Playing with your mind

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Abstract. A Brain-Computer Interface (BCI) is a communication system between the brain and a machine like a computer. Some BCI systems have been used to help people with disabilities and sometimes, with entertainment purposes. In this paper, a BCI-game system is developed. It allows controlling the altitude of a ball inside of a glass pipe according to mental concentration level, which is measured on EEG signals of the user. The system is automatically adjusted to each user, hence, it is not needed any calibration step. Ten subjects participated in the experiments. They achieved effective control of the ball in a few minutes, demonstrating the feasibility of the BCI-game system.

1. Introduction

A Brain-Computer Interface (BCI) is a non-muscular communication and control channel [1]. Communication can be defined as a process to express and share experiences among people, where the machine can be used as an accessory tool. A new trend for man-machine interaction is using the brain signals to promote a natural interface [2]. In such sense, a BCI has been used for helping people with disabilities to command a robotic wheelchair [3], to spell on a computer screen [4] or to navigate through virtual worlds [5].

On the other hand, a BCI system was used for entertainment purposes. For example, a race car was controlled on a computer screen with a BCI based on steady-state visual evoked potentials [6]. A BCI was used to gain the control on the balance of an animated character on a tightrope in an immersive 3D game [7]. Moreover, some commercial BCI systems for entertainment purposes have been developed. For example, Mattel Inc. presented a toy which uses brain waves to steer a ball through an obstacle course, the MindFlex [8]. A summary of commercial BCI systems can be found in a Wikipedia webpage named: Comparison of consumer brain-computer interface devices [9].

In this paper, a method to calculate the attention (or concentration) level of the user is presented. Moreover, a BCI-game for controlling the altitude of a ball inside a glass pipe (Figure 1) is proposed. The elevation of the ball is correlated with the attention level, i.e., higher altitude corresponds to higher concentration of the user.

The remainder of this paper is organized in two parts. The first one is a description of the preliminary study which was performed in order to evaluate the attention level of the subjects and then, designing the BCI-game. In the second part, the developed BCI-game system is described.

2. Preliminary study

The preliminary study was performed to determine the best EEG channel configuration, as well as to detect changes in the EEG signals, which are related to the concentration of the user. Hence, the

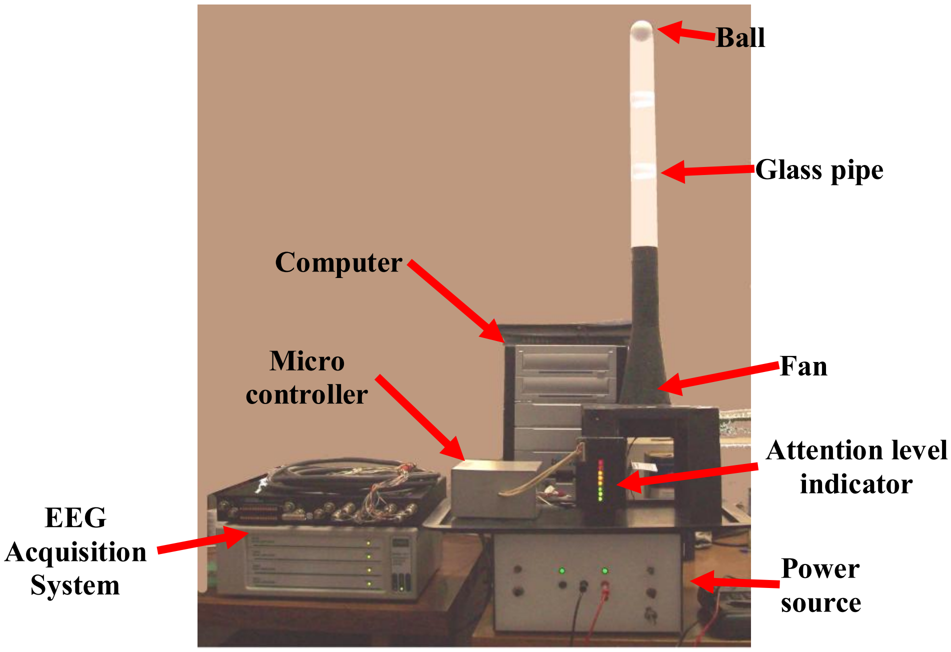


Figure 1: The BCI-game system

attention level is measured over the pre-frontal and frontal cortex where complex cognitive processes are located [10]. The EEG was measured with five channels as depicted in Figure 2.

Four subjects (33.5±1.9 years old) participated in the preliminary study. Each subject performed three different mental tasks of 2 minutes duration each, namely:

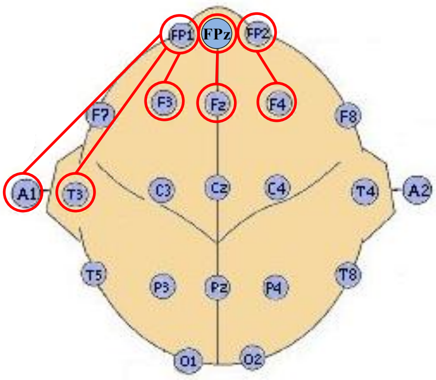
- **Relaxation:** The subject was told to simply relax and try to think of nothing in particular.
- **Math operation:** The user performs a countdown in steps of 3 beginning with a random number of 4 digits.
- **Geometric task:** the user was instructed to visualize a three-dimension block figure being rotated about an axis.

Note that the last two mental tasks leads to the high-attention level, whereas the first one corresponds to the low-attention level. The EEG signals were acquired using a Grass 15LT amplifier system and digitalized at 256 Hz with a NI-DAQPad6015. The analogical pass-band filters were set at 3 and 100Hz and a notch 50 Hz filter was applied as well.

The EEG spectral content was divided into several rhythms or bands [11]:

- Delta rhythm (<4Hz): it is encountered during deep sleep stages.
- Theta rhythm (4-7Hz): it occurs during drowsiness.
- Alpha rhythm (8-13Hz): it is related to relaxation stages.
- Beta rhythm (14-30Hz): it is associated with an activated cortex.
- Gamma rhythm (>30Hz): it is related to a state of active information processing of the cortex.

Hence, the alpha, beta and gamma rhythms were considered in the current work for analyze the attention level. The power spectral density of the EEG was estimated with the periodogram method (see section 3.1) and then, the power of each band was calculated. The periodogram was calculated using windows of 2, 3, 4 and 5 s duration.



Channel	Electrode position
1	Fp1- F3
2	Fpz - Fz
3	Fp2 - F4
4	Fp1 - T3
5	Fp1 - A1
GND	A2

Figure 2: EEG channel measured in the preliminary tests.

2.1. *Results of the preliminary study*

The figure 3 depicts the EEG power bands during the *relaxation* and *math operation* tasks. The four subjects presented a similar behaviour on the alpha and beta rhythms, as showed in figure 3. In other words, the alpha and beta powers are lower as higher the attention level is. The gamma rhythm also presented differences for each mental task; however those variations were different to each subject.

Those changes in the EEG rhythms were observed with more amplitude in two EEG channels: Fp1-A1 and FP1-T3. Consequently, the configuration Fp1-A1 is adopted, because those positions are free of hair, which allows an easy electrodes placement.

Finally, a one-way ANOVA test was applied to the EEG power bands in order to evaluate the statistical significance of the differences between relaxed and attention states. The EEG power bands were calculated using the periodogram of 5 s EEG segments; thus, 47 segments were extracted from each 2 minutes mental task. Theta rhythm do not present differences between both states ($p=0.269$). However, alpha, beta and gamma rhythms present significant differences ($p<0.05$) between low- and high-attention level.

With the results obtained from this preliminary study the BCI-game system was developed. The following section describes the BCI-game system.

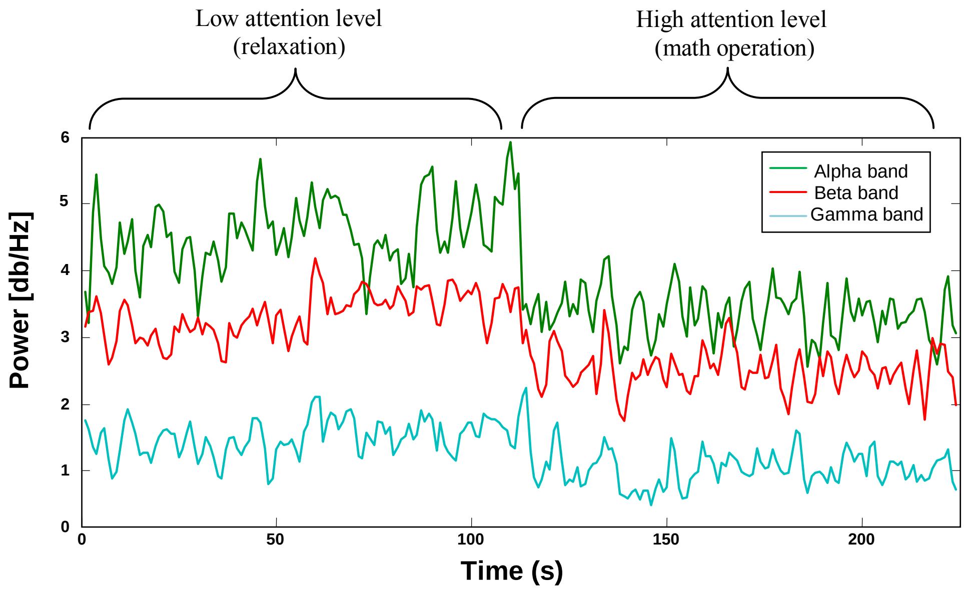


Figure 3: Power EEG bands when the *relaxation* and the *math operation* tasks were performed. The EEG was measured at Fp1-A1 channel.

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3. BCI-attention-game

Figure 4 presents a scheme of the BCI-game system. It is composed of an EEG acquisition system, which measures the brain activity. Then, the EEG signal is fed into the computer and the user's attention level is calculated. According to this attention level, the computer sends a command to the microcontroller. The microcontroller has two functions, the first function is controlling the rotation speed of the fan, and the second one is commanding the attention level indicator. Finally, the air expelled by the fan moves up/down the ball inside the glass pipe.

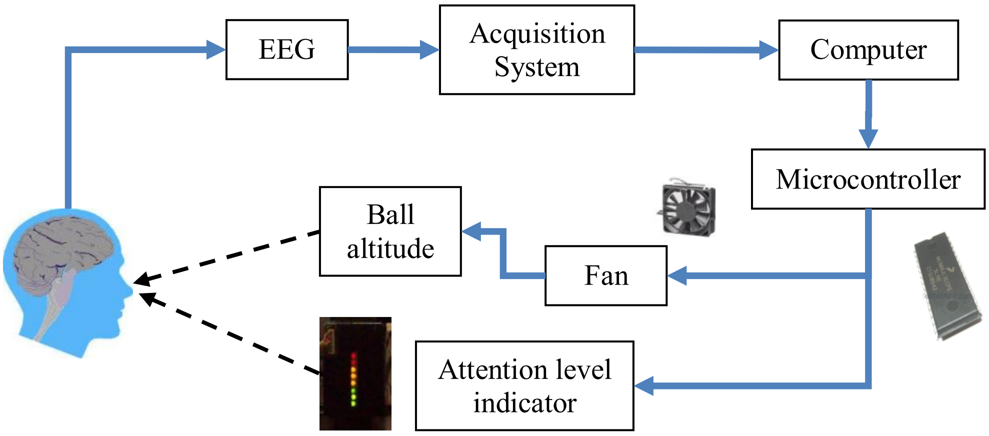

Figure 4: The different BCI-game components.

3.1. EEG signal processing method

First, a Butterworth band-pass digital filter, order 6, with 6 and 30 Hz cut-off frequencies was utilized. Afterwards, the periodogram was computed. It is an estimation of the power spectral density based on the Discrete Time Fourier Transform (DTFT) of the signal x[n]:

$$P_{xx}(f) = \frac{T_s}{N}\left|\sum_{n=1}^{N} x[n]e^{-j2\pi f n T_s}\right|^2 \tag{1}$$

where $P_{xx}(f)$ is the periodogram, T_S is the sampling period, N is the number of samples of the signal and f is the frequency. To compute the periodogram, the Fast Fourier Transform (FFT) with 5 s length Hann window was used.

Then, a value representing the attention level, named Attention Power (AP), is proposed. It is based on the power of alpha and beta rhythms and is calculated as:

$$AP = \sum_{f=8}^{25} P_{xx}(f) \tag{2}$$

The AP value is lower as higher the attention level of the user is and vice versa, i.e., they are inversely related. This is in according with the results obtained from the preliminary study, i.e., the alpha and beta powers are lower as higher the attention level is. Finally, the AP values were filtered with a moving average filter of 5 points length and thus, a smoothed version of AP was obtained. Hence, artifacts that could affect the power of the EEG rhythms (and the AP value) were attenuated or eliminated. Consequently, smoothed movements of the ball into the glass pipe were achieved. In figure 5, the AP values for different attention levels are depicted.

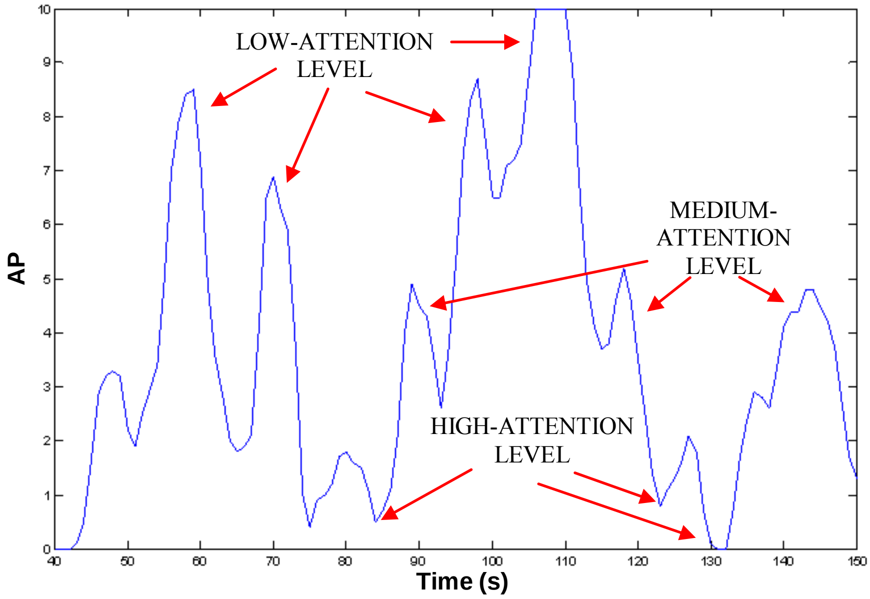

Figure 5: Smoothed version of the AP values for different attention levels.

3.2. *Quantification of AP values*

The AP value is a continuous variable (as depicted in figure 5), but the speed of the fan is a discrete variable. Hence, in order to translate AP values to different speeds of the fan a quantification process is needed. These quantification levels were determined empirically from the preliminary study and were defined as percentages of the maximum AP value.

The maximum and minimum AP values were automatically adjusted by the algorithm (figure 6), thus avoiding any calibration/configuration step. On the other hand, sometimes the user achieves a very high-attention level which is hard to reach again. Consequently, the user cannot reach the quantification levels based on that maximum AP value. Therefore, the user cannot moves up the ball again. The same effect was observed for minimal AP values. Hence, a modification of the maximum and minimum values is proposed. This modification is a slowly decrease of the maximum value across the time. The minimum AP value is slowly increased across the time (see figure 6).

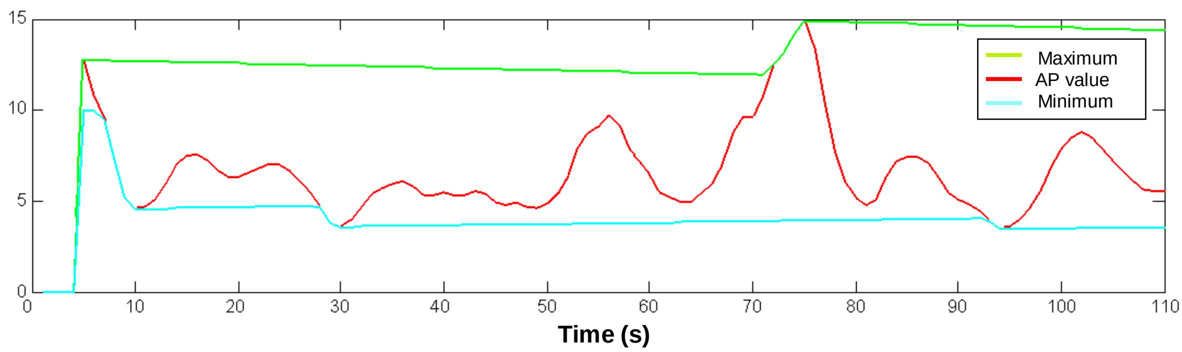

Figure 6: The AP values for different attention levels and the automatic adjustment of the maximum and the minimum.

3.3. Ball altitude control system

In order to conduct the air expelled by the fan into the glass pipe a structure was designed (Figure 1 and 7). Consequently, a light ball levitates inside the glass pipe. The altitude of the ball is controlled by the air expelled by the fan. A microcontroller Motorola 68HC908JL3 was programmed to control the rotation speed of the fan through a pulse width modulation (PWM) scheme. Therefore, when the user is concentrated (corresponding with low-AP value) the microcontroller increases the rotation speed of the fan.

On the other hand, the microcontroller commands the attention level indicator (figure 4). It is an arrangement of light-emitting diodes (leds), which indicates the changes in the attention level of the user. Due to air and ball dynamics, the movement of the ball inside the glass pipe presents a delay in reflecting the concentration changes. On the contrary, the attention level indicator produces a faster feedback to the user of his/her attention level (figure 1 and 7). Each led represents a specific attention level. Thus, green leds represent low-attention levels, yellow leds correspond to medium-levels and red leds represent high-concentration levels.

Therefore, the attention level indicator and the rotation speed of the fan are simultaneously adjusted by the microcontroller according to the attention level of the user. This is translated into different velocities of the ball inside the glass pipe. For example, when green leds are on, the ball descends inside the glass pipe (as fast as less green leds are on). When red leds are on, the ball ascends inside the glass pipe (as fast as more red leds are on). When yellow leds are on, the ball is still or moves very slowly.

In the glass pipe are limited three zones with white stripes (figure 1 and 7). These zones are used to evaluate the user performance (see Results section).

4. Results

Ten subjects (2f and 8m; 39.5± 15.5y) played with the BCI-game. They were randomly asked to levitate the ball to one of the three zones in the glass pipe. The task was repeated three times per position and the results are presented in table 1.

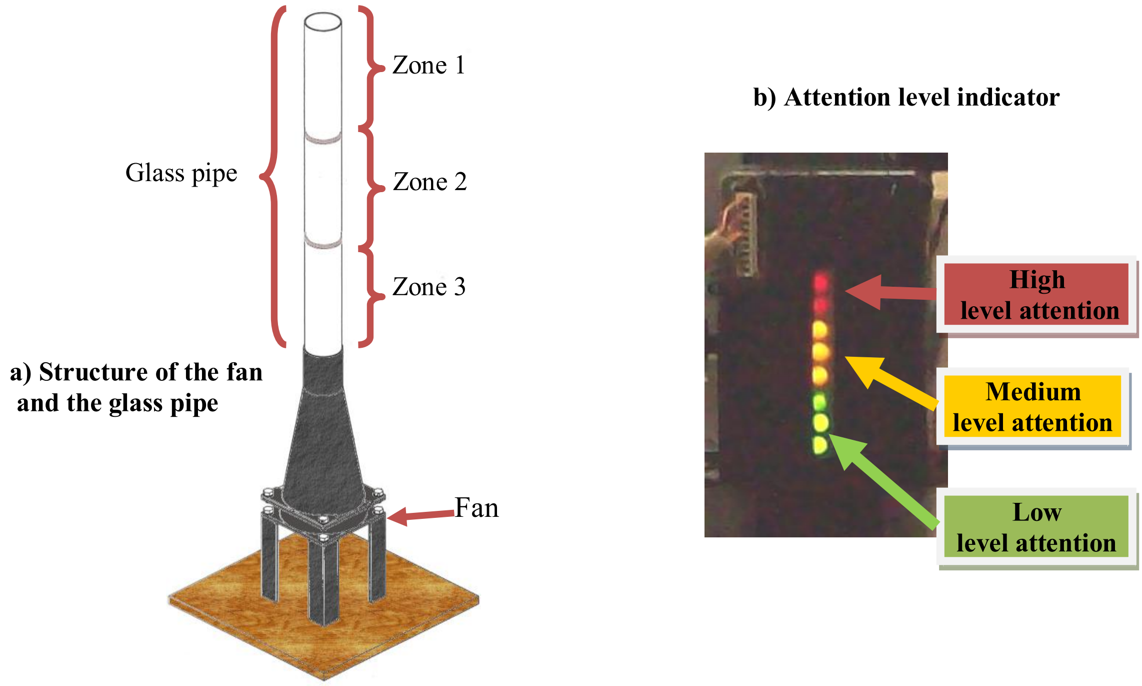

Figure 7: a) The design of the structure where the glass pipe and the fan are mounted on.
b) The box and the leds of the attention level indicator

Table 1: Results of the ball levitation

Subject	Altitude Low (zone 1)	Altitude Medium (zone 2)	Altitude High (zone 3)	Average
1	3	2	3	88.9 %
2	3	3	3	100 %
3	3	3	3	100 %
4	2	2	3	77.8 %
5	3	3	3	100 %
6	3	2	3	88.9 %
7	3	3	3	100 %
8	3	0	3	66.7 %
9	3	3	3	100 %
10	3	3	3	100 %
Total	**29**	**24**	**30**	
Average	**96.7 %**	**80 %**	**100 %**	

Finally, the subjects answered a questionnaire about their own perception of the BCI-game.The questions were:

A) Was it hard to conduct the ball to the top of the pipe (zone 1)?
B) Was it hard to conduct the ball to the middle of the pipe (zone 2)?
C) Was it hard to drive the ball to the bottom of the pipe (zone 3)?
D) Do you think that your attention level was correlated with the altitude of the ball?
E) While the experiment advances, did you achieve a better control of the ball?
F) With training, do you think that you could perform it better?

The subjects could answer as 1) Yes; 2) No or 3) Medium to each question. The answers of the subjects are resumed in the table 2.

Table 2: Answers of the subjects expressed as percentages

Question	Yes	Medium	No
A: the ball to the top	--	--	100%
B: the ball to the middle	50%	20%	30%
C: the ball to the bottom	10%	70%	20%
D: correlation of attention level and the altitude	80%	20%	--
E: better control with the time	60%	40%	--
F: performing better with training	100%	--	--

5. Discussion

From the preliminary study some useful insights were obtained. For instance, when a subject modifies his/her attention level, it is possible to detect the corresponding modifications in the EEG signals. These modifications were observed in the spectral content of the EEG signals measured from the pre-frontal and frontal cortex. Moreover, those changes are reflected in the alpha, beta and gamma rhythms. This fact was statistically confirmed using a one-way ANOVA test.

During the game, the subjects were not specifically instructed how to perform the relaxation or concentration mental tasks. Hence, each subject chooses a different way to change his/her attention level. For example, some subjects close his/her eyes to relax, other ones breathe deeply trying to relax. A subject achieves low-attention levels speaking about anything in particular and another subject concentrates in environmental sounds in order to increase his attention level.

Achieving high-attention levels is a relatively easy task since everybody can concentrates in something. Once the subject is concentrated and the ball is in the top of the glass pipe, relaxing is a harder task, which takes several seconds driving the ball to the bottom of the glass pipe. However, conducting the ball to the zone 2 is more difficult, i.e., it is hard to maintain a medium-attention level. This is in according with the answer to the questionnaire, to drive the ball to the middle zone (zone 2) was the hardest task, while to conduct the ball to the top of the glass pipe was the easiest task.

The 80% of the subjects (question D) found correlation between his/her attention level and the altitude of the ball, while 20% of the subjects found a medium correlation. The ability to control de ball inside the glass pipe increases with the time (question E), which can be improved even more with training (question F). This shows that controlling the ball requires some training.

Subjects with different ages and gender tested the BCI-game, no differences in the performance were observed among them. The system is based on electrodes collocated at Fp1-A1 position. This is very important because only one EEG channel is acquired; besides those positions are free of hair allowing the easy electrodes placement. The proposed EEG signal processing method is a simple way to estimate the attention level of the user. The AP value, along with the automatic adjustment of the maximum and minimum AP values, allows a suitable controlling of the ball inside the glass pipe.

6. Conclusions

In this paper, an automatic method to detect the attention level of a person was presented. Moreover, the system does not need any calibration or adjustment. Then, a system to control the altitude of a ball inside a glass pipe was designed. This allows that people play with their own brain activity.

The proposed BCI-game is simple, although, it allows evaluating how people change their own attention level. Besides, the system could be used in some diseases like deficit-attention disorders. Moreover, the attention level BCI could be used to operate some systems by people with motor disabilities.

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