing

Before using the system to test the two paradigms, subjects had to follow an initial training that consisted of two sessions: a first one without feedback and a second one providing continuous feedback. As we have indicated in the previous section, those subjects who obtained a low error rate in the first session continued with the experiment. These two training sessions were used for calibration purposes.

This training used the paradigm proposed by our group (UMA-BCI) in (Ron-Angevin & Díaz-Estrella, 2009), based on that proposed by the Graz group (Guger et al., 2001), in which subjects immersed in a virtual environment (VE) had to control the displacement of a car to the right or left, depending on the mental task carried out, in order to avoid an obstacle (a puddle), see Fig. 1. The training entailed discriminating between two mental tasks: mental relaxation and imagined right hand movements (right hand MI). The subjects did not receive any feedback in the first session, which was used to set up classifier parameters for the second session, in which continuous feedback was provided. In this first session, subjects were instructed to carry out four experimental runs consisting of 40 trials each. After a break of 5–10 min, the time necessary to do the offline processing (see (Ron-Angevin & Díaz-Estrella, 2009) for details) to determine the parameters for the feedback session, subjects participated in the second session. This feedback session consisted of one experimental run, intended to check the effectiveness of the chosen parameters and the ability of the subject to control his or her EEG signals.

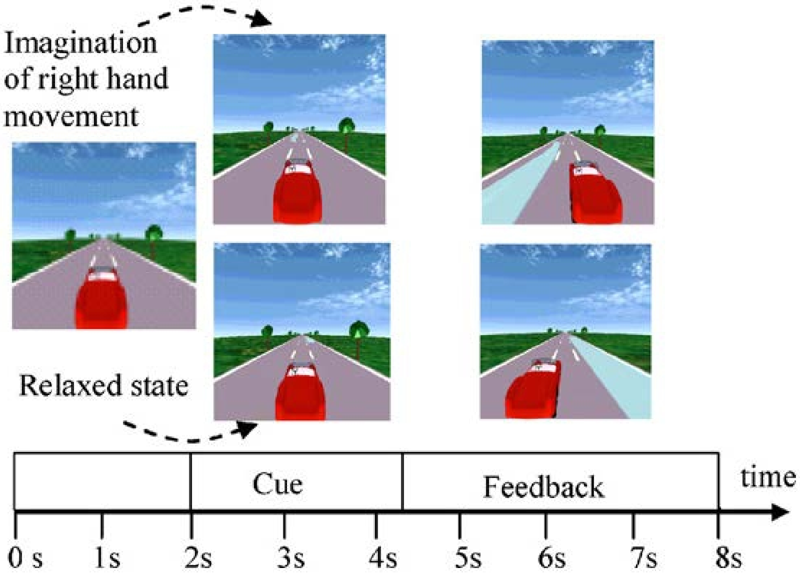

Figure 1: Timing of one trial of the training with feedback.

The same parameters obtained were used to calibrate the system for the virtual environment (VE) navigation sessions. This processing is based in the procedure detailed in (Pfurtscheller, 2003), and consisted of estimating the average band power of each channel in predefined, subject-specific reactive frequency (manually selected) bands at intervals of 500 ms. In the feedback session, the movement of the car was computed on-line every 31.25 ms as a result of a Linear Discriminant Analysis (LDA) classification. The trial paradigm and all the algorithms used in the signal processing were implemented in MATLAB.

Navigation Paradigm

The main objective of the BCI research at the University of Málaga is to provide an asynchronous BCI system (UMA-BCI) which, by the discrimination of only two mental states, offers the user several navigation commands to be used in a VE. An asynchronous (or self-paced) system must produce outputs in response to intentional control as well as support periods of no control (Schlögl, Kronegg, Huggins, & Mason, 2007); those are the so-called intentional control (IC) and non-control (NC) states, respectively. Both states are supported in the study presented in this paper: the system waits in a NC state in which an NC interface is shown (Fig. 2a). The NC interface enables subjects to remain in the NC state (not generating any command) until they decide to change to the IC state, where the control is achieved through the IC interface (Fig. 2b).

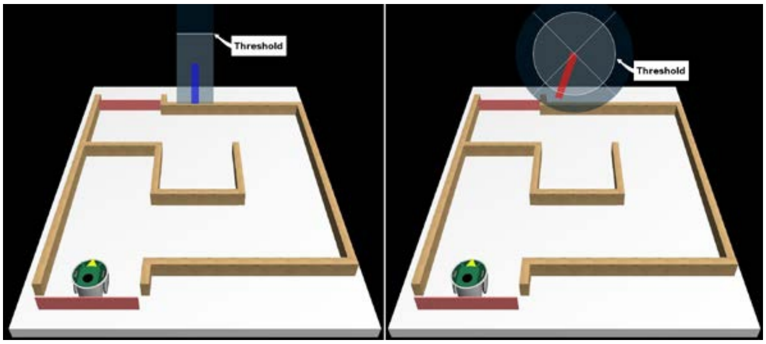

Figure 2: a) NC interface (left) and b) IC interface (right)

The NC interface consists of a semi-transparent vertical blue bar placed in the centre of the screen. The bar length is computed every 62.5 ms as a result of the LDA classification: if the classifier determines that the mental task is right-hand MI, the bar extends; otherwise, the bar length remains at its minimum size. In order to change from the NC to the IC state, the subject must accumulate more than a “selection time” with the bar over the “selection threshold”. If the length is temporarily (less than a “reset time”) lower than the selection threshold, the accumulated selection time is not reset, but otherwise it is set to zero.

The IC interface is similar to the one presented in (Ron-Angevin, Díaz-Estrella, & Velasco-Álvarez, 2009): a circle divided into four parts, which correspond to the possible navigation commands (move forward, turn right move back and turn left), with a blue bar placed in the centre of the circle that is continuously rotating clockwise. The subject can extend the bar carrying out the MI task to select a command when the bar is pointing at it. The way the selection works in this interface is the same as in the NC interface, with the same selection and reset time and the same selection threshold. In the IC interface, another threshold is defined: stop threshold, which is lower than the selection threshold, and not visible to the subject. When it is exceeded, the bar stops its rotation in order to help the subject in the command selection. The rotation speed was fixed to 24 degrees every second, so it took 9 s to complete a turn if there was not any stop.

Subjects receive audio cues while they interact with the system. When the state changes from IC to NC they hear the Spanish word for ‘wait’; the reverse change is indicated with ‘forward’, since it is the first available command in the IC state. Finally, every time the bar points to a different command, they can hear the correspondent word (‘forward’, ‘right’, ‘backward’ or ‘left’).

In the next two sections, the two paradigms to be compared will be described, which are based in the interfaces explained above.

1) Continuous Mode

Once a command is selected, the bar changes its color to red and the virtual robot starts moving forward or backward, or turning left or right at a fixed speed. The movement is maintained as long as the bar length is above the selection threshold (this means that the subject is still carrying out the MI mental task). If the bar is temporarily under this threshold (less time than the reset time), the movement stops, but the system allows the subject to continue the same movement if the bar again exceeds the selection threshold. While it happens, the bar keeps its red color to indicate this possibility to the subject. In the case that the bar remains under the selection threshold longer than the reset time, the bar changes its color to blue and continues rotating (if it is under the stop threshold) so that the subject can select a command again. The position of the rotating bar does not change; it takes its rotation up again from the same point at which it last stopped to select a command. In this way, the subject can select the same command several times in a row, in case the reset time passes without the subject wanting to stop the movement.

2) Switch Mode

Once a command is selected, the movement starts (as it happened in the previous case) and the bar color is set to green. The main difference is that, in the present case, when the bar is shortened under the selection threshold the movement does not stop, but it is kept until the user enlarges the bar length above the selection threshold again (carrying out a MI mental task); at that moment the robot stops. Besides, as it was the case of a command selection, if the bar still remains above the threshold for the same "selection time", the command is unselected and the bar turns blue and continues its rotation. If the time that the bar is above the threshold is lower than the "selection time", the movement of the robot starts again.

Experimental Procedure

This experiment consisted of controlling a virtual robot through a group of corridors which formed a sort of small maze. This proposed virtual robot was designed with the same features as the EPFL educational e-puck robot, (www.e-puck.org). The task was to drive the virtual robot the from the start position to the goal as fast as possible, using the minimum number of navigation commands, trying to always move forward (the forward direction is indicated by an arrow on the top of the robot), and avoiding collisions. The proposed VE (and the virtual robot) is presented in Fig. 2. The robot was configured to stop automatically when they approached within 2 cm of an obstacle, to move at a speed of 3.9 cm/s, and to turn at 42.9 degrees/s. The VE was created with OpenGL for the graphics, OpenAL for the 3D audio, and ODE for physics simulation. The C programming language was used. Interaction between MATLAB and the VE was achieved with TCP/IP communications, which allowed us to use different machines for data acquisition and processing, and environment simulation and display.

Each subject participated in four sessions, carried out on different days: a first one for adaptation purpose and the other three to evaluate the two different paradigms. The first session was considered an adaptation to the paradigm navigation session, in which subjects should get familiarized with the environment and the navigation paradigm using only the audio-cued interface. After a short training period controlling the virtual robot using the graphical and the audio-cued interfaces together, the subjects practiced to control it trough using only the audio-cue interface. The duration of this fist session was depending on the ability of the subject to acquire control (30-60 min). Due to a lack of control, two out of six subjects were discarded and did not participate in the rest of the experiment. Finally, four out of twelve subjects participated in the all experiment.

After this first session, the four subjects participated in three sessions, with two experimental runs each. During the two first experimental sessions (denoted session 1 and session 2), the first experimental run consisted of controlling the virtual robot using discrete mode for turn commands: once the command is selected, the virtual robot turn 90 degrees to the right or to the left. In the second experimental run, continuous mode was used to turn right and left. In the last session (denoted session 3), each experimental run was performed to control the robot using the two navigation paradigms, using continuous mode for turn commands. The order in which the navigation paradigms were tested was counterbalanced over participants in order to control for the potential effect of experience.

After each session, the participant filled out a usability questionnaire based on the NASA-TLX test (Hart, & Staveland, 1998). This questionnaire consisted of 5 affirmative statements: mental and temporal demands, fatigue/effort, stress and performance, scored between 0-20 in which higher values are indicative of higher workload.

Results

In table 1, the values of different parameters obtained from each session are shown. The nomenclature used in ‘Run’ parameter is: ‘S’: switch mode; ‘C’: continuous mode; ‘d’: discrete mode for turn commands; ‘c’: continuous mode for turn commands. The analyzed parameters are: the time in seconds necessary to generate the desired trajectory (Time), the number of times that the robot collided with the wall (Coll.), the number of selected commands of each type (Forward, Right, Left, and Backward) and the total number of commands used to drive the robot from the start position to the goal (Total). Rows in italics correspond to not finished runs (S/c for S1; C/d, C/c and S/c for S3). For these runs, subjects did not get to drive the robot to the goal position, and was the operator who decided to stop the run when he considered it too long. In the last rows (indicated by ‘All’), the values averaged over the subjects for each mode are shown. To obtain theses values, only finished runs were considered. ‘S’ and ‘C’ correspond to the average over all ‘Switch’ and ‘Continuous’ experimental runs respectively.

Subj	Ses	Run	Time (s)	Coll.	Forward	Right	Left	Backward	Total
S1	1	S/d	910	7	7	12	12	14	45
		S/c	*1487*	*38*	*37*	*22*	*16*	*13*	*88*
	2	C/d	228	1	5	2	2	0	9
		C/c	382	9	6	6	9	5	26
	3	S/c	640	6	11	13	9	10	43
		C/c	686	3	4	9	9	11	33
S2	1	C/d	334	7	8	5	5	9	27
		C/c	228	1	7	2	3	3	15
	2	S/d	860	16	14	18	26	9	67
		S/c	394	18	18	6	4	11	39
	3	S/c	492	5	6	10	7	6	29
		C/c	442	2	7	5	6	4	22
S3	1	*C/d*	*1635*	*20*	*45*	*37*	*35*	*39*	*156*
		C/c	644	2	38	18	16	9	81
	2	S/d	960	1	2	14	14	7	37
		S/c	570	3	4	5	21	5	35
	3	*C/c*	*1107*	*17*	*30*	*27*	*31*	*17*	*105*
		S/c	*2609*	*73*	*62*	*92*	*69*	*69*	*292*
S4	1	S/d	310	0	1	2	2	0	5
		S/c	1916	38	38	55	53	37	183
	2	C/d	2390	14	34	13	12	18	77
		C/c	308	0	15	6	3	0	24
	3	S/c	1229	0	31	11	15	2	59
		C/c	202	1	8	2	5	0	15
All		S/d	760±302.7	6±7.3	6±5.9	11.5±6.8	13.5±9.8	7.5±5.8	38.5±25.6
		S/c	873.5±589.1	11.6±14.3	18±13.8	16.6±19	18.1±18.1	11.8±12.7	64.6±58.8
		S	**828.6±476.2**	**9.4±11.8**	**13.2±12.5**	**14.6±14.9**	**16.3±14.8**	**10.1±10.3**	**54.2±48.2**
		C/d	984±1218.8	7.3±6.5	15.6±15.9	6.6±5.7	6.3±5.1	9±9	37.6±35.2
		C/c	413.1±191.2	2.57±2.9	12.1±11.9	6.8±5.5	7.3±4.6	4.6±4.2	30.8±22.9
		C	**584.4±656.1**	**4±4.5**	**13.2±12.4**	**6.8±5.2**	**7±4.5**	**5.9±5.8**	**32.9±25.3**

Table 1: Performance for each subject and session.

Regarding the subjective measures, the average values over the subjects and runs for each mode and question are shown in table 2. To obtain theses values, only scores of finished runs were considered.

Mode	Questions				
	Mental demand	Temporal demand	Fatigue/effort	Stress	Performance
Switch	14.4±1.6	5.5±3.9	12±3.2	8.6±5.4	10.7±4.9
Continuous	12.3±5.1	4.6±4.2	12.3±3.5	7.9±6.4	13.4±4

Table 2: Subjective measures.

Discussion and Conclusion

The main objective of this study was to compare two different paradigms to control a virtual robot. Unfortunately, eight out of twelve subjects were discarded due to their lack of control (six subjects in the training sessions, and two subjects in the experimental phase). The number of participants is too low to obtain strong conclusions. However, the objective of this work was to test the feasibility of the navigation paradigms, and this has actually been proved with the satisfactory results of a small group of subjects.

The obtained results for continuous mode are in concordance with those obtained in a similar experiment (Velasco-Álvarez, Ron-Angevin, da Silva-Sauer & Sancha- Ros, 2013). Even if questionnaire results do not show significant differences between both control mode (table 2), comparing average values in the different parameters related to performance (data in bold in table 1), we can conclude that using the continuous paradigm it was easier to control the virtual robot (less time, collisions and commands). Although the number of ‘forward’ commands are very similar for both control mode, a high number of collisions for switch mode control has probably induced an increase in the rest of commands (in order to recover the path) and, consequently, in time.

One reason to explain these high values in controlling the virtual robot when using the switch mode control could be the difficulty for the subject to manage the brain-switch mode. As it is suggest in (Müller-Putz, Kaiser, Solis-Escalante & Pfurtscheller, 2010), brain-switch is usually controlled by the post-movement beta rebound found after foot movement imagery. In our work, subjects use motor imagery hand because is more appropriate for continuous control, being necessary for turn commands.

For further studies, it could be interesting to combine both mental tasks for both control modes: continuous and switch.

Acknowledgement

This work was partially supported by the University of Málaga, by the Spanish Ministry of Economy and Competitiveness through the project INCADI (TEC 2011-26395), by the European Regional Development Fund (ERDF). This project benefited from specific funding through The Excellence Initiative of the University of Bordeaux (IdEx Bordeaux). We would like to thank the volunteers for their time and contribution to the experiment.

References:

Barbosa, A.O, Achanccaray, D.R., & Meggiolaro, M.A. (2010). Activation of a mobile robot through a brain computer interface. In Proceedings of *IEEE Int. Conf. on Robotics and Automation* (ICRA).

Guger, C., Schlögl, A., Neuper, C., Walterspacher, D., Strain, T., & Pfurtscheller, G. (2001). Rapid prototyping of an EEG-based brain compute interface (BCI). *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 9(1), 49-58.

Hart, S.G., & Staveland, L.E. (1998). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in psychology*, 52, 139-183.

Kronegg, J, Chanel, G., Voloshynovskiy, S., & Pun, T. (2007). EEG-based synchronized brain–computer interfaces: a model for optimizing the number of mental tasks, *IEEE Transaction on Neural System Rehabilitation Engineering* 15 (1), 50–58.

Kübler, A., & Müller, K.R. (2007). An introduction to brain-computer interfacing. G. Dornhege, J. d. R. Millán, T. Hinterberger, D. J. McFarland, & K. R. Müller (Eds.). *Toward Brain-Computer Interfacing* (pp. 1-25). Cambridge, England.

Mason, S.G., & Birch G.E. (2000). A brain-controlled switch for asynchronous control applications. *IEEE Transactions on Biomedical Engineering* 47, 1297–1307.

Millán, J.R., Renkens, F., Mourino, J., & Gerstner, W (2004). Non invasive brain-actuated control of a mobile robot by human EEG. *IEEE Transactions on Biomedical Engineering* 51 (6), 1026–1033.

Müller-Putz, G., Kaiser, V., Solis-Escalante, T., & Pfurtscheller, G. (2010). Fast set-up asynchronous brain-switch based on detection of foot motor imagery in 1-channel EEG. *Medical & Biological Engineering & computing* 44(3), 229-233

Neuper, C., & Pfurtscheller, G. (1999). Motor imagery and ERD. In G. Pfurtscheller, & F. H. Lopes da Silva (Eds.). *Event- Related Desynchronization.Handbook of Electroencephalography and Clinical Neurophysiology (*pp. 303-325). Elsevier. Amsterdam.

Pfurtscheller, G. (2003). How many people are able to operate an EEGbased brain-computer interface (BCI)? *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 11(2), 145-147.

Ron-Angevin, R., & Díaz-Estrella A. (2009). Brain-computer interface: Changes in performance using virtual reality techniques. *Neuroscience Letters*, 449(2), 123-127.

Ron-Angevin, R., Díaz-Estrella A., & Velasco-Álvarez, F. (2009). A two-class brain computer interface to freely navigate through virtual worlds. *Biomedizinische Technik*, 54(3), 126-133.

Ron-Angevin, R.,Velasco-Álvarez, F., Sancha-Ros, S., & Da Silva-Sauer, L. (2011).A two- class self-paced BCI to control a robot in four directions. In Proceedings of the *IEEE Int. Conf. on Rehabilitation Robotics* (ICORR).

Schlögl, A., Kronegg, J., Huggins, J.E., & Mason, S.G. (2007). Evaluation criteria for BCI research. In G. Dornhege, J. d. R. Millán, T. Hinterberger, D. J. McFarland, & K. R. Müller (Eds.). *Toward Brain-Computer Interfacing* (pp. 327-342). Cambrigde, England.

Solis-Escalante, T., Müller-Putz, G., Brunner, B., Kaiser, V., & Pfurtscheller, G. (2010). Analysis of sensorimotor rhythms for the implementation of a brain switch for healthy subjects. *Biomedical Signal Processing and Control 5(1),* 15-20.

Tsui, C.S., Gan, J.Q., & Roberts S.J. (2009). A self-paced brain–computer interface for controlling a robot simulator: an online event labelling paradigm and an extended kalman filter based algorithm for online training. *Medical & Biological Engineering & computing* 47(3), 257–265.

Varona-Moya, S., Velasco-Álvarez, F., Sancha- Ros, S., Fernández-Rodriguez, A., Blanca, M.J., & Ron-Angevin, R. (2015). Wheelchair Navigation with an Audio-cued, Two-Class Motor Imagery-based Brain–Computer Interface System. To be presented at Int. Conf. on *IEEE EMBS Neural Engineering Conference*.

Velasco-Álvarez, F., Ron-Angevin, R., Da Silva-Sauer, L., & Sancha-Ros, S. (2010). Brain-computer interface: Comparison of two paradigms to freely navigate in a virtual environment through one mental task. In Proceedings of the *Int. Conf. on Broadband and Biomedical Communication* (IB2Com).

Velasco-Álvarez, F., Ron-Angevin, R., da Silva-Sauer, L. & Sancha- Ros, S., (2013). Audio-cued motor imagery-based brain–computer interface: Navigation through virtual and real environments. *Neurocomputing* 121, 89–98.

Wolpaw, J.R., Birbaumer, N., McFarland, D.J., Pfurtscheller, G., & Vaughan, T.M. (2002). Brain-computer interfaces for communication and control. *Clinical Neurophysiology 113(6),* 767-791.