EVALUATION OF VARIOUS STRATEGIES TO IMPROVE THE TRAINING OF A BRAIN COMPUTER INTERFACE SYSTEM

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ABSTRACT
Brain-computer interfaces (BCI) allow for communication between the human brain and computers. They have been used to create systems able to generate control over a software or mechatronic device, becoming an important tool for the rehabilitation of handicapped people, especially for patients with quadriplegia. Due to the importance of BCIs, any attempt to improve their response has a great value. The work described in this paper consists of the evaluation of various stimuli applied to improve the training of a BCI based system. The device is the Emotiv® EPOC which includes a Software Development Kit (SDK) to train the system. During the usual training of the SDK; *images, videos, thoughts, movements* and *gestures* were used as stimuli to improve the users' skills for accomplishing specific actions. After the evaluation of these stimuli, they were ranked according to their effectiveness. Finally, a powered wheelchair was controlled using the Emotiv® EPOC by applying the best-ranked stimulus and an assessment protocol was used in order to evaluate the performance of users driving the wheelchair with the BCI, with satisfactory results.

KEY WORDS
Brain-computer interfaces, Emotiv®, Sense stimulation, Powered wheelchairs, Human-computer interfaces, Brain-machine interface, Skill rating, Brain signals.

1. Introduction

Brain-Computer Interfaces (BCIs) are devices that are able to read the human brain electric signals and translate them into control signals for a computer [1]. One of the most important uses of BCIs is their application for the rehabilitation of handicapped patients.

According to the World Health Organization, in 2010 around 15% of world's population lives with some form of disabilities, which means there were over 1 billion persons in this difficult situation [2]. In United States, for instance, approximately 265.000 persons had spinal cord injury (SCI) and nearly 55% of the people registered with disabilities suffered some form of tetraplegia [3].

Thanks to technological and neurological developments, new possibilities arise of improving the condition of handicapped people. In particular, the emergence of more efficient BCIs, allow for the development of diverse systems to improve the mobility, communication, comfort and lifestyle of quadriplegic patients.

Due to the importance of the BCIs for the rehabilitation of patients with severe handicaps, any attempt to improve the response of these systems and reduce the efforts to successfully use them has a great value.

2. Related Work

Research on applications for BCIs to control different kinds of systems is increasing. Among the works developed with a BCI, the following can be found:

- Bin et al. [4], report the creation of a high-speed word spelling system based on a BCI, which allows users to choose a character from a matrix in a monitor by the use of a binary code. By this way, the user is able to complete entire words with a speed of 15-20 characters per minute.
- BCIs were used as a feedback by Ang et al. [5] to facilitate the rehabilitation of stroke patients. By the use of this method, the achieved results were comparable with those obtained by the use of a robot for the rehabilitation.
- A system based on a BCI which allows the patient to paint by the use of a matrix, similar to the spelling matrix used in [4], was created by George et al. [6]. Their system contains various tools allowing the user to draw.
- The use of a BCI to recognize the thoughts and therefore determine the word that a person is thinking about when a recorded image is shown was reported by Palatucci et al. [7].
- Szafir and Signorile [8] successfully controlled a Parallax Scribbler Robot using a BCI.
- Khar et al. [9] report accomplishing the control of a powered wheelchair using a BCI based system using Wavelet Packet Transform (WPT) and Radial Basis Function neural networks.

- Galan et al. [10] controlled a virtual wheelchair using a BCI in which the patient has to follow a specific route in a graphic environment.
- More recent advances include the control of a robotic prosthesis with seven degrees of freedom, as reported by Collinger et al. [11], by the use of a Brain-Machine Interface (BMI), which is similar to a BCI but having the signals from the brain received directly by a machine instead of the computer.

Another kind of works have been developed in order to improve the response of the BCI-based systems, as those reported by Choi et al. [12] who combined some audio-visual cues so as to improve the training of an electroencephalogram (EEG)-BCI based system; and the one presented by Jin et al. [13] where some visual strategies were applied in order to increase the accuracy and diminish the calibration time for event-related potential (ERP)-based BCIs.

This wide range of applications with BCIs, along with the efforts to improve the response of such systems, demonstrate the importance of the BCIs in the scientific world and specifically in the field of the rehabilitation for severely handicapped patients. Still many fields are currently objects of active research such as sensors, signal acquisition, user´s comfort, data processing, electrode positioning, among others; in order to improve the response and reliability of BCIs. This paper focuses mainly on the evaluation of different stimuli and its effectiveness within a state of the art BCI. Similar work can be found in [1] where the steady state visual evoked potential (SSVEP) is evaluated as feedback to determine the mental state of a user.

3. Our Proposal

In the first stage of the work reported in this paper, the use a BCI to control a mechatronic device was tested as a first approach to create a system that could help handicapped people, particularly tetraplegic patients.

The selected BCI was the Emotiv® EPOC and the mechatronic device was built with a LEGO® Mindstorm kit. To reach our purpose, we used the available APIs (Application Programming Interface) supplied by Emotiv® to extract the signals from the SDK and later, these signals were sent via Bluetooth to the mechatronic device in order to control it in different directions (forward, backward, left turn and right turn).

After following the instructions given by the Emotiv® SDK user manual [14] to train the system with the Cognitive Suite (CS), which is the detection suite that recognizes the user's conscious thoughts [14], we tried to control the mechatronic device but it didn't respond according to the user's will most of the times.

Due to these poor results, we implemented some strategies to improve the correspondence between the user's will and the actions executed by the mechatronic device using the Cognitive Suite of the SDK.

The strategies consisted of exposing the user to stimuli in order to get more consistent brain signals. Thus the signals could be easier to identify by the SDK, and could lead to more accurate instructions for the mechatronic device.

The proposed strategies to train the SDK with the Cognitive Suite were:

- *Use of thoughts:* according to the Emotiv® SDK user manual, the training has to be made via the thoughts, i.e., trying to move a 3D virtual cube within a graphical environment as if the user had "superpowers".
- *Use of images:* based on the theory that familiar images can produce variations in the electrical signals of the brain, proposed by Gorman [15], images related to the action being trained were used. In this way, for instance, while training the *lift* action, three arrows pointing up, were used (Fig. 1). A variation of this stimulus was the use of 3D images obtained by stereogram (Fig. 2); with this stimulus the intention was to keep the focus on the image in order to get more consistent brain signals; since it requires the user to focus her sight on the image without any movement. The results obtained with flat images and stereograms were similar, thus they are presented together in results.

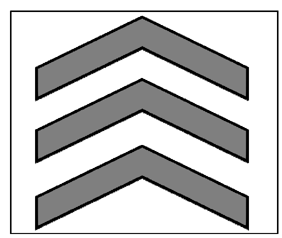

Fig. 1. Arrows (flat image) used to stimulate the brain.

Fig. 2. Stereogram used to keep the focus (taken from www.magiceye.com on December 27th 2012).

- *Use of videos*: moving images were used in the direction of the action being trained. For example, if the action to be trained was *Left*, then we used arrows moving towards the left. This same stimulus is used by the SDK if the option of *move cube according to training action* is active.
- *Use of movements*: the use of physical movements to stimulate the brain was used also. In particular,

movements of the hand were chosen, due to its electrical activity, according to Cardona [16]. This kind of stimulus was applied in different ways. Dynamic movements were used, on which the user kept moving a limb following certain patterns. Static tension, on which the user applied force continuously over a particular limb, was also used. Furthermore, unilateral movements and bilateral movements were used. The results obtained with all the trials with movements were similar, so they are together in the results.

- *Use of gestures*: Although the Emotiv® SDK user manual in the part of CS reads explicitly otherwise, we tried to train the system with gestures, due to the fact that facial expressions have high electrical activity in the outer layer of the head [16], and the Emotiv® EPOC uses the electric signals of the cortical layer, that is the more superficial layer of the brain.
- *Use of smells*: The sense of smell is directly processed by the deep limbic system of the brain, according to Amen [17], the same place in the brain where the remembrances are processed. Since the Emotiv® works with superficial signals, it was decided not to use this stimulus.

The bar of Skill Rating (SR), present in the SDK, was used as indication to evaluate all the stimuli applied when trying to improve the correspondence between the intention of movement produced by the brain and the action executed by the device. The SR bar provides a measure of how consistently the user can mentally perform the intended action [14].

In order to get enough and good sensitive results, the SR bar was read every two trials until either reaching 50 trials, or until observing that the user reached a good level of training.

After the evaluation of the different stimuli, a powered wheelchair was controlled using the BCI with the stimulus that obtained the best results. In order to control the wheelchair, the joystick was replaced by the commands interpreted by BCI-based software. The ability of a user to drive the wheelchair using the BCI was evaluated by the application of the Power-Mobility Indoor Driving Assessment (PIDA), proposed by Dawson et al. [18]. This evaluation gave us a score of the controllability of the wheelchair with the BCI, which is shown in section 4.3.

4. Results

The SDK allows for the training of up to four different actions for each user when the CS is used. The actions to be trained were chosen by each user (according to his/her will) between a list of 13 possible actions such as push, pull, lift, left and right, among others. In our case, users chose either one, two or three actions, depending on his/her time availability. The trained actions were used to control the mechatronic device.

From the four possible actions, only three were tested. Each added action is more difficult to train than the previous ones, as reported by Emotiv® [14]. This means that it is expected for the first action to obtain better results than the second one, and the second action better than the third one.

The strategies mentioned above were tested with 12 different healthy users from 20 to 35 years old of both genders. Each stimulus was evaluated with at least 4 users in the *first action* and with at least 3 users in the *second action*.

In order to evaluate the different stimuli, important information about the trials was recorded, such as the maximum Skill Rating (SR), number of trials required to reach at least 75% of SR, number of users that didn't reach at least 75% of SR, among others.

The results of the different stimuli are presented using graphs and adding a sixth order polynomial tendency line which is darker than the raw data. A graphic of the average results is also shown to understand the general behavior of each stimulus.

4.1 Graphical Results

Following, the graphics with the results obtained by the training of a single action using the BCI with the Cognitive Suite are presented. The results are based on the application of the suggested stimuli and intend to demonstrate the different responses for each stimulus.

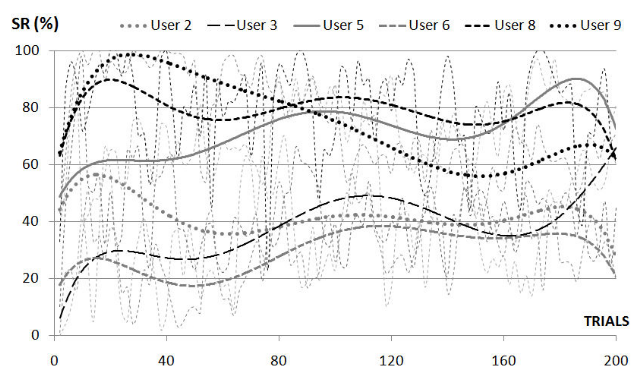

Fig. 3. Results using the Cognitive Suite with *Thoughts*.

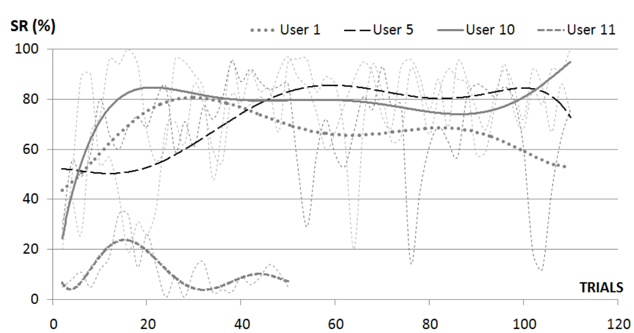

Fig. 4. Results using the Cognitive Suite with *Videos*.

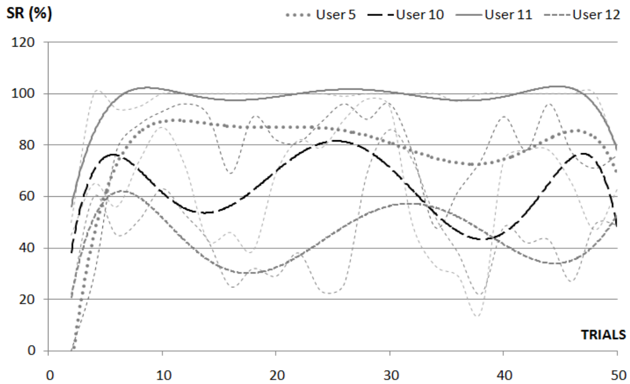

Fig. 5. Results using the Cognitive Suite with *Images*.

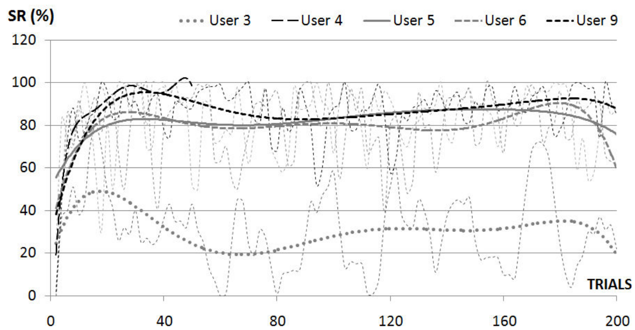

Fig. 6. Results using the Cognitive Suite with *body Movements*.

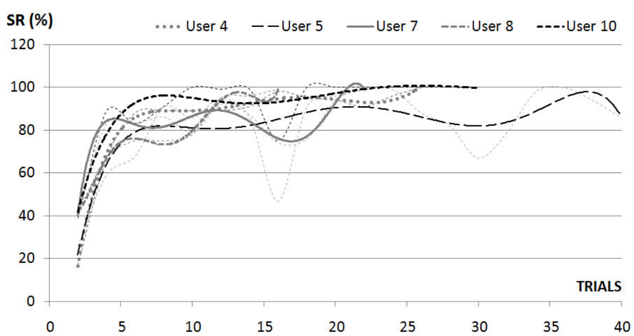

Fig. 7. Results using the Cognitive Suite with *Gestures*.

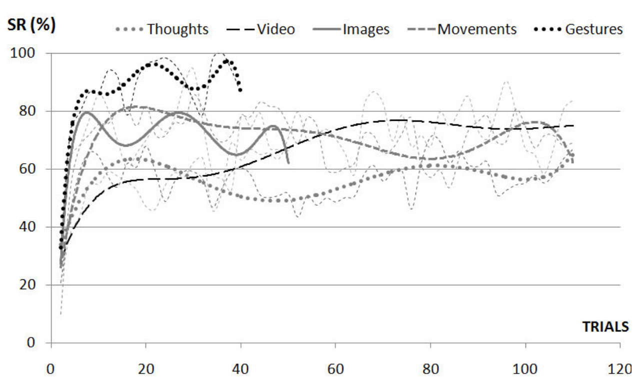

Fig. 8. *Average results* of each stimulus using the Cognitive Suite.

From the previous graphic representation of the results, it is possible to conclude that the average behaviours across the stimuli are different, especially in the peak value and in the initial upslope, which suggests that some stimuli are better than others. The best stimulus could be used to improve the level of the training and the correspondence between the user's will and the system´s response. According to the results presented in Fig**.** 8, *Gestures* stimuli had a superior average behaviour, whereas *Thoughts* stimuli present the worse results with the Cognitive Suite.

It can also be observed, from most of the figures, that the response of the users to the same stimulus varies widely, implying that the response of applying a specific stimulus depends on each particular user. The graphic with the most similar behaviour across the users was *Gestures* (Fig. 7).

Another important observation is the fluctuating behavior of almost all the curves, showing periods of focus and lack of it. According to this, a period of focus is followed by a period of lack of focus, but later the focus is recovered. The periods of focus and lack of focus are almost similar in duration in the most of the cases.

Although not shown explicitly in the previous graphics, the results also showed that users do not respond in the same way to different stimuli. Some stimuli could improve the results while some could worsen it. The clearest case is user 11, a healthy 20 year old male user with a thin build, abundant straight hair and an Engineering degree, who had outstanding results with the *Images* stimulus but poor results with *Videos*, which can be seen in Fig. 9.

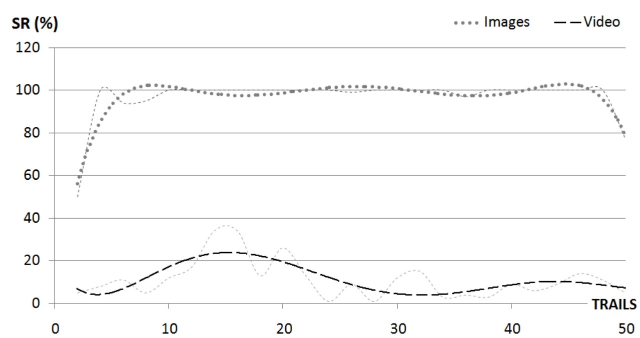

Fig. 9. Results of user 11 with *Images* and *Videos* using the Cognitive Suite.

4.2 Statistical Results

To generate a point of comparison between the different stimuli, relevant information about the results of the users training three actions is presented next. Table 1, Table 2 and Table 3 show some statistics about the different stimuli in each trained action.

Table 1. Training of *first action* using different stimuli with the Cognitive Suite.

First action					
Indicator	**Stimulus**				
	Thg.	Vid.	Img.	Mov.	Gest.
Min. Trials to Reach 75% SR	4	6	4	4	4
Max. Trials to Reach 75% SR	110	12	30	16	8
Avg. Trials to Reach 75% SR	27	9	13	8	6
% Users not Reaching 75% SR	17%	25%	0%	0%	0%
Max. SR reached	100	100	100	100	100
Trials to reach Max. SR	10	16	4	12	10
Avg. Max. SR	89	82	95	96	100
Avg. Trials to reach Max. SR	71	46	19	21	22
Max. Trials to reach Max. SR	172	116	30	34	26
Users	6	4	4	5	5

Table 2. Training of *second action* using different stimuli with the Cognitive Suite.

Second action					
Indicator	**Stimulus**				
	Thg.	**Vid.**	**Img.**	**Mov.**	**Gest.**
Min. Trials to Reach 75% SR	N.R.	N.R.	N.R.	N.R.	6
Max. Trials to Reach 75% SR	N.R.	N.R.	N.R.	N.R.	32
Avg. Trials to Reach 75% SR	N.R.	N.R.	N.R.	N.R.	12
% Users not Reaching 75% SR	100%	100%	100%	100%	0%
Max. SR reached	53	25	35	36	100
Trials to reach Max. SR	4	2	8	22	14
Avg. Max. SR	30	16	17	13	95
Avg. Trials to reach Max. SR	47	4	6	10	33
Max. Trials to reach Max. SR	136	6	8	22	64
Users	6	4	4	3	5

N.R: Not reached

Table 3. Training of *third action* using different stimuli with the Cognitive Suite

Third action					
Indicator	**Stimulus**				
	Thg.	**Vid.**	**Img.**	**Mov.**	**Gest.**
Min. Trials to Reach 75% SR	N.A.	N.A.	N.A.	N.A.	8
Max. Trials to Reach 75% SR	N.A.	N.A.	N.A.	N.A.	30
Avg. Trials to Reach 75% SR	N.A.	N.A.	N.A.	N.A.	16
% Users not Reaching 75% SR	N.A.	N.A.	N.A.	N.A.	0%
Max. SR reached	N.A.	N.A.	N.A.	N.A.	96
Trials to reach Max. SR	N.A.	N.A.	N.A.	N.A.	26
Avg. Max. SR	N.A.	N.A.	N.A.	N.A.	91
Avg. Trials to reach Max. SR	N.A.	N.A.	N.A.	N.A.	32
Max. Trials to reach Max. SR	N.A.	N.A.	N.A.	N.A.	32
Users	N.A.	N.A.	N.A.	N.A.	3

N.A: Not applied

According to Tables 1, 2 and 3, the only stimulus that obtained good results in the *second action* and *third action* was *Gestures*, while the other stimuli didn't reach the 75% of SR either in the *second action* or in the *third action*. Obtaining good results with *Gestures* using the Cognitive Suite demonstrates that the trials were done in the correct way.

The *third action* was evaluated only with *Gestures* due to the fact that the other stimuli didn´t reach the 75% of SR in the *second action*, and the next action (the *third action* in this case) is more difficult than the previous one as it was indicated previously.

It's not explicit in the tables but the graphics show it slightly; more than 73% of the maximum SRs were reached in the first 30 trials and nearly 85% in the first 50 trials. This suggested that training with more than 50 trials could be a waste of time and an overtraining which could decrease the accuracy, as reported by Emotiv® [14].

In order to facilitate the comparison between the stimuli and rank them, we extracted the most representative indicators such as the average number of trials required to reach 75% of SR in the *first action*, average of the maximum SR reached in the *first action*, average of the maximum SR reached in the *second action* and the percentage of users that couldn´t reach a 75% SR.; and graph them as follows.

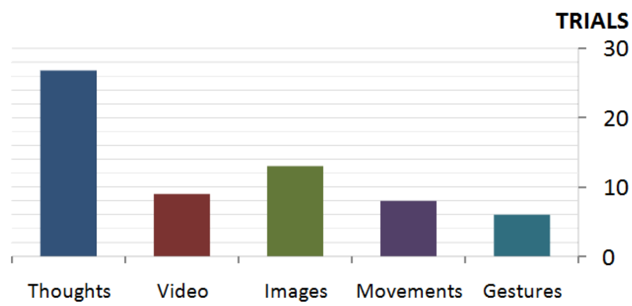

Fig. 10. *Average number of trails* to reach 75% of SR in *first action*.

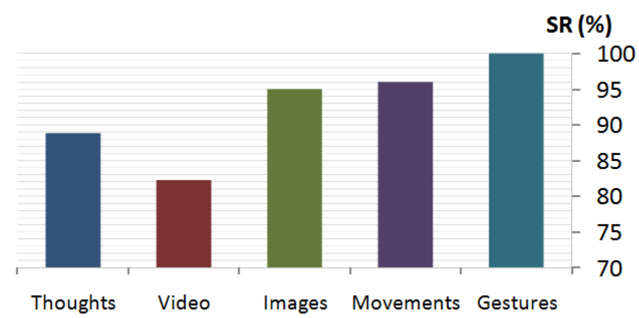

Fig. 11. *Average maximum SR* in *first action*.

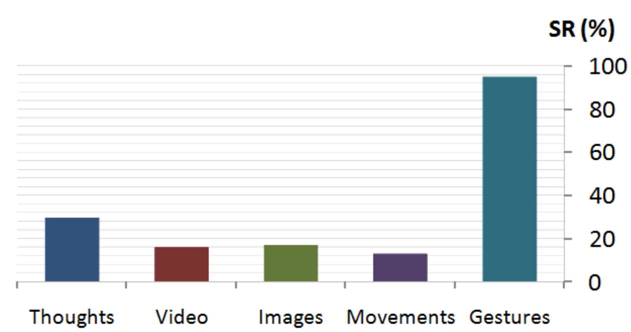

Fig. 12. *Average maximum SR* in *second action*.

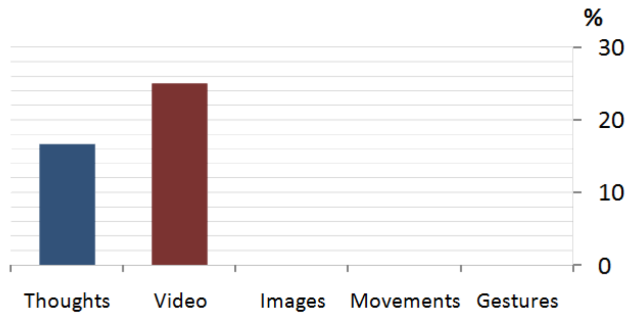

Fig. 13. Percentage of users that *didn't reach* the 75% SR.

These comparative bar diagrams allowed a visual evaluation of every stimulus in order to score each one in each figure from 1 to 5, 5 being the maximum score. The evaluations were collected in Table 4.

Table 4. Comparative evaluation of each stimulus based on statistics.

Stimulus	Fig. 10	Fig. 11	Fig. 12	Fig. 13	Total
Thoughts	1	2	4	2	9
Videos	3	1	2	1	7
Images	2	3	3	4	12
Movements	4	4	1	4	13
Gestures	5	5	5	4	19

The results given by Table 4 are consistent with the observations made in the section 4.1, where *Gestures* seemed to be the best stimulus while *Thoughts* among the worst ones. Based on these graphic and statistic results, a ranking of the stimuli in order to improve the SR of the training with an Emotiv® EPOC is shown in Table 5.

Table 5. Rank of stimuli in order to improve the SR using the Cognitive Suite.

Rank	Stimulus
1st	Gestures
2nd	Movements
3rd	Images
4th	Thoughts
5th	Videos

Due to the results, and considering that only *Gestures* had a good performance in the three actions using the Cognitive Suite, the mechatronic devices were controlled by the *Gestures*. The fact that the other stimuli didn't respond satisfactorily in the *second action* and in the *third action*, made them unsafe to control the powered wheelchair which could represent a hazard for the user's health.

4.3 Result of Driving Assessment with Emotiv® EPOC

After choosing *Gestures* as the stimulus for the Emotiv® EPOC to control a powered wheelchair, a Pride Jazzy® Select Elite wheelchair was selected to perform the tests on. For this purpose the joystick of the wheelchair with a circuit managed by a microcontroller was modified, so that each of the 3 actions was converted into a correspondent order for the wheelchair. Given that only 3 actions could be performed, as concluded in the previous sections, combinations of these actions were used to generate the necessary movements to control the wheelchair. The equivalence between the 3 actions and the instructions to the wheelchair is shown in Table 6.

Table 6. Equivalence between actions and instructions to the wheelchair.

Action	Interpretation
First action	Forward/Backward
Second action	Turn left/right
Third action	Invert
Neutral	Stop

The *third action* corresponds to the *Invert order* which is used to change the direction of the current instruction being performed. Thus, if the wheelchair went forward and the invert order was received, the wheelchair drove backwards.

After having a defined way to control the powered wheelchair, the PIDA protocol, proposed by Dawson et al. [18] to evaluate the driving of the wheelchair, was applied. This protocol includes activities in a bathroom, in a bedroom, with doors, in an elevator, with ramps, parking tests and manoeuvrability activities. Among the 27 tests performed, only six presented difficulties, especially in the bathroom, and only one couldn't be performed, *unexpected obstacles*, which suggests that there is a high latency in the response of the system. The rest of the activities were achieved in an easily and successfully. The general evaluation gave a total score of 79%, which is acceptable. The score obtained performing the test with the joystick was 99%.

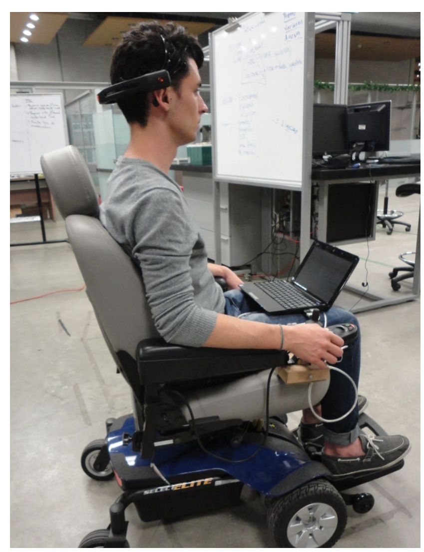

Fig. 14. Healthy user controlling the powered wheelchair with the BCI using *Gestures* with the Cognitive Suite (picture taken on Dec 20th 2012).

5. Conclusions and Future Work

After the evaluation of the different stimuli proposed for the use of Emotiv® EPOC with the Cognitive Suite, the best results were obtained by *Gestures*. This is a singular result given that the Emotiv® SDK user manual [14] reads explicitly that the user has to avoid dramatic expressions during the training with the Cognitive Suite. This result was confirmed with the successful control of a powered wheelchair using the Emotiv® EPOC with *Gestures* and the Cognitive Suite. Users controlling the powered wheelchair completed a series of tests that evaluate driving skills. In these tests, users reached a score of 79% when it was controlled by the BCI trained with *Gestures*. This proved the effectiveness in the pursuit of a successful control of a mechatronic device through a BCI.

Based on the presented results, it is possible to conclude that different stimuli produced variations in the response of the user to the SDK training with BCI. This suggests that the use of a particular stimulus, depending on each user, could improve the reliability of the systems controlled by BCI. Furthermore, different users responded in different ways to the same stimulus. A similar behavior takes place when the same user is stimulated with different stimuli, while one of them could help to improve the performance of the trials, another one could be an obstacle to the training. The graphs show oscillations in the curves, which suggests alternating periods of focus and lack of focus.

Several observations were made during the process of trials with the Emotiv® EPOC. The first one is that the SDK has a latency period which forces the user to get in focus before the start of each trial; otherwise the Skill Rating would be affected. It is also difficult to keep the focus for a period longer than eight seconds in each trail, which could bring trials with a lack of focus affecting the Skill Rating which is difficult to recover. Another fact that was observed after this evaluation was that the system is hard to be trained with more than one action; at least through our approach; from all the stimuli applied, only *Gestures* obtained satisfactory results with more than one action.

As future work we plan to evaluate different BCIs, applying the stimuli mentioned in this paper and comparing them with the Emotiv® EPOC. Furthermore, we plan to perform the same tests with tetraplegic patients with the purpose verifying whether they are able to control the powered wheelchair or not.

Last but not least, depending on the final function it might not be worth dealing with the big signal analysis required for cognitive recognition, when by gestures recognition a similar function can be obtained. Therefore the superficial electrical signals above the human's neck should all be considered as useful as the electrical signals from thoughts.

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References

[1] S. Wang, E.T. Esfahani, & V. Sundararajan, Evaluation of SSVEP as Passive Feedback for Improving the Performance of Brain Machine Interfaces, *Proc. of the ASME 2012 IDETC/CIE,* Chicago, IL, 2012.

[2] World Health Organization, *World report on disability 2011* (Geneva, Switzerland, WHO, 2011).

[3] National Spinal Cord Injury Statistical Center, *Spinal Cord Injury Facts and Figures at a Glance* (Birmingham, AL, NSCISC, 2011).

[4] G. Bin, X. Gao, Y. Wang, Y. Li, B. Hong, & S. Gao, A high-speed BCI based on code modulation VEP, *Journal of Neural Engineering, 8*(2), 2011, 025015.

[5] K. K. Ang, C. Guan, K. S. G. Chua, B. T. Ang, C. W. K. Kuah, C. Wang, K. S. Phua, Z. Y. Chin, & H. Zhang, A Large Clinical Study on the Ability of Stroke Patients to Use an EEG-Based Motor Imagery Brain-Computer Interface, *Clinical EEG and Neuroscience, 42*(4), 2011, 253–258.

[6] H. George, A. Hosle, D. Franz, & A. Kubler, Brain Painting – BCI Meets Patients and Artists in the Field, *BCI Meeting*, Asilomar, CA, 2010, D-3.

[7] M. Palatucci, D. Pomerleau, G. E. Hinton, & T. M. Mitchell, Zero-shot Learning with semantic Output Codes, *23rd Annual Conference on Neural Information Processing Systems*, Vancouver, Canada, 2009, 1410-1418.

[8] D. Szafir, & R. Signorile, An Exploration of the Utilization of Electroencephalography and Neural Nets to Control Robots, *INTERACT (4) - 13th IFIP TC13 International Conference*, Lisbon, Portugal, 2011, 186-194.

[9] V. Khare, J. Santhosh, S. Anand, & M. Bhatia, Brain Computer Interface Based Real Time Control of Wheelchair Using Electroencephalogram, *International Journal of Soft Computing and Engineering, 1*(5), 2011, 41-45.

[10] F. Galán, M. Nuttin, E. Lew, P. W. Ferrez, G. Vanacker, J. Philips, & J. del R. Millán, A brain-actuated wheelchair: Asynchronous and non-invasive Brain–computer interfaces for continuous control of robots, *Clinical Neurophysiology, 119*(9), 2008, 2159-2169.

[11] J. L. Collinger, B. Wodlinger, J. E. Downey, W. Wang, E. C. Tyler-Kabara, D. J. Weber, A. JC McMorland, M. Velliste, M. Boninger, & A. B. Schwartz, High-performance neuroprosthetic control by an individual with tetraplegia, *The Lancet, Early Online Publication, December* 17, 2012.

[12] D. Choi, Y. Ryu, Y. Lee, & M. Lee, Performance evaluation of a motor-imagery-based EEG-Brain computer interface using a combined cue with heterogeneous training data in BCI-Naive subjects, *BioMedical Engineering OnLine, 10*(1), 2011, 91.

[13] J. Jin, E. W. Sellers, Y. Zhang, I. Daly, X. Wang, & A. Cichocki, Whether generic model works for rapid ERP-based BCI calibration, *Journal of Neuroscience Methods, 212*(1), 2013, 94-99.
[14] Emotiv® Software Development Kit, User Manual for Release, Version 1.0.0.4, 29-33.
[15]C. Gorman, The Mind-Reading Machine, *IEEE Spectrum, July*, 2012.
[16] Edgar A. Cardona, Clinical Neurologist, SaludCoop Clinic, Personal Communication, Medellin, June 23, 2012.
[17] D. G. Amen, Cambia tu Cerebro, Cambia tu Vida, *Spanish Pubs Llc*, 2011.
[18] D. Dawson, E. Kaiserman-Goldenstein, R. Chan, & J. Gleason, *Power-Mobility Indoor Driving Assessment manual*, 2006.