International Journal on Advanced Science Engineering Information Technology

Vol.10 (2020) No. 4
ISSN: 2088-5334

Serious Game Design of Virtual Reality Balance Rehabilitation with a Record of Psychophysiological Variables and Emotional Assessment

Juan D. Abril[a,1], Oswaldo Rivera[a,2], Oscar I. Caldas[a,3], Mauricio Felipe Mauledoux[a,4], Oscar F. Avilés[a,5]

[a] *Universidad Militar Nueva Granada, Bogotá, Colombia*
E-mail:[1]u3900253@unimilitar.edu.co; [2]u3900248@unimilitar.edu.co; [3]oscar.caldas@unimilitar.edu.co; [4]mauricio.mauledoux@unimilitar.edu.co; [5]oscar.aviles@unimilitar.edu.co

***Abstract*— Virtual Reality (VR) offers an alternative to complement physical or neurological rehabilitation based on the efficacy of Gamification as a technique to get compromised, enjoy, and turn treatment periods less annoying through an immersive task. This work presents the design of a VR environment and takes into a count three levels of presence: self-presence, physical, and social. Thirteen healthy participants performed a traditional balance session with a wobble board through a parachute game. The direction of the fall is controlled with the inclination of a wobble board platform instrumented with a Gyroscope, electrocardiography (ECG), electrodermal activity (EDA), and respiratory rate (RESP) signals are simultaneously recorded. These psychophysiological responses of the Autonomous Nervous System (SNA) are contrasted with a standardized emotional self-report questionnaire to gather information about the experience and was filled out by the participant with the eye selection of the Oculus Rift device. The integrated Unity-Matlab system stored and processed some of the extraction data of 15 characteristics associated with the biosignals and three emotional levels, In addition to proposing a severe game as a solution to problems of conventional methodology such as low attention, monotonous and predictable sessions, combining computerized simulation and innovative technologies for more pleasant recovery therapy.**

***Keywords*— virtual reality; gamification; balance; psychophysiology; emotions.**

I. INTRODUCTION

Active Video Games (AVG) are utilized for the rehabilitation of lower limbs, balance, and gait, obtaining good results in young and adults, being lower in older adults due to a lower level of interaction with video games [1]. Among the most important challenges in Neurorehabilitation, technology must reduce the complexity of devices and costs, limited widespread use, and develop a more trustworthy to increase their therapeutic benefits [2], [3]. Technology also should adopt the principles of motor learning. Besides, taking advantage of neuroplasticity in compensating, restoring, and recovering the loss of sensorimotor function is also urgent. Patients recovering from Stroke and Cranial Trauma, with a head injury or a Cerebrovascular Accident (CVA) [4] includes biometric data into VR games to add value to traditional forms of treatment.

About 40% of people with disabilities in Colombia report having lower limbs affected, so they must perform physical rehabilitation, mainly balance recovery sessions [5]. Specific treatments are used in rehabilitation of lower limbs, as bilateral training. They implicate many repetitions of specific training of the affected limb with or without the restriction of the unaffected limb. These involve the use of the limbs simultaneously but independently or as feedback from the center of pressure of the body and the weight under each foot through a platform strength, or the distribution of weight between the legs with visual or auditory feedback to the patient or therapies [6]. Other therapies work on the peripheral neuromuscular system, employing electrodes to give biofeedback of the electrical potentials of the motor units. Also, the training of electromechanical devices assisted walking, for non-ambulant patients to improve or maintain muscular strength [7].

On the other hand, studies show that good results in the rehabilitation processes are strongly related to the great motivation and commitment of the patient and his family [8]. Also, transdisciplinary teams make concerted decisions and include all the actors involved in rehabilitation: patient, occupational therapist, doctor, psychologist, nurse, for the benefit of the recovery [9]. The first 6 months of recovery are vital to recovering mobility due to a neuromotor problem, retraining nerve connections taking advantage of neuronal plasticity that is higher in this period in the patient recovery, although recovery may continue for months or years after a Stroke, for example [8], [10].

Numerous immersion applications have been developed in VR environments and enhance patients with neuromotor conditions to show satisfactory results in their recovery process, overcoming boredom and attrition resulting from repetitive movements traditional treatment [3], [4]. Measuring the evolution of the treatment, significant physiological changes of the galvanic skin response, the breathing level, the hearth rhythm were detected. This study showed the effect in the autonomic nervous system dues to the emotions linked to the activity [11], [12].

Balance Rehabilitation is relevant because this is a clinical symbol found in many medical diseases from the integrity of the mayor systems: vestibular, visual, and somatosensory systems. The purpose must be routed to restore or increase the proprioception and the performance of balance and posture. The notion of feedback and to be aware of the chance of the position of the different body parts in space are the benefits that happened with the severe active video games to the patient's body interaction. Literature also suggests training or retraining balance in two scenarios: improving balance after a disease that causes balance impairment (rehabilitation) or trying to increase performance (sports training) [13]. Studies reflect a high level of patient recovery outcomes in the treatment of pathologies exergaming [14]. Another study was developed on a lower limbs injured group of athletes with similar results in the video game than a standard treatment, but with a high level of satisfaction, the authors observed that early use of video games speed up the process due to the phenomenon of visual feedback provided and have a positive effect on visual-vestibular integration [15].

Also, patients with Meniere's disease involved in a session of serious games and virtual reality had decreased dizziness and increased the perimeter of stability reported by the authors in a previous study [16]. So, it can be inferred that Patients with lower lib diseases performing this exercise could benefit from the use of this kind of video game and has a more fun therapy session. Moreover, outcomes from studies with commercial video games developed on game platforms like Nintendo Wii and Xbox Kinect Platforms with balance rehabilitation. Studies with both conventional therapy groups and virtual reality participants demonstrated improvements after the virtual game; consequently, gaming could be used as a balance training tool, in dynamic and static balance, gait speed, muscle strength, and enjoyable sessions as an alternative to rehab although one study shows no significate change in touch vibration, proprioception [17]. Another one indicates that the early use of visual feedback for balance training accelerates the recovery after Vestibulopathy [15].

We propose providing immersive visual and auditory stimuli during an exercising task of balance, which could provoke significant changes in dimensional emotions (or psychophysiological signals [18]). This system both captivate the user with a VR immersion and record real-time performance data of the user, which can be an essential tool for psychiatrists and therapists [19], [20]. A VR game was designed to test the emotional levels of subjects via a balance motion task. Fifteen features were elicited from the bio-signals (EGG, EDA, and RESP) [21] throughout 2-minutes trials. The following sections describe the used procedure.

II. Material and Methods

A. Study Protocol

The experiment was carried out in the laboratory of the Davinci research group of the Universidad Militar Nueva Granada in Bogotá, Colombia. The procedure indicated in Table 1 was followed in the application of the test:

TABLE I
TEST APPLICATION PROTOCOL

VR Balance Game Protocol	
Idle	
Acquisition of control signals	5 minutes
Exercise	
Parachute Serious Game	2 minutes
Filling up the SAM Test	1 minute

The task was guided by a serious VR game with a simple narrative that asks the player to reach objects located at the ends of the environment during the fall by tilting the platform to score. Besides, it could also become falling into a target at the time of landing. The exercise lasted 150 seconds. In the end, participants were asked to complete the standardized Self-Assessment Manikin Test [18], reporting their emotions experienced in three dimensions: exaltation, valence, and dominance. The physiological signals of the participant were measured during the process.

B. Hardware and Software

A Wobble Board type platform of 35 mm in diameter and with a capacity of 135 Kg, was used for the balancing exercise. It was set in such a way that it was allowed pitching and rolling tilt without translation, with a range of movement between -11° and 11°. The inclination of the platform was calculated in Arduino with the GY-50 sensor reading at the pitch and roll angles through the I2C protocol. Then, the information is transmitted by Serial Port to the Unity environment, corresponding to the movement during the Parachutist Fall in the environment. Psychophysiological responses were acquired through the Biosignlas Plux Explorer device, with a sampling rate = 1 KHz and resolution = 16 bits. Figure 1 indicates the implementation.

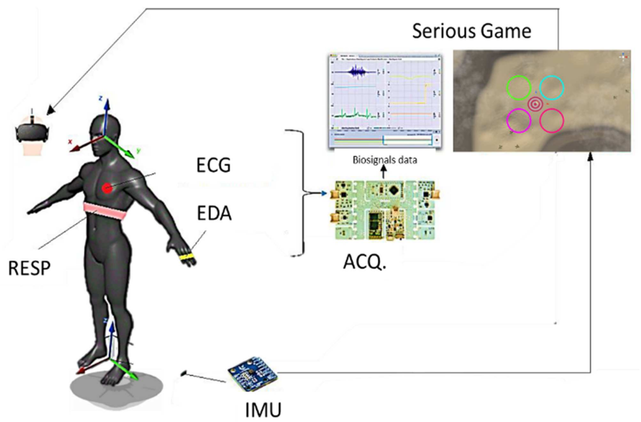

Fig. 1 Implemented Software, Devices, and Bio signals involved in Serious Game and Analysis Software

The team measured electrocardiography (ECG), electrodermal activity (EDA) and respiration rate (RESP). The ECG was sampled by 3 surface electrodes placed in the upper right part of the chest, the lower left part of the chest and the left part of the chest, on the ribs (ground). The EDA signal was measured by a galvanic skin response sensor of surface electrodes placed on the index and middle fingers of the non-dominant hand. Breathing was measured with a piezoelectric sensor on an elastic strap around the thorax. Figure 2 shows the user on the balance platform. The extraction of characteristics of the signals was developed according to (Caldas, 2019) [22]. Figure 3 illustrates the user in the virtual reality activity and the arrangement of the rings in the environment.

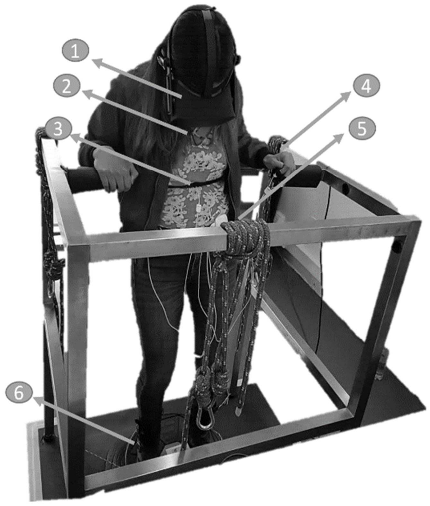

Fig. 2 Acquisition of psychophysiological signals and platform inclination. The image highlights: the HMD (1), ECG sensor (2), flexible breathing band (3), EDA sensor (4), data acquisition device (5), wobble board with gyroscope (6).

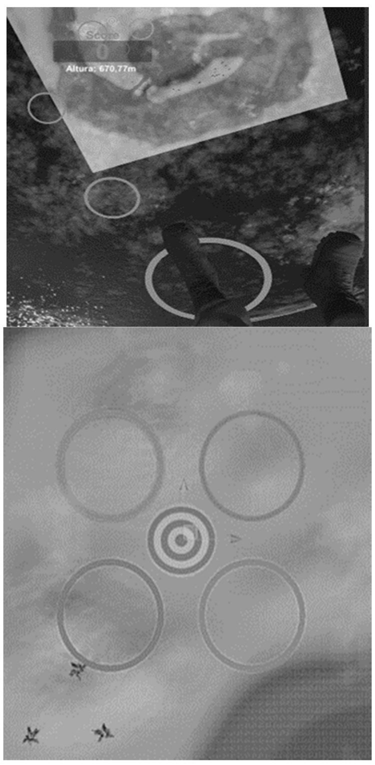

Fig. 3 Parachuting game, above the first-person view, under the landing zone

The virtual environment immersion was supplied by a Head Mounted Display (HMD) of Oculus Rift reference. The equipment allows audio-visual stimulation defining the workspace through two infrared sensors that track the position and orientation of the user through the helmet. A pre-fall animation from the helicopter was created.

III. Results and Discussion

A. *Game* Objective

The serious game proposes a precision parachute activity, it was, bounded in time, with the serious game that proposes a precision parachute exercise, with a record of score and emotional levels through the registration of the involuntary psychophysiological responses of the ANS and the standardized self-report questionnaire of the participants.

The fall of a parachute helicopter was recreated with to enter the hoops located in the descent. In the activity, the direction of the fall is controlled with the inclination Wobble Board type passive platform instrumented with a Gyroscope, movements are contained in the procedure of a traditional balance therapy [19], inclinations are made in the sagittal and frontal plane, with the aim of holding a certain position. Additionally, their psychophysiological responses were measured at rest and during the virtual reality session. Figure 4 exposes the algorithms implemented in the serious game with the acquisition of physiological data.

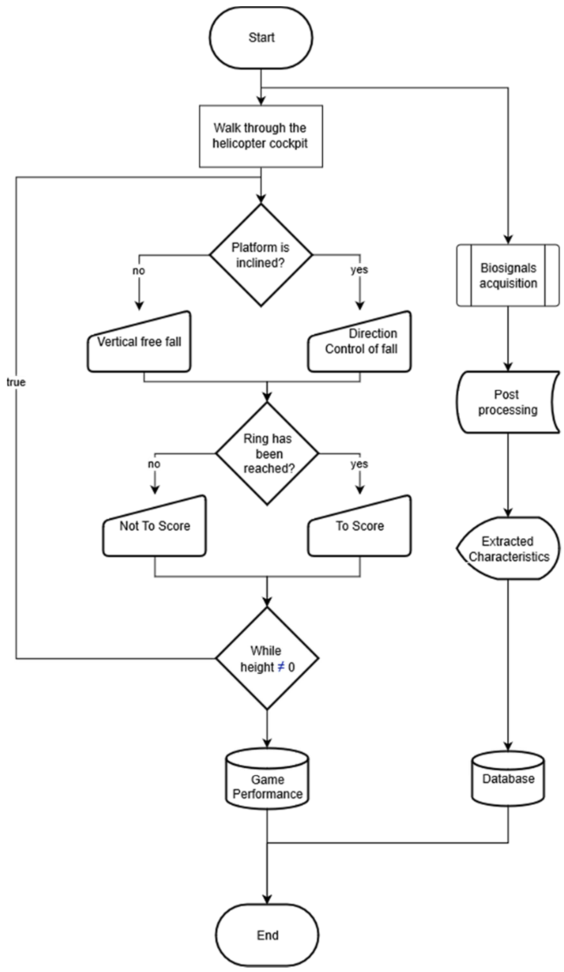

Fig. 4 Flowchart of Parachuting game

Social interaction in-game happened with indicative guidelines to move through the hoops controlling the direction of fall in the virtual environment with the platform. At the end of the game, a SAM standardized questionnaire was carried out.

B. Architecture

The system, shown in Figure 5, comprises the game that runs on a computer through the engine Unity game, which projects images of the environment through a VR helmet, receives the tilt platform level of an inertial measurement unit (IMU). The change of position of the character in the virtual environment during the fall occurs with the interaction with the wobble board.

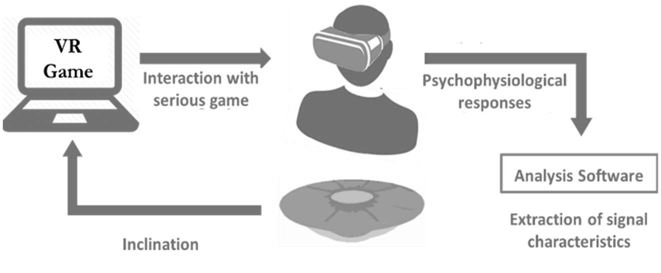

Fig. 5 Serious virtual reality game architecture with the balance platform

The game synchronizes with a MATLAB application of the bio-signals acquisition device and stores data during the activity, this software is used for the treatment and extraction of characteristics of the ECG, EDA and RESP signals. Figure 6 shows in detail the hardware of the implemented equipment.

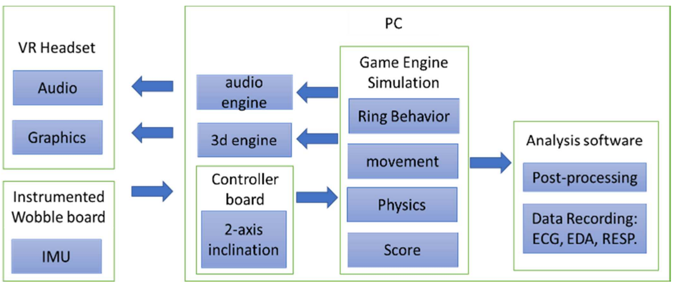

Fig. 6 Game Design: Hardware and Software Interfaces

C. VR Immersion

The world was established with the idea of let immersion into VR; therefore, three outstanding topics were involved in the multimedia section:

1) Self-presence: Attribute affected: Sense of physical connectivity. Asset: Visible player's body for a sense of proprioception and help to pass through the rings and landing.

2) Physical presence: Attribute affected: Spatial realism. Assets: Audiovisual animations to mimic the environment, e.g. clouds, ocean, wind, and helicopter engine.

3) Social presence: Attribute affected: Sense of coexistence. Asset: A remote voice indicates the game directions by radio, instead of plain text displayed on the screen.

D. Game design elements

Four outstanding elements were built up (1) Helicopter (2) Target (3) Rings Zone (4) Avatar thus:

1) Helicopter: The Starting point, the game explained to the participant at this moment, after that, the user took control of the direction of the avatar during the falling.

2) Target: The Endpoint of the balancing exercise, is the landing place designed for the soldier inside the game, a badge that is got with a perfect landing.

3) Rings Zone: Intermediate region through the falling, which the player must pass. When the user enters the hoop, area scores, and then it is displayed a blow-up and a sound.

4) Avatar: A soldier was created; he should undertake the parachute activity and is instructed by the helmet intercom.

E. Outcomes

1) Body responses due to activity: The interaction between the Game and the Analysis Software occurs when activeness starts. Matlab routine receives a command and triggers the acquisition of bio signals, after, the post-processing of raw data is done.

2) Psychophysiological signals: The interaction between the Game and the Analysis Software occurs when activeness starts. Matlab routine receives a command and triggers the acquisition of biosignals, after, the post-processing of raw data is done. The participant was induced to develop the activity, driven from the visual and auditory stimuli, and leading the trajectory to score.

For each participant, the storage of the ECG, EDA, and RESP signals was generated. From these data, the extraction of 15 characteristics associated with each signal was accomplished. Figure 7 shows the ECG record of one of the participants from the serious VR game, in the upper part the signal with heart rate detection from raw data and in the lower part the trending rate and average for the player calculated on the Analysis Software.

Figure 8 shows the Skin Conductance Level and the Skin Conductance Response (SCL and SCR respectively) calculated as from signal, which makes up the EDA signal and from which the feature extraction is accomplished. RESP signal of one participant is observed in Figure 9, above the raw signal detecting breathing rate, below the rate of change, and the average for the player is calculated.

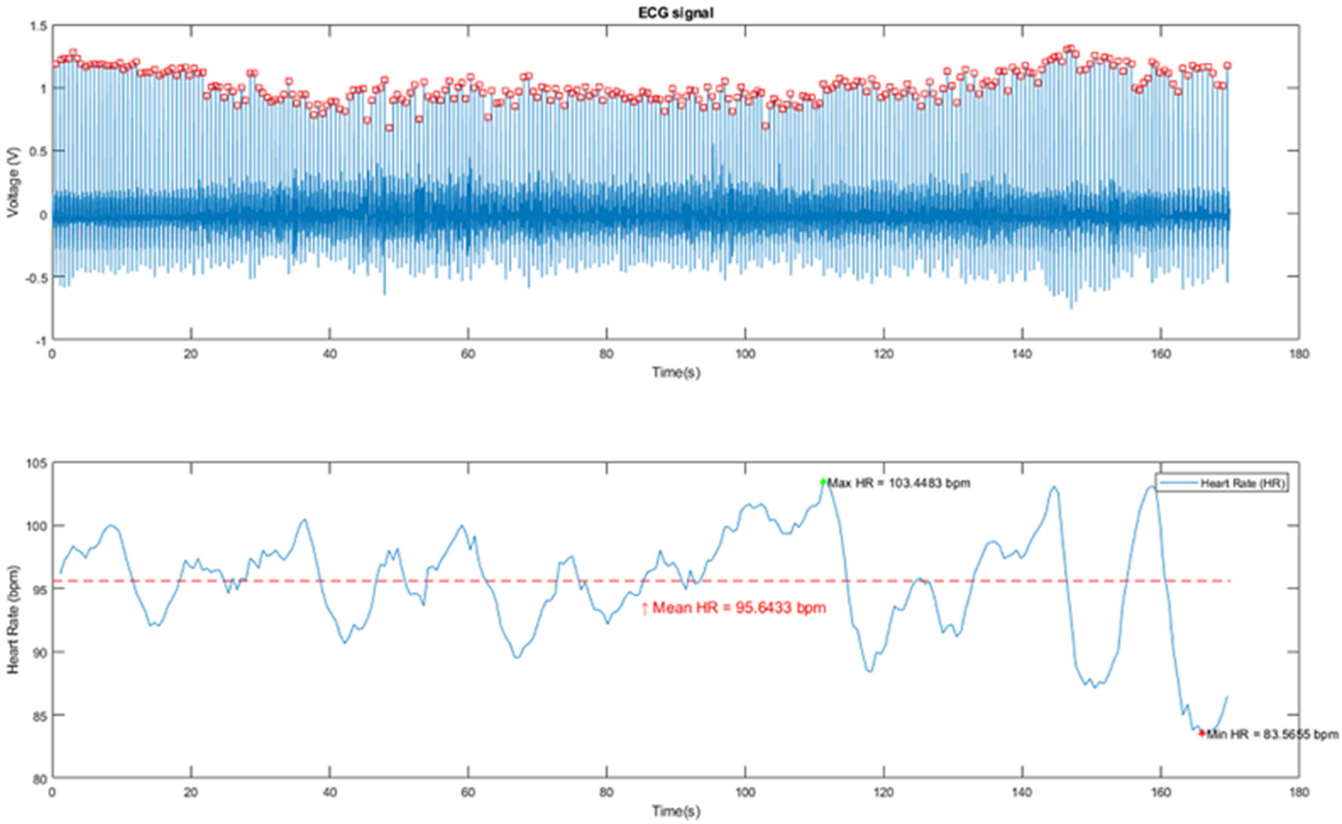

Fig. 7 ECG signal acquired in the serious virtual reality game with the balance platform

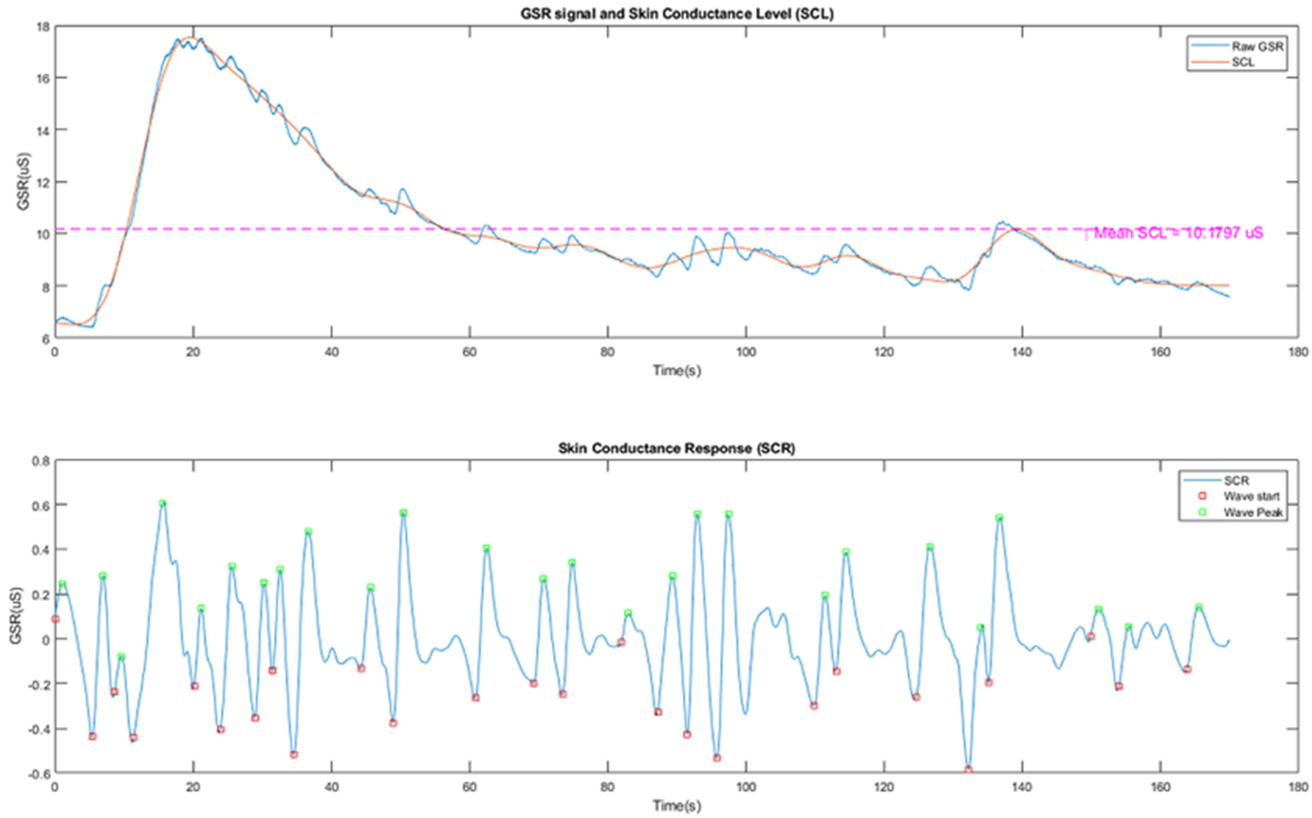

Fig. 8 EDA signal acquired in the serious virtual reality game with the balance platform

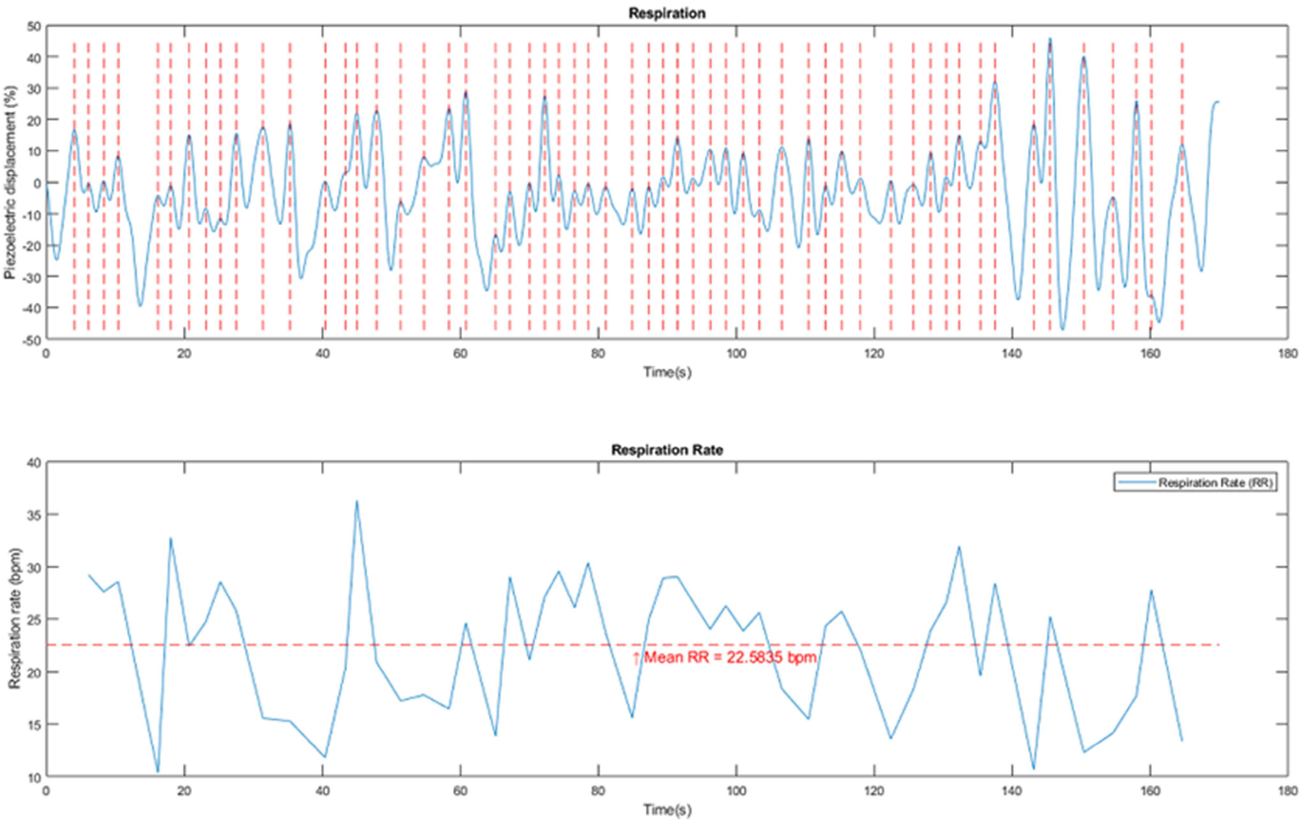

Fig. 9 RESP signal acquired in the virtual severe reality game with the balance platform

3) Self-Report Questionnaire. Through the "Gaze Selection" set with the Oculus Rift device, the self-report questionnaire (shown in Figure 9) was implemented, in which the participants evaluated their emotional states using 10 levels to evaluate each dimension of happiness, excitement, and dominance.

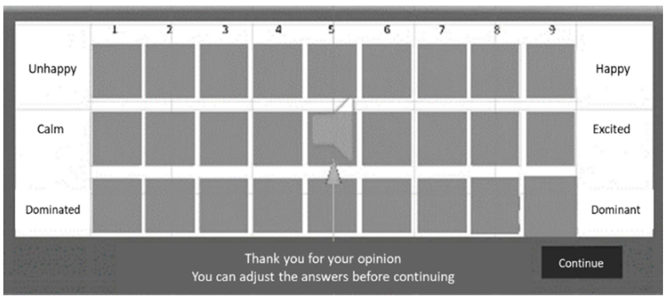

Fig. 10 Self-Report Questionnaire presented at the end of the parachuting game

The statistical weighting of the test is shown in Figure 10. For the Valence level a 9 represents joy with the session and 0 with a feeling of misfortune, the average recorded was 8 out of 9 points, the emotional level of greater cohesion of the 3 registered by the participants, which is a satisfactory result of the immersed balance serious game. For "Arousal," the value 9 represents an energetic state and 0 relaxed before the activity, average recorded was 7 out of 9 points. It can be inferred from the statistical information that this result is probably due to the previous experience of some participants with virtual reality immersion, so the game did not influence their level of exaltation.

The average "Dominance" value was 8, which is a good result for the evaluation of the user interface with the VR environment through the platform and helmet.

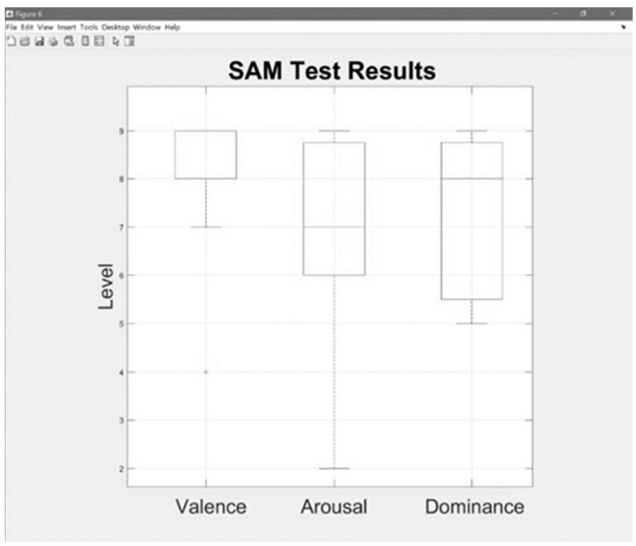

Fig. 11 Consolidated results of self-reports of the participants

IV. CONCLUSIONS

The game dynamics and the virtual environment developed with the Unity graphic engine designed generated an immersive and interactive experience with the experiment participants achieving high emotional levels of valence (joy-boredom) and exaltation. It was present in the SAM test, so it is concluded the proposed VR parachute can contribute to future activities that involve the wobble board platform because it is an exercise that encouraged and exalted the participants of the test. For what is related to future work, it is intended to include psychomotor learning theory procedures in motor rehabilitation therapies, recommended in the reference literature of this work, as well as an evaluation with health professionals for validity is proposed. Feasibility of the use of the activity within the traditional therapy. It is also recommended to use wireless VR helmets, and that set up more commands between the system with biosignals acquisition software. As a pertinent improvement to the system that contributes to obtaining high dominance levels of the self-report test, as well as the comfort of the character's handling in the virtual environment and allow integrated position-orientation tracking in the HMD.

ACKNOWLEDGMENT

System development was supported and funded by the Universidad Militar Nueva Granada through the project IMP-ING-2657. The participation of researchers from the DAVINCI group involving serious game testing is appreciated. Ethical approval was provided.

REFERENCES

[1] J. P. Salmon, S. M. Dolan, R. S. Drake, G. C. Wilson, R. M. Klein, and G. A. Eskes, “A survey of video game preferences in adults: Building better games for older adults,” Entertain. Comput., vol. 21, pp. 45–64, Jun. 2017.

[2] M. Ortiz-catalan, S. Nijenhuis, K. Ambrosch, T. B. Eerdt, S. Koenig, and B. Lange, “Virtual Reality,” pp. 249–265, 2014.

[3] M. Bayón-Calatayud et al., “Virtual rehabilitation,” in Biosystems and Biorobotics, vol. 10, Springer International Publishing, 2016, pp. 303–318.

[4] M. S. Cameirão, S. B. I. Badia, E. Duarte, A. Frisoli, and P. F. M. J. Verschure, “The combined impact of virtual reality neurorehabilitation and its interfaces on upper extremity functional recovery in patients with chronic stroke,” Stroke, vol. 43, no. 10, pp. 2720–2728, Oct. 2012.

[5] Ministerio de Salud y Protección Social, “Sala situacional de las Personas con Discapacidad (PCD),” Of. Promoción Soc., p. 36, 2018.

[6] D. H. Saunders, M. Sanderson, M. Brazzelli, C. A. Greig, and G. E. Mead, “Physical fitness training for stroke patients,” Cochrane Database of Systematic Reviews, vol. 2013, no. 10. John Wiley and Sons Ltd, 21-Oct-2013.

[7] C. English, S. L. Hillier, and E. A. Lynch, “Circuit class therapy for improving mobility after stroke,” Cochrane Database of Systematic Reviews, vol. 2017, no. 6. John Wiley and Sons Ltd, 02-Jun-2017.

[8] P. Langhorne, J. Bernhardt, and G. Kwakkel, “Stroke rehabilitation,” Lancet (London, England), vol. 377, no. 9778, pp. 1693–702, 2011.

[9] J. N. Kaufman, S. Lahey, and B. S. Slomine, “Pediatric rehabilitation psychology: Rehabilitating a moving target,” Rehabilitation Psychology, vol. 62, no. 3, American Psychological Association Inc., pp. 223–226, 01-Aug-2017.

[10] J. Bernhardt, J. M. Collier, P. J. Bate, M. N. T. Thuy, and P. Langhorne, “Very Early Versus Delayed Mobilization After Stroke,” Stroke, vol. 50, no. 7, pp. e178–e179, 2019.

[11] R. Friedrich, P. Hiesel, S. Peters, D. P. Siewiorek, A. Smailagic, and B. Brügge, “Serious games for home-based stroke rehabilitation,” in Studies in Health Technology and Informatics, 2015, vol. 213, pp. 157–160.

[12] C. Jeria, R. Hernández, and C. Benn, “Alteración de la variabilidad del ritmo cardíaco en pacientes con síndrome coronario agudo sin supradesnivel del segmento ST: Experiencia preliminar,” Rev. Chil. Cardiol., vol. 30, no. 2, pp. 104–112, 2011.

[13] B. Bonnechère, “Serious Games in Physical Rehabilitation,” in Serious Games in Physical Rehabilitation, Springer International Publishing, 2018, pp. 72–78.

[14] J. Sims, N. Cosby, E. N. Saliba, J. Hertel, and S. A. Saliba, “Exergaming and static postural control in individuals with a history of lower limb injury,” J. Athl. Train., vol. 48, no. 3, pp. 314–325, May 2013.

[15] I. Sparrer, T. A. Duong Dinh, J. Ilgner, and M. Westhofen, “Vestibular rehabilitation using the Nintendo® Wii Balance Board - A user-friendly alternative for central nervous compensation,” Acta Otolaryngol., vol. 133, no. 3, pp. 239–245, Mar. 2013.

[16] A. P. Garcia, M. M. Ganança, F. S. Cusin, A. Tomaz, F. F. Ganança, and H. H. Caovilla, “Reabilitação vestibular com realidade virtual na doença de Ménière,” Braz. J. Otorhinolaryngol., vol. 79, no. 3, pp. 366–374, 2013.

[17] J. C. Nitz, S. Kuys, R. Isles, and S. Fu, “Is the Wii FitTM a new-generation tool for improving balance, health and well-being? A pilot study,” Climacteric, vol. 13, no. 5, pp. 487–491, Oct. 2010.

[18] M. M. Bradley and P. J. Lang, “Measuring emotion: The self-assessment manikin and the semantic differential,” J. Behav. Ther. Exp. Psychiatry, vol. 25, no. 1, pp. 49–59, 1994.

[19] M. Van Diest, C. J. Lamoth, J. Stegenga, G. J. Verkerke, and K. Postema, “Exergaming for balance training of elderly: State of the art and future developments,” Journal of NeuroEngineering and Rehabilitation, vol. 10, no. 1. BioMed Central Ltd., 2013.

[20] S. C. Gobron et al., “Serious games for rehabilitation using Head-Mounted display and haptic devices,” in Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 2015, vol. 9254, pp. 199–219.

[21] N. Goljar et al., “Psychophysiological responses to robot training in different recovery phases after stroke,” in IEEE International Conference on Rehabilitation Robotics, 2011.

[22] O. I. Caldas, J. D. Abril, O. Rivera, C. Rodriguez-Guerrero, and O. F. Avilés, “Contribution of Virtual Environments to the Perception of Balance Rehabilitation Tasks: A Psychophysiological Study,” 2020, pp. 1200–1207.