A Serious Game for Training and Evaluating the Balance of Hemiparetic Stroke Patients

F. Noveletto[1], P. Bertemes-Filho[1], M.S. Hounsell[1] and A.V. Soares[2]

[1]State University of Santa Catarina, Dept. Electrical Engineering, Joinville/SC, Brazil
[2]Educational Association of Santa Catarina, Physiotherapy Clinic, Joinville/SC, Brazil

Abstract— **Stroke is the major cause of disabilities in adults and the second major cause of deaths worldwide. People that survive a stroke present deficits that affect their functional capacities and require rehabilitation for long periods. The use of digital entertaining games has shown to be a helping ally to the rehabilitation process, despite its therapeutic limitations. An alternative to these limitations is the development of games and control interfaces targeted the needs of patients, the so called Serious Games. The aim of this paper is to present the development of a Serious Game for training and evaluation of balance in hemiparetic stroke patients. An integrated biomedical system was, which consists of a balance board with inertial sensors instrumentation and a computer system that runs the game. The aim of the game, called *myBalance*, is to direct a ball to a target position according to the board signals. Various parameters of the game can be adjusted to comply with patients' limitations. The game has a scoring system that extracts metric information regarding patients' performance during gaming. Preliminary results indicate that the system (board and game) can be easily used for training and evaluation of patients' balance. It was also showed that the game can be used as a metric system for clinical studies. Future works include comparing game scores to standard clinical scales for balance.**

Keywords— **Serious Game, Rehabilitation, Balance, Stroke.**

I. INTRODUCTION

Stroke is a major cause of death worldwide and is the most important disease to cause physical and mental disabilities in adults. Corresponding death rates in Brazil are the highest among Latin America countries, either for men (128 per 100,000 subjects) and women (98.7 per 100,000 subjects), and can be related to social determinants [1,2]. A conspicuous symptom is the commitment of one side of the body characterized by hemiparesis. There is an inability to shift the weight to the affected side highlighting disabilities and limitations, particularly related to balance and normal gait [3,4].

Under normal circumstances, postural control and balance require integration of somatosensory, visual and vestibular information to central nervous system that interpret these messages and return a motor response allowing the maintenance of balance [5]. To keep standing, walk and interact with the environment in a safe and efficient manner, both good postural orientation and balance are necessary, which is achieved through proper postural control. Orientation is the setting that allows the positioning and alignment of the body. But the balance keeps the body in position and proper orientation during motor actions [6].

Therefore, deficiencies in the integration processes of the different systems involved, resulting from stroke, both neural and musculoskeletal, will directly affect the postural control [7], committing daily life activities and increasing the risk of falls of these individuals [8,9,10]. In addition, the deficit in balance generates greater fatigue - commitment found in a study that compared the energy expenditure of patients with and without stroke during activities on a force plate, the stroke patients group had energy demand twice as large as the control group [11].

Strategies for the balance rehabilitation have been researched and are in fact necessary for the recovery of these patients. The use of virtual reality and computer games in neurological rehabilitation have proven an effective strategy to provide an attractive system that motivates patients to perform tasks that make the rehabilitation process easier [12,13]. Specifically in the balance training of hemiparetics by stroke, games have shown good results [14,15].

A systematic review [16] pointed out that the virtual reality systems are promising in the rehabilitation of hemiparesis due to stroke, despite the reduced amount of well-conducted studies and small number of subjects involved in the studies. According to this review, most studies use commercially available computer games. As a rule of thumb, commercial games have been developed for entertaining health subjects and need to be adapted for therapeutic use which often entails risks in the procedures, in addition to not having proper gameplay settings for different degrees of severity of patients. Thus, it is crucial to use games specially designed for rehabilitation, which would allow safer training and better exercises that comply to individual conditions of patients. The games that target specific aspects such as education and health, for example, combined with the playful aspect of entertainment, are so called Serious Games [17,18].

This paper presents a Serious Game for balance training and evaluation in hemiparetic stroke patients.

D.A. Jaffray (ed.), *World Congress on Medical Physics and Biomedical Engineering, June 7-12, 2015, Toronto, Canada*,
IFMBE Proceedings 51, DOI: 10.1007/978-3-319-19387-8_274

II. METHODOLOGY

Novel hardware and software solutions have been developed to allow training and evaluation of individuals balance conditions. The biomedical system is composed of a specially built balance board with an inertial sensors unit (accelerometer and gyroscope) coupled to a computer system. The characteristics and dimensions of the specific balance board were based on previous studies, where the board was developed and validated using concurrent validation method against a force plate [19,20]. Figure 1 shows an overview of the whole system.

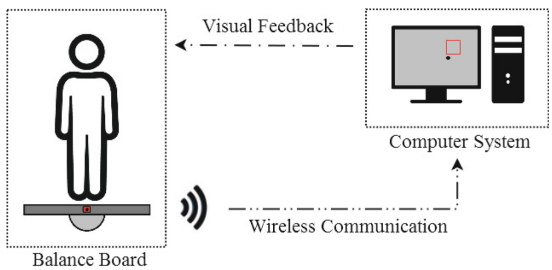

Fig. 1 Overview of the system for balance training and evaluation

A. Hardware Overview

The developed hardware consists of two microcontrolled systems (primary and secondary) based on the ATmega328 microcontroller (Atmel). Two nRF24L01 RF modules (Nordic) make the wireless communication between the main system (connected to the computer) and the secondary system (coupled to the balance board). The board tilt angles are obtained by an inertial sensors unit MPU-6050 (InvenSense).

B. Serious Game Design

The game, called *myBalance*, was developed in Delphi language and is compatible with Microsoft Windows Operating System. The visual design of the game is simple to allow patients to focus on the task of placing the ball inside the target area. The ball moves depending on sensors signal which identify the board tilt angle. Figure 2 shows a printout of the game screen.

The game was designed according to the Flow Theory [21], which establishes a relationship between the level of challenge and the level of skill of the player. The goal is to keep the game at a level that is not too easy, leading the patient to boredom, and not too hard, leading the patient to frustration. According to this theory, as the players' skill progresses, the challenge level must evolves, making the player enters a high level of concentration. In games for rehabilitation, a high level of concentration makes the patient focus only on the challenge, mitigating problems related to rehabilitation and maintaining the commitment to the continuity of the treatment.

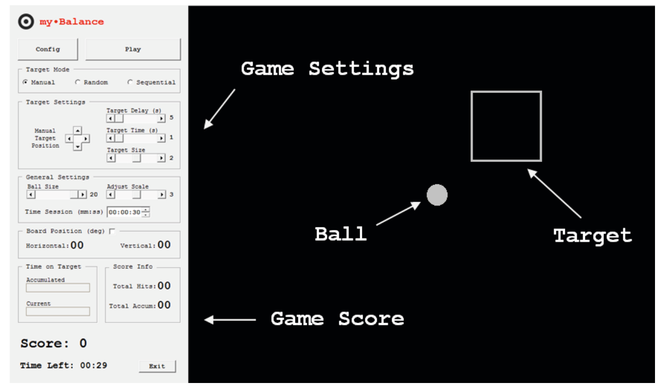

Fig. 2 Screenshot of *myBalance* serious game where the main components are highlighted

To maintain the game flow, various configurations can be set by the therapist according to the physical limitations of each patient. Flow is achieved thus, by a proper scoring system, which also aims to motivate patients to improve their performance [18]. The scoring system is based on an empirical model that relates game variables with the degree of difficulty for the patient to position the ball on the target area. Equation (1) shows how the score is calculated considering target hits and game settings.

$$Score = \left(80 \times Hits + 20 \times Accum\right) \times \frac{TM \times TT \times TL}{TS} \qquad (1)$$

where:

Target Mode (TM): Defines how the target area will appear on the screen; TM can be set to manual (set by the therapist in real time), sequential (concentric from level 0) and random. The TM values can be: 2 to random mode, 1.5 to manual mode and 1 to sequential mode.

Target Time (TT): Sets the elapsed time (in seconds) the ball must be in the target area to increase the variable Hits.

Target Level (TL): It is the target position on the screen where the screen center represents level 0 and level 3 is the farthest position from center. The TL values can be 2, 1.2, 1.5 and 1.8 to level 0, 1, 2 and 3, respectively.

Target Size (TS): Sets one of 3 target area sizes. The TS values can be 3 (smallest), 2 and 1 (biggest).

Hits: Represents the number of hits on target. This variable increases when the ball is within the target area loner than TT. As the aim of the game is to place the ball inside the target area, *Hits* variable has 80% weight on the total score.

Accum: Represents the cumulative number that the ball passes through the target area. Each time the ball passes through the target area, the *Accum* variable is incremented. The aim of this variable is to score (with a lower weight, equal to 20%) when the ball passes through the target, regardless if the patient cannot keep the ball inside the target area and therefore, avoiding frustration.

Another feature of the game is the ability to record data from a game session. The data extracted from the user interacting with the game can be used to define the metrics of the game [22]. In serious games these data can be used to extract intrinsic details of the game and can bring relevant information for the assessment of the rehabilitation process.

III. RESULTS AND DISCUSSIONS

Although this work was focused on developing a biomedical system in the form of a Serious Game for balance in order to allow evaluation and training of hemiparetic stroke patients, the system can also be used for other pathologies that affect balancing.

Preliminary trials were focused on the use of the game and evaluating its metric features, operated one of the co-authors with the following characteristics: male subject, right-handed with no history of neuromuscular dysfunctions, 44 years old, 1.80 m stature and 85 kg body weight.

To perform the test, the board was positioned in front of the computer screen, with the subject standing barefoot, looking at the screen (positioned at eye level), at a distance of 1 m. The feet were far apart in a natural and comfortable position but not more than shoulder width [23].

Table 1 shows the data collected in a session of gaming, where the goal was to keep the ball within the target-area located at various levels: from the center of the screen (level 0) to more peripheral positions (levels 1, 2 and 3) at the left or right side of the screen.

Table 1 Data from a game session (Target Time set to one second and Total session time of 30 s).

Level	Hits		Accum		Score	
	Left	Right	Left	Right	Left	Right
0	11	11	15	15	3300	3300
1	19	21	21	23	3472	3830
2	19	24	22	25	4410	5445
3	14	18	19	21	4050	5022

Data shown in Table 1 indicate a better balance control to reach targets on the right side of the screen. In a related study [19] the best performance in the balance also occurred on the dominant side of the subject.

Other information that can be extracted directly from the table is the oscillation level. The greater the difference between the *Hits* and *Accum* variables, the greater the degree of oscillation. This characteristic can be observed especially at level 0, where the degrees of freedom of movement are higher.

An important feature in *myBalance* is the possibility to record the data section of the game, which is crucial to determine metrics for evaluating the patient. For instance, a Dynamic Stabilometry test is proposed. Figure 3 shows a plot from Matlab software with the data from the game for such Dynamic Stabilometry test. This technique is different from classical stabilometry that uses quiet standing data collected in a stable force platform [24].

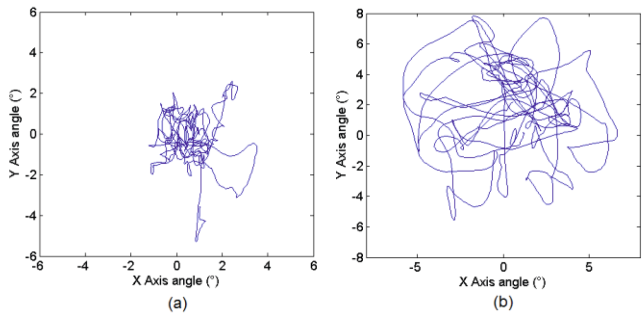

Fig. 3 Dynamic Stabilometry plots in Matlab: (a) eyes opened and; (b) eyes closed.

The use of serious games in rehabilitation of stroke patients is considered a promising therapeutic approach [14, 15,25] because they allow a wide range of exercises and increase attention and motivation of patients during treatment sessions.

Preliminary tests indicate some advantages of *myBalance* and the board developed if compared to commercial games used therapeutically: a) allows balance training by performing specific tasks (random targets, concentric sequential targets or manually, where the therapist chooses the target); b) allows the customization of the game with many tunable parameters such as: size of the ball, target size, length of stay on target, changing time of the target position; c) Metric properties: in addition to the proposed new test - Dynamic Stabilometry, game scores will be compared to classic clinical scales, such as the Berg Balance Scale [26].

IV. CONCLUSIONS

The proposed and developed system (hardware, computer game, scoring strategy and dynamics test) offers a practicable and inexpensive option to train and evaluate balance. The system generates controllable balance disturbances and measures objectively how patients compensate, different to that used in clinical facilities, where the board is not instrumented. It yields quanti and qualitative data to better assess patients' capabilities. Additionally, it uses a Serious Game which includes various balance exercises on an unstable platform, stimulating and motivating a progressive and interesting training of the complex function, which is the balance.

Acknowledgment

The authors thank the financial support of the State University of Santa Catarina (UDESC), and the institutional support of the Technological Institute Foundation of Joinville (FITEJ) and the Guilherme Guimbala Faculty.

Conflict of Interest

The authors declare that there are no conflicts of interest.

References

1. Cabral NL, Longo A, Moro C et al. (2011) Education Level Explains Differences in Stroke Incidence among City Districts in Joinville, Brazil: A Three-Year Population-Based Study. Neuroepidemiology, 36:258-264
2. Lotufo PA (2005) Stroke in Brazil: a neglected disease. São Paulo Med J., 123(1): 3-4
3. Trípoli F, Moreira SR, Oberg TD et al. (2008) Tarefas orientadas e biofeedback: efeitos na transferência de peso em hemiparéticos. Acta Fisiátrica, 15 (4):220-4
4. Barcala L, Colella F, Araujo MC et al. (2011) Análise do equilíbrio em pacientes hemiparéticos após o treino com o programa Wii Fit. Fisioter Mov., 24 (2): 337-43
5. Kerdoncuff V, Durufle A, Petrilli S et al. (2004) Intérêt de la rééducation par biofeedback visuel sur plateforme de stabilométrie dans le prise en charge des troubles posturaux des hémiplégiques vasculaires. Ann Readapt Med Phys, 47:169–76
6. Horak FB (2006) Postural orientation and equilibrium: what do we need to know about neural central of balance to prevent falls. Age and Ageing, 35:117-121
7. Oliveira CB, Medeiros IR, Frota NA et al. (2008) Balance control in hemiparetic stroke patients: main tools for evaluation. J Rehabil Res Dev., 45(8):1215–1226
8. Giriko CH, Azevedo RAN, Kuriki HU et al. (2010) Capacidade funcional de hemiparéticos crônicos submetidos a um programa de fisioterapia em grupo. Fisioterapia e Pesquisa, 17(3): 214-219
9. Belgen B, Beninato M, Sullivan PE et al.(2006) The association of balance capacity and falls self-efficacy with history of falling in community-dwelling people with chronic stroke. Arch Phys Med Rehabil., 87(4):554-61
10. Weerdesteyn V, Niet M, Duijnhoven HJ et al. (2008) Falls in individuals with stroke. J Rehabil Res Dev, 45:1195-1213
11. Houdijk H, Hoeve N, Nooijen C et al. (2010) Energy expenditure of stroke patients during postural control tasks. Gait Posture, 32(3):321-326
12. Holden MK, Dyar TA, Schwamm L et al. (2005) Virtual Environment-Based Telerehabilitation In Patients With Stroke. Cyberpsychology & Behavior, pp. 212-219
13. Rizzo A (2001) Virtual reality definitions and rationale for its use for cognitive assessment and rehabilitation. Torino, Italy, 4th World Congress on Brain Injury, 243-244
14. Lloréns R, Gil-Gómez JA, Alcañiz M et al. (2014) Improvement in balance using a virtual reality-based stepping exercise: a randomized controlled trial involving individuals with chronic stroke. Clin Rehabil., November 23. DOI: http://dx.doi.org/10.1177/0269215514543333
15. Lloréns R, Noé E, Colomer C et al. (2014) Effectiveness, usability, and cost-benefit of a virtual reality-based telerehabilitation program for balance recovery after stroke: a randomized controlled trial. Arch Phys Med Rehabil., November 13. DOI: http://dx.doi.org/10.1016/j.apmr.2014.10.019.
16. Lohse KR, Hilderman CGE, Cheung KL et al.(2014) Virtual Reality Therapy for Adults Post-Stroke: A Systematic Review and Meta-Analysis Exploring Virtual Environments and Commercial Games in Therapy. Plos One, 9(3) 1-13
17. Alvarez J, Djaouti D (2011) An introduction to Serious Game Definitions and Concepts. In Proceedings of the Serious Games & Simulation for Risks Management Workshop, 11-15.
18. Susi T, Johannesson M, Backlund P (2007) Serious Games - An overview, University of Skövde, HS-IKI-TR-07-001.
19. Soares AV, Bertoni A, Borges L et al. (2007) Development and validation of a biomechanical instrumentation to evaluation of the trunk balance. Motor Control, 1:1-56
20. Soares AV, Hochmüller ACOL, Silva P et al.(2009) Biorretroalimentação para treinamento do equilíbrio em hemiparéticos por acidente vascular encefálico: estudo preliminar. Fisioterapia e Pesquisa, 16 (2): 132-136
21. Csikszentmihalyi M (1991) Flow: The psychology of optimal experience. Harper Perennial
22. Drachen A, Canossa A (2009) Towards Gameplay Analysis via Gameplay Metrics. In press for 13th MindTrek (Tampere, Finland), ACM-SIGCHI Publishers
23. Duarte M, Freitas SMSF (2010) Revisão sobre posturografia baseada em plataforma de força para avaliação do equilíbrio. Rev Bras Fisioter, 14 (3): 183-192
24. Raymakers JA, samson MM, Verhaar HJJ (2005) The assessment of body sway and the choice of the stability parameter(s). Gait and Posture, Oxford, v.21, pp 48-58
25. Soares AV, Woellner SS, Andrade CS et al. (2014) The use of Virtual Reality for upper limb rehabilitation of hemiparetic Stroke patients. Fisioter Mov, 27(3): 309-317
26. Tyson SF, DeSouza LH (2004) Reliability and validity of functional balance tests post stroke. Clin Rehabil, 18: 916-923

Author: Fabrício Noveletto
Institute: State University of Santa Catarina (UDESC)
Street: Paulo Malschitzki
City: Joinville/SC
Country: Brazil
Email: fabricio.noveletto@udesc.br