BKI: Brain Kinect Interface, a new hybrid BCI for rehabilitation

J. Muñoz[1*], J. F. López[2], O. Henao[2], and J. F. Villada[1]

[1]Universidad Tecnológica de Pereira,
La julita, Pereira, Colombia
http://www.utp.edu.co
[2]Clínica de Dolor del Eje Cafetero
Pereira, Colombia
http://www.hcigroup.tk

Abstract In this paper we propose the creation of a novel hBCI, which combines biomechanical signals acquired by the Kinect sensor with signals from the BCI system Emotiv EPOC through the strategy of selective attention, using SSVEP signals. SSVEP are neural signals that occur in response to visual stimulation of certain frequency, they can be captured by BCI systems to generate an interaction through the selective attention of the user. The combination of these signals (MoCap and EEG-BCI) is used for interaction in a rehabilitation game for patients with motor and/or cognitive impairments. The system, providing a long and fluid interaction time, enables effective data collection that is aimed to objectively describe body movements through software developed for this purpose. The interaction with the BCI system is performed by the SSVEP which allows the user to explode objects in the air, through the controlled focus in a particular visual stimulus; the EEG signals are processed in the OpenVibe software. The Interactive Room for Rehabilitation, a real space plus a digital environment in which patients with neuromotor disabilities interact through their movements and thoughts, allows specialists to perform objective assessments of motor and/or cognitive aspects. Previous results suggest that acute exercise may enhance cognitive control through the management of visual stimulus.

Keywords: Exergame, Kinect, Brain-Computer Interface, Rehabilitation

1. Introduction

One of the most significant and promissory applications of brain computer interfaces (BCI) is used in the therapies to recover the loss of motor control caused by diseases and conditions such as strokes [17]. BCI have turned into a new and effective system for controlling applications such as video games (BCI games) and platforms of virtual reality (VR). One of the first investigators who

* Corresponding author: jemunozc@misena.edu.co

contemplated the idea of combining simulations or games in VR with the BCI was Nijholt [13] who described the first games controlled by these interfaces focused in the diagnosis of cerebral signs in aspects as the measurement of the attention of the user or the relation of affective components with the games. To achieve the interaction of people in immersive games with BCI systems they are trained in the habit of using a mental strategy known as selective attention where, among others, visual predetermined stimuli (videos, images, animations on a screen) can be used to generate in the user Visual Steady State Evoked Potentials (SSVEP). In a typical configuration of a BCI video game the sign of every stimulus is associated with a command that controls a specific action inside the video game. In order to select a command the user has to focus his attention in the corresponding stimulus generating the intended mental intention [4]. The combination of motion capture sensors with BCI systems within a videogame could become a novel methodology for therapies with patients with brain problems that affect directly their motor skills, such as a stroke, Parkinson's disease, sclerosis, hemiparesis, neuropathies, squeals of trauma or surgery interventions, among others. In this paper we propose a new paradigm for immersive videogames where we use a combination of gestural and brain commandos to achieve a unique gaming experience. The resulting system supports the fundamental goal of the ubiquity: make the user (in this case the patient) move away from the classic desktop scenario of the computer-assisted rehabilitation, demanding physical mobility and mental dynamism to improve his/her evolution.

1.1. Kinect like tool for rehabilitation

Inside the context of the serious games there is a specific type that seeks to promote the physical activity by means of different roles in gameplay: the Exergames. These stimulate the mobility of the entire body by using interactive environments with immersive experiences that simulate different sensations of presence. The Kinect sensor allows a perfect integration with a computer beyond the console Xbox-360; in rehabilitation, the characteristics of follow-up and automatic assignment of points of interaction (Joints) to the users have turned this sensor into a powerful tool for the objective analysis of the movement. The Kinect allows performing motion capture (MoCap) and saving this in the standard format BioVision Hierarchical (bvh) [14], that can be used later in software designed for biomechanical analysis. Comparative investigations of the Kinect have been made by other systems of capture of movement that need big assemblies and costly equipments [2] [3]. These works conclude that though the Kinect sensor is less precise, the measurements are inside a reliable range of measurement in aspects like positions and angles of movement. There are also works that aim to measure user's coordination and balance [8], whereas others make an extraordinary combination between entertaining video games and capture targets of information to generate a more accurate diagnosis [10]. The main reasons why the Kinect sensor is considered to be a successful tool for the rehabilitation are the following:

- The low cost of the sensor compared with the most economic system of motion capture in the market.
- Portability and comfort. This feature has pushed the researchers to propose systems of online therapies, which can be used by the patients in house or can be taken to places of difficult access. The information of capture can be processed in a remote way by the specialist to generate a diagnosis without the need of a physical displacement of the patient to a specialized center. At the moment of using the Kinect sensor there are not any necessary specific lighting conditions or complex configurations neither in hardware nor software to carry out an information capture procedure.
- The perfect integration with tools of animation and video games allows the generation of interactive activities using virtual environments, virtual reality, augmented reality and immersive experiences across the use of corporal gestures and real time interaction. This allows breaking with the classic paradigm of a therapy where the specialist indicates routines and specific procedures in every session to the user.
- The possibility of recording patient's information in real time turns Kinect sensor into a powerful tool for the biomechanical analysis of the joints. Thanks to the depth camera of the sensor and its ability to trace points on the body of the patient in an effective way, there can be made mathematical calculations of movements relative to a system of reference in 3 coordinates, as well as the estimation of the Euler angles of each joint in each moment of the session. This type of information can be registered in graphs that record a log-book of the evolution of the patient in a specific period of time.

Platforms like IGEN of the University of Milan, VirtualRehab of the company VirtualWare and SeeMe [16] are clear examples of robust systems for the managing therapy of rehabilitation through the Kinect sensor. The integration of the Kinect sensor in engines of video games like Unity3D is the point of convergence where the BCI systems like the Emotiv EPOC can be used as a whole by simple systems of movement capture as the Kinect or the Asus XtionPro. This type of technological mixture can be classified within what is known today as the hybridization of the Brain-Computer Interfaces.

1.2. Biomechanical analysis across Euler's angles

In the human body every segment is joined to its adjacent one forming joints that are fixed points in which the changes of position of the segments take place. For example when a forearm flexion is made, both the forearm and the hand with any weight that might be bearing are rotating on the articulation of the elbow. As the movement of the bodies in the space has six degrees of freedom, to be able to study the dynamics of the movement of the human body six independent coordinates are needed. Three variables correspond to the centers of mass of the body members, coordinates XYZ and three coordinates of movement, which are three angles of movement known as Euler's angles. Given these systems of coordinates with common origin, it is possible to specify the position of a system in terms of another using three angles α, β and γ. Euler's angles constitute a way of giving a numerical description of any rotation in a three-dimensional space using three numbers. Nevertheless, this approach has been widely criticized as a method for describing the possible articulated movements, since the use of this method imposes a very strict order of sequence in the description of the rotations that cannot be altered [19]. Due to this problem with the goniometric description of the angles in 1983 Grood and Suntay introduced the concept of a coordinated system of a joint to describe Euler's angles in the joints of the human body [5]. To present Euler's angles in a form that is much easier to understand for a biomechanical clinical investigator, they determined the angles using vector analysis from a system of articular coordinates of the position of every joint, not with a fixed axis but with a floating or movable axis in the frontal, sagittal and rotational planes, describing three natural movements of the joints of the human body in spatial coordinates that allow to determine the Euler's angles or rotation of each of them in a most successful way.

1.3. Steady State Visual Evoked Potentials (SSVEP)

SSVEP are neural signals that occur in response to visual stimulation of certain frequency, they can be captured by BCI systems to generate an interaction through the selective attention of the user. The SSVEP have three distinct components: a primary component located in the gamma band (25-60) Hz, with little inter-subject variability and a latency of (30-60) ms, a secondary component in the range of (15-25) Hz with high variability between subjects and latencies ranging between (85-120) ms and finally a rhythm component of 15 Hz below with a mean latency of 250 ms. The paradigm of using SSVEP to handle the BCI system was introduced by Regan in 1979, the idea is to control interfaces of buttons with visual evoked potentials [18]. The robustness of the SSVEP-BCI systems controlled by external visual stimuli has become a more manageable tool for the implementation of these interfaces since their ratio signal/noise is becoming more reliable. Accuracies within SSVEP games have been measured according to each player's correct responses to the stimuli. SSVEP games had a high average accuracy of 92 %. This suggests that the paradigm is accurate and works well within BCI games. Subjects within SSVEP game trials were given little training in comparison to subjects of motor imagery mental strategy, within certain trials the subjects learned to control the game and were tested within the same session. This suggests that SSVEP is an excellent paradigm for BCI games (high accuracy and short training periods) [11].

1.4. Hybrid BCI

Despite impressive advances in the industry of BCI systems, product diversification and globalization of the study of this area of neuroscience, the state of the art in multiple applications shows that effective interaction with BCI applications and assistive devices is not usually maintained for long periods of time without the aid of an expert [12]. This statement is not intended to delegitimize the great moment this technology is experiencing; it simply seeks to bring closer the BCI community to a possible solution: using the BCI systems as an additional input channel for the application. A hybridization using a combination of multiple signals, including at least one BCI channel, called a hybrid BCI (hBCI). The combination of signals coming from BCI systems with other biosignals, e.g. electromyography (EMG) signals or particular biomechanical signals obtained through motion capture systems (MoCap), may allow more stable and durable control of an application or device. As additional input signals electrocardiographic signals (ECG), or external signals of other control devices such as cameras, proximity sensors, accelerometers, pulse oximeters and other electronic sensors can be used. Hybrid BCIs, like any BCI, must fulfill four criteria to function as BCI [15]:

- Direct: the system must rely on activity recorded directly from the brain.
- Intentional control: at least one recordable brain signal, which can be intentionally modulated, must provide input to the BCI (electrical potentials, magnetic fields or hemodynamic changes).
- Real time processing: the signal processing must occur online and yield communication or signal control.
- Feedback: the user must obtain feedback about the success or failure of his/her efforts to communicate or control.

2. SYSTEM OVERVIEW

The proposed hybrid scheme for testing videogames for rehabilitation in this work is one that involves the motion capture data from a non-invasive Kinect sensor, which allows a natural interaction through body gestures and real-time avatars, objects and virtual environments, a BCI system that works with visually evoked potentials which allow to establish a relationship of the concentration level of the user in a particular action within a game role. The system has been called BKI (Brain-Kinect Interface) and figure 1 shows a general scheme of it:

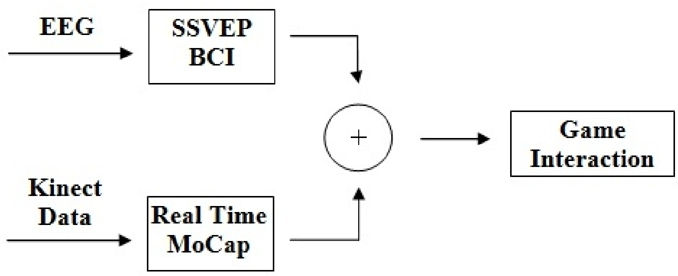

Figure 1. Scheme of the Hybrid BCI system proposed (BKI)

The resulting hBCI system actively involved patients with neuromotor diseases in video games with motion capture and BCI interactions, significantly improving the dynamics of the classic BCI game systems through the change of traditional systems of data input such as the keyboard and the mouse, for a real time motion capture system which enables the movement of the body parts assigned to an avatar as hands, feet, knees, head and trunk (among others), allowing the interaction with the BCI system more punctual actions such as the levitation of objects, the collision of an object with another, among others. The system is completely wireless, which greatly facilitates the comfortable interaction of the user with the videogame, also uses a large video projection, subdued illumination and sound effects to make the experience more immersive.

The final platform is implemented in an Interactive Room for Rehabilitation (SIR) where assessment of motor and cognitive aspects of the patients is done through video games, using the Kinect and Emotive EPOC sensors. This room is located in a rehabilitation center where therapies and sessions are conducted for the recovery of patients who have suffered motor damages and/or cognitive/neuromotor diseases. It is an interactive space where we use Exergames specially designed to improve motor skills such as balance and dissociation. Recently, the inclusion of the EPOC and the study of BCI systems have opened up the range of variables to be analyzed by the medical community in the rehabilitation center: cognitive variables that range from the attention and concentration level of the user to the objective measurement of emotional states. Although studies in patients are still ongoing, this paper seeks to fathom into the technology assembly and proposed hybridization to expose the previous results obtained from the study in patients. These video games projected on an immersive room allow specialists to work on variables such as balance, coordination, dissociation, the recovery of mobility and strength. Once identified the pathology, the required type of exercise and other parameters of the session, the patient is located approximately 200 cm from the Kinect sensor and the projection and is ready to interact with the game through his/her gestures and movements.

Now, one of the most common weaknesses in research and implementation of serious games for health, as reported by the psychologist and world expert Pamela Kato in [6] is that appropriate or objective measures are not performed while conducting sessions with video games. The incorporation of standardized measures in the research project usually facilitates comparison with other studies looking for increasing the amount of objective results and reducing the anecdotal [7]. However, in order to generate objective measures relating to displacement and the angles of precession, nutation and rotation of each joint, we have created the Bio-Cirac v.1.0 software, which allows the quantitative analysis of the user's movements session by session.

The inclusion of BCI interaction requires a prior training of the user, which is to perform an initial calibration of a state of "neutral" thinking of the user 10 seconds approximately, after this, using a specific animation action that is required to be controlled in the game through the BCI system. Afterwards, the animation produces in the user an SSVEP, which is registered in the EPOC software. This

training allows the system to distinguish between the so-called neutral state of the user and his/her reaction to particular visual stimuli, which are evoked within the dynamics of the game. Once registered, the user must concentrate to perform the levitation of the object (for example) just at the moment where instructed to do so, if this fails, the user is re-trained using the same procedure previously described. This is done in order to obtain the maximum level of control over the BCI interaction to generate a dynamic fluid interaction as is done with the Kinect sensor; this aspect keeps the patient entertained throughout the whole proposed session, making more efficient the therapy. This methodology allows the inclusion of interactivity through the BCI system using visual evoked potentials within Exergames. Generally, the movement of the user tend to cause the so-called artifacts into the EEG signals, to avoid this, we used the Temporal Filter tool with a 1 Hz - 60 Hz pass-band filter in OpenVibe software for EPOC signal preprocessing. OpenVibe is a free and open source software platform for design and implementation of BCI experiments (http://openvibe.inria.fr).The game engine used is Unity3D in its free version, which enables a complete integration with the Kinect sensor motion capture data; the Cognitive Suite of the EPOC is used to achieve the BCI interaction within the virtual scenario through the effective generation of SSVEP by training performed.
The complete system includes a workstation for the BKI system, the Kinect sensor located at the bottom of the enclosure, a video projection and the BCI system connected to the patient. Image 2 shows a diagram of the SIR assembled in the *Unidad de Acción Motora* of the *Clínica del Dolor del Eje Cafetero*.

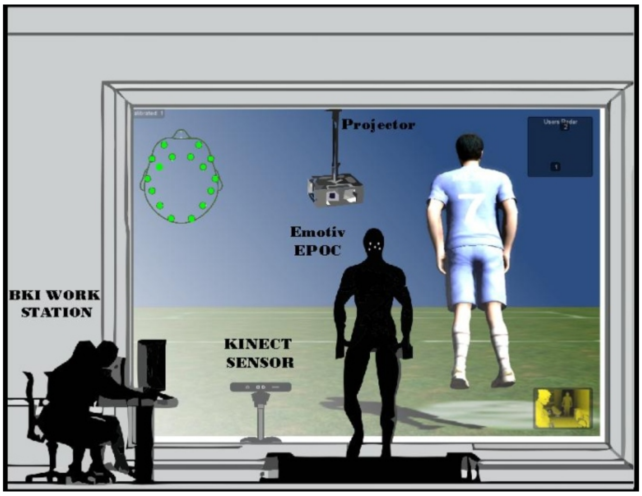

Figure 2. Proposed BKI System assembly.

The interactive system used by the patient and the specialist can be divided in three fundamental parts:

2.1. Interaction

The test begins with the video projection of the game. It is important to mention that the lighting conditions and the quality and size of the image are important elements at the time of achieving an immersive experience. The games must be a simple dynamic in which the specialist seeks to introduce the patient in a role playing game of a trivial level of competitiveness. Grasp elements, jump obstacles, move, bend and swing with balance are the active parts of the interaction proposed by these games. The time of interaction can be programmed by the specialist according to the patient and the characteristic of the game, often the user can use elements such as weights, ribbons, strips and any other physiotherapeutic elements that do not obstruct widely the space between the user and the sensor. In the interaction with the BCI system, the user, after being trained, uses his mental-control skills to perform an action over a specific object of the scene (levitation, destruction, removal, etc.) when the game requires him to do so. Usability andfluidity tests are performed in the interaction with the whole system in order to verify the relevance of hybridization in the field of rehabilitation. Generally the user takes an average of 3 trials in the concentration required to generate the signal in the first interaction with the game after the training session, however in the following sessions and to the extent that the user increased their physical activity within the game, the mental action control improved and only needed a single attempt to reach the goal, which suggests that acute exercise may enhance cognitive control through the management of visual stimulus. For optimum system operation, perform the tests in the early hours of the day is recommended, because is where generally considered the least possible stress on the user. This condition allows the user a better disposition with the BCI system in particular, in order to achieve a more fluid and controlled interaction. Now, with respect to the interaction using the Kinect sensor, the specialist has to ensure that the patient understands the activity perfectly, that is, the user understands what kinds of gestures are necessary to achieve the objectives within Exergame dynamics, considering that for the majority of patients, this kind of interaction is novel and requires an adaptation stage (generally a couple of sessions) for interaction can be fluid and does not create frustrations for the user.

2.2. Data Capture

In parallel the specialist can run the application of motion capture BrekelKinect (www.brekel.com) which is a powerful free tool for capturing Kinect sensor data to a bvh file. This standardization of monitoring data from the user's skeleton has allowed a more dynamic integration with the medical community in the rehabilitation area with this technology, as it allows transforming a measurement process that is usually done in analog way through goniometers in a fully automated, user-friendly way, without annoying connections, portable, easy to install and with reliable measurements. In [9] is shown that the random error of the depth measure in the Kinect sensor is directly proportional to the distance between the sensor and the user, ranging from a few millimeters up to a maximum of 4 cm in the maximum range of the sensor (about 4 m). The user registration is organized in the form of log-book segments each session for review at any time by specialist.

At this stage, the specialist must ensure to capture the user's movement at the right time; an extensive capture can yield a file of great weight that often becomes difficult to manage in the analysis stage. The convention managed by the file format and the Kinect sensor is as shown in image 3. The specialist chooses the right time to start capturing data as well as to stop doing it. This stage ends with one or more records of the movement of users through bvh extension files, for example "capture_0000.bhv", which are the raw material for the analysis stage. Data from the BCI system is captured using OpenVibe through the acquisition of the Emotiv EPOC Research Edition Pack and these data is labeled when the user has to perform the mental task to continue the game. Monitoring by OpenVibe to generate topographic maps in 2D, 3D and voxels while the user is playing, this tool allows correlating movements and mental intentions of users with sensorimotor rhythms throughout the entire game.

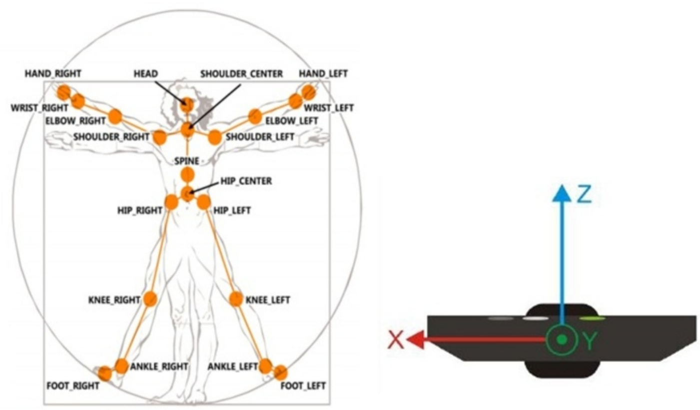

Figure 3. : Left: convention of Joints handles by BVH file captured by the Kinect sensor. Right: Kinect sensor coordinate system.

2.3. Data Analysis

At this stage, the specialist after completing the session with the patient and having obtained the corresponding MoCap file will have to use the Bio-Cirac v.1.0 software developed by the team to load the file into a proposed user interface. This software uses libraries developed by Neil Lawrence for the use of MoCap files with bvh extension. Bio-Cirac allows visualization of the BVH files, the software shows a graph relating the joints (each element of the skeleton) with the skeleton of the user in three a dimensional space and shows also each joint axes (X-red, Y-green, Z-blue). Image 4 shows a preview of the software developed for the analysis of motion capture data obtained through the Kinect sensor, Bio-Cirac v. 1.0.

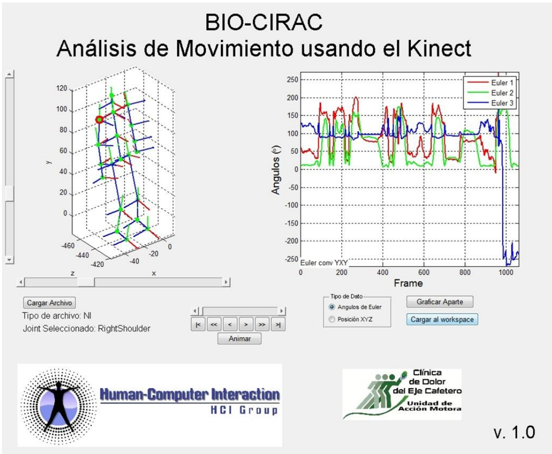

Figure 4. GUI designed for Bio-Cirac v.1.0 software, which allows loading the motion capture file and generating graphs for analysis.

Now, in order to obtain the graphs of the Euler angles of each joint, the desired articulation is selected in the 3D skeleton of the user. There are two types of graphics that the software makes; the first is the Euler angles which is a two-dimensional graph that contains information concerning the frames vs. the Euler angles, which are calculated according to the ZXY convention. This graph shows the behavior of the precession angle, frontal plane (α: Euler 1, red), the angle of nutation, sagittal plane (β: Euler 2, green) and rotation angle, transversal plane (γ: Euler 3, blue) vs. total catch in frames, this graph can be analyzed separately through the graph apart button, allowing the use of graphical analysis tools such as zoom and cursor data and export of the graph in an image as JPEG format. For easier analysis, it is recommended not to take more than 1 minute captures, because the volume of data contained in these files requires a significant processing capacity for analysis. The software has a very simple user interface, where no prior knowledge is required. The second type of graph is relative to the XYZ position of each joint, these are captured according to the coordinate system of the Kinect sensor although the origin is relocated to the initial body position (in line with the spine, but at the level of the floor).
For analysis of data from EPOC we use OpenVibe where scenarios are designed using the concept of box, blocks or elementary components that contain algorithms that help to reduce the development time of BCI experiments. The

proposed design for the analysis of signals containing an acquisition stage, filtering and removal artifacts (temporal filter), windowing and signal averaging and finally create 2D /3D topographic maps. With these maps we perform pre and post analysis of neuronal plasticity of users and previous results show a significant increase of activity in the occipital cortex measured at O1 and O2 EPOC electrodes. A figure of the scenario on OpenVibe with maps is shown below:

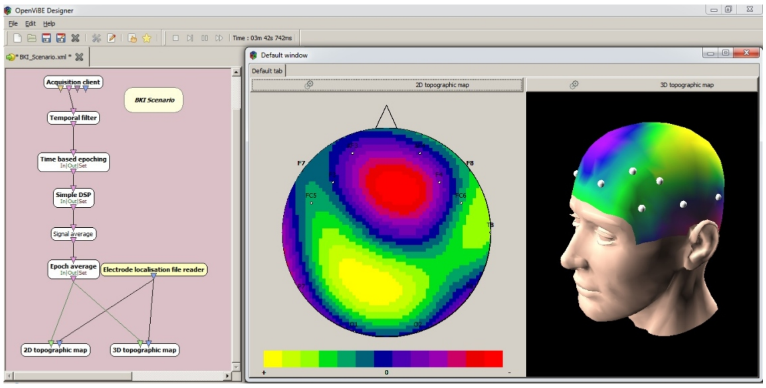

Figure 5. BKI Scenario designed for EEG-BCI data analysis using OpenVibe.

Deeper analysis of the platform may lead to correlate the duration and type of stimulus to exercise-induced changes in variables such as the latency of the SSVEP signal.

2.4. Cognitive Balance Game Description

To test the operation of the interactive system we made a video game to improve the ability of balance, arms movement and the concentration of the user. The game consists of an avatar that skates over a fixed virtual trunk, the user must try to remain standing through balancing while following a proposed route. When the user starts to lose his/her balance, the avatar is inclined to one side, moment in which the user must compensate this inclination with movements (light or exaggerated) towards the other side. Even there, the game works like a traditional Exergame, however every 15 seconds an object approaches towards the user in the trunk line from the virtual sky, at which time the user must gaze the object and evoke the prior-trained mental command to explode the object in the air before it collides with the avatar. In the case that the user achieves to explode the object before the collision, the avatar can follow its course by the infinite trunk, however if the user fails to concentrate to produce the required SSVEP signal for the object explosion in an approximate time of 8 seconds, the object will collide with the avatar making it fall from the trunk and forcing it to start again. The explosion of the objects is counted within the game as well

as the duration of the avatar without falling from the trunk in order to generate positive stimuli and encourage the patient to continue efforts to get better scores after each session [1]. The user must have an optimal control of the BCI system, i.e., must be able to generate the signal dynamics trained to continue playing. The game ends when the user reaches a determined score by exploding a number of objects.
The integration between the medical staff of the Unidad de Acción Motora and engineers of the Universidad Tecnológica de Pereira has allowed the creation of this hBCI system, which despite being in its implementation stage, promises to be a robust tool for a comprehensive analysis of the rehabilitation processes of motor and/or cognitive diseases of patients across the country, providing not only an outstanding interactive dynamics for the patient but also accurate and reliable movements and cognitive intentions specialist referral.

3. CONCLUSION

We developed a new hybrid interface that combines the signals of motion capture acquired by the Kinect sensor with the obtained by a system BCI to combine in a video game for the rehabilitation of motion and/or cognitive impairments; the system BKI is a new hybrid approach of the BCI systems, which offers a significant improvement in the naturalness of the interaction of these interfaces specifically in video games. We developed a video game based on the combination of an Exergame with a BCI game, in which there used the real time motion capture of the Kinect sensor and a methodology for the interaction across SSVEPs taken of the neuroheadset Emotiv EPOC for rehabilitating patients with neuromotor injuries or disease. The system besides offering a entertaining therapy to the patient, allows the medical specialists an objective analysis of the movements of the user across the developed software Bio-Cirac v.1.0, which shows graphs of the movements of up to 20 joints in the body sensed by the Kinect, as graphs that relate frames to the 3 Euler's angles used in biomechanics to describe the angular movements of every joint in the frontal, sagittal and transverse planes. Finally, the use of OpenVibe software allows recording and processing of EEG data captured from the user while playing for measurement of concentration, relaxation or SSVEP signal latencies, as well as the impact that physical activity can have on the control of BCI system. We think that this hBCI allows enriching the therapies of users' rehabilitation with multiple disabilities, at the time that it allows to save a log-book of the evolution of the patient in cognitive aspects and proper mobility. Probably one day in the future we manage to have an ideal connection between our movements and our thoughts in a physically real avatar, in the best of James Cameron style.

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