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BioTrak: a comprehensive overview

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***Abstract*—This paper describes the BioTrak system, a balance rehabilitation system that uses virtual reality technology to immerse patients in a virtual environment where they are challenged to fulfill simple tasks by means of their own movements. The system tries to motivate and involve patients in order to improve their adherence to the treatment, their effort and, thus, their recovery. This manuscript presents an overview of the system and an early validation. Thirteen patients with acquired brain injury participated in 15 sessions with the system and show significant improvement in Berg Balance Scale, Tinetti Gait Assessment, and balance control in medial-lateral and anterior-posterior plane, quantified with a posturography study.**

Keywords-balance recovery; virtual rehabilitation, virtual therapy, neurorehabilitation

I. Introduction

Balance requires the concurrent processing of inputs from multiple body systems including perceptual (visual, vestibular and proprioception), cognitive (mainly attentional and executive functions) and obviously sensori-motor systems. Such complex mechanism makes postural instability a common symptom in diseases affecting not only the central nervous system (acquired and degenerative brain disease) but also those affecting perceptual senses and peripheral nervous system (spinal cord injury, polyneuropathies, myopathies, etc.). Since balance control is required to achieve autonomy in activities of daily living (ADL), functional mobility and prevention of falls [1],[2], the recovery of trunk control in sitting and standing position is one of the earliest and most important goals in motor rehabilitation. As an example, several studies have demonstrated that trunk control is a clear prognostic factor of regaining functional gait after a brain injury [3].

Conventional balance recovery therapy includes nonspecific postural control techniques whether on a stationary basis (weight-shift and weight-bearing training) or while performing voluntary movements (transfer and reaching mobility tasks). Novel approaches of balance therapy combine several theories of motor control and principles of motor learning [4]. This task-oriented intervention has been quickly assimilated by new technologies, especially virtual reality (VR).

In the last years, the potential benefits of VR in the rehabilitation process (i.e., virtual rehabilitation) have been highlighted [5]-[8]. Virtual rehabilitation provides several benefits to patients, such as the immersion in safe and controlled environments [9] or the increase of motivation and adherence to the treatment [10], and for therapists, such as the objective analysis of the patients' evolution or tele-rehabilitation [5].

Up to now, several virtual rehabilitation systems have been presented. Most of these systems have been specifically designed for the rehabilitation of upper extremities [11]-[13] and less for lower extremities [14]. However, interesting systems have been developed for balance recovery. The IREX system [15], a chroma key based system, has been used to immerse patients in a virtual scenario with task-oriented exercises. Adaptations of the system have been in tested in patients with paraplegic spinal cord injury [16] and multiple sclerosis [17]. Other systems, based on force platforms have also been used for motor rehabilitation in stroke patients, including balance recovery [18][19].

From a therapeutic point of view, there is still a need for rehabilitation systems that can be easily fitted into the clinical facilities and that allow a quick recovery and improvement of trunk control in sitting and standing position for acute patients and also for those in more advanced clinical stages. This paper describes BioTrak, a new balance training system for patients with different pathologies, and presents a pilot study evaluating its clinical effectiveness in stroke patients.

II. System Description

BioTrak is a balance rehabilitation system that immerses the patients in a virtual scenario to perform game-oriented tasks. The objectives to be achieved in the virtual world are simple and easy to follow even by patients with balance disorders that can present underlying cognitive impairments. The objectives of the exercises are fulfilled by means of body movements, which have been clinically designed to strengthen the postural control and thus, the balance rehabilitation. The patients' movements are transferred to the virtual world by means of a tracking system. BioTrak allows different tracking systems (optical, electromagnetic, kinetic) to be used. The

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tracking systems provide 3D information of specific anatomical positions of the patients, and the BioTrak system processes these data and reacts as required. All the tracking options have their own advantages and disadvantages depending on the physical principle they are based on [20], but it is not the objective of this paper to discuss this topic. The multi-tracking orientation of BioTrak makes possible the adaptation of the system to different environments.

BioTrak provides audio and video feedback of the virtual world. The audio signal is positional and can be played through a multi-speaker system. The video output can be displayed in any video display. The system runs on a standard PC. The software testing process has been carried out on a Intel® Core™2 Quad Q945 @2.66Hz with 3 GB of RAM and 512 MB video card with Windows XP.

A thorough description of the framework and exercises of the system is presented below.

A. Framework

As shown in Figure 1. , BioTrak framework can be divided into different modules.

- Manager: this module allows the therapists to manage all the clinical staff and patients, configure patient's sessions, check their evolution, etc. The manager retrieves and updates the data of the system and launches the session of exercises. This module can be run on a web browser. Figure 2. shows a couple of snapshots of the manager module.
- Database: this module stores the registries of users, session settings, results achieved, etc.
- Exercises: BioTrak includes a bundle of 6 exercises distributed in both standing and sitting position.

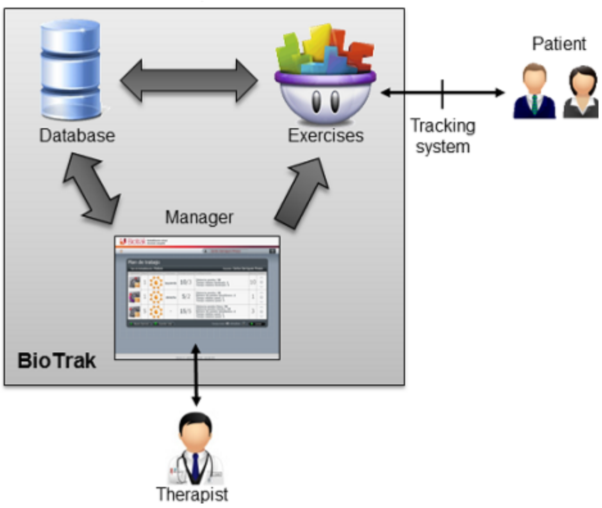
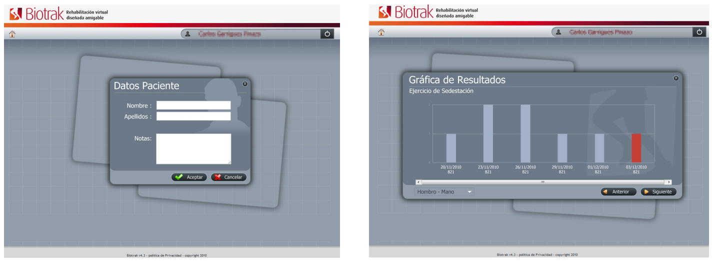


Figure 1. BioTrak framework. The system combines different modules developed in different programming languages. The correct communication among them is fundamental for the full system performance.



a) b)

Figure 2. Snapshots of the manager module. (a) shows the registration form. (b) shows the evolution of a patient in a game.

Each module has been programmed in different languages. The manager has been fully developed in Visual C++. The database has been programmed in Visual Basic .NET and SQL Server. The exercises have been fully developed in Lite-C. As a result, a specific scheme has been designed to link all the modules. All this protocol is transparent to the therapist.

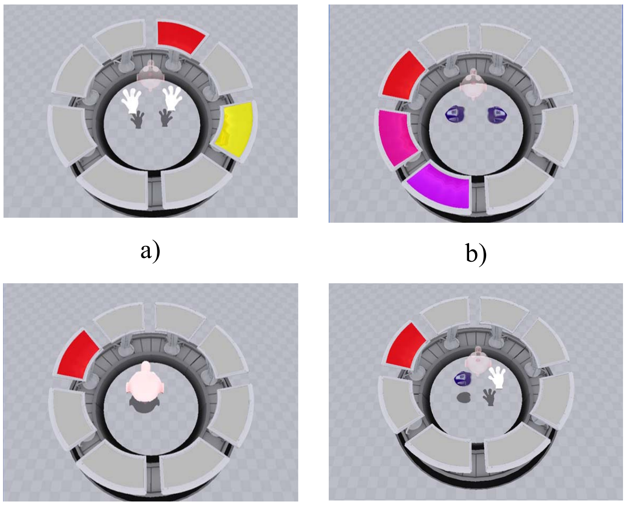
B. Exercises

The exercises are the most important part of the system. It is commonly assumed that exercises based on motor learning principles improve the achievements of the rehabilitation therapy [21]. Consequently, BioTrak exercises are repetitive, intensive and meaningful.

In order to achieve an immediate correspondence with the virtual environment, the exercises use a third-person point of view and the patients are represented by a simplified avatar. In the sitting exercises, the patients are represented by a head and the currently working extremities (see Figure 3.). In the standing exercises, the patients are represented by two trainers, and a cane when needed (see Figure 4.). The learning curve has proved to be steep and patients report to have control over the game. The system provides an immersive experience that evades the patients from the therapy, provides them an enjoyable session and motivates them to keep on the rehabilitation process.

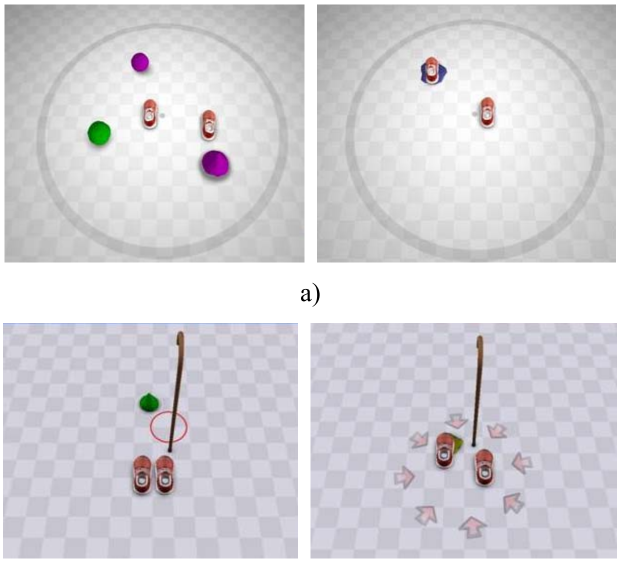
A complete description of the exercises is provided next.

- Sitting: the patient is surrounded by panels. The objective is to reach (i.e. switch down) the highlighted panel and then return to the resting position before the panel switches off. As shown in Figure 3. , the reaches can be performed with different parts of the body: hand, shoulder, head or a combination of the above.
- Standing: the patient has to stomp the flubber-made items that appear around him/her before they disappear. In this case, the reaches can be performed using the patient's own feet or a cane.



a) b) c) d)

Figure 3. Snapshots of the BioTrak gameplay in sitting position. The patient, represented by an avatar, has to turn off the colored panels by reaching them with his/her hands (a), shoulders (b), head (c) or a combination of the above, for example, hand and shoulder (d).



a) b)

Figure 4. Snapshots of the BioTrak gameplay in standing position. The patient, represented by an avatar, has to reach the Play-Doh items that emerge from the ground using his/her own feet (a) or a cane (b).

Game configuration

The BioTrak system is versatile and adaptable since it covers a wide range of balance disorders and is useful for the rehabilitation of the patients in every stage of their recovery. This is achieved allowing flexible interfaces with the system (see Figure 3. and Figure 4.) and providing a setup application to configure the exercises.

Although all the parameters are configurable, previous tests of the system in a clinical setting proved that, in practice, only a few parameters were tuned by the clinical staff in both sitting and standing cases. The manager allows the therapists to completely configure the rehabilitation session and exercises according the patient's dysfunction with a friendly and intuitive setup, showing the main parameters in every exercise (see Figure 5.). The therapist can set the position and lifetime of the reachable items, number of simultaneous items, break time, etc. This way, the patients do not have to fit the system. The system fits the patients.

For the therapist, the everyday operation of the system consists in choosing a specific patient, configure the session (when considered) and fix the tracking sensors to the patient's body (if required). Next, the therapist can launch the session. The system will run all the exercises with the chosen configuration and the programmed break times. When an exercise requires changing the constellation of tracking sensors, the system alerts the therapist, who only has to change the sensors and "click on next". This process will repeat until the end of the session.

Figure 5. Snapshot of the session planning. The manager is designed and oriented to clinical staff according to their needs. A therapist can choose a specific patient, check their evolution, adjust the session if needed, and launch the session with the programmed breaks. If the patient, for instance, presents stability difficulties in the anterior-posterior plane, the manager allows to bound the area of appearance of the items to that region.

III. CLINICAL VALIDATION

In order to evaluate the clinical benefits of the BioTrak system, different studies have been planned.

Figure 6. Pictures of a therapist training with the standing exercise.

In the present article, an early clinical validation of the standing exercise with optical tracking is presented (see Figure

6.). The hardware configuration consisted of a standard PC, two IR cameras and reflective markers. An LCD screen was used as a video display device.

A. Participants

Thirteen patients (11 men, 2 women) who presented balance disorders due to a traumatic brain injury (4 subjects) or an ischemic (8 subjects) or hemorrhagic stroke (1 subject) participated in the study. The participants presented a variable chronicity (200.38±95 days). TABLE I. shows more characteristics.

TABLE I. CHARACTERISTICS OF THE PARTICIPANTS

Clinical scales	*Values*	
	Female	*Male*
Age[a]	50.50±12.02	39.73±15.02
Etiology • Traumatic • Ischemic • Hemorrhagic	 0 2 0	 4 6 1
Hemiparesis • Left • Right	 0 2	 8 3
Chronicity[b]	164±52.30	207±101.10

Results expressed in years (a) and days (b) in mean ± standard deviation

All the patients were treated at an acquired brain injury rehabilitation service of a large metropolitan hospital.

Inclusion criteria were:

- Age ≥16 and <80 years.
- Enough ability to maintain standing balance: Berg Balance Scale ≥ 33.
- Fairly good global mobility: Clinical Outcome Variable Scale ≥ 65.

Exclusion criteria were:

- Dementia or aphasia.
- Severe visual or hearing impairment.
- Unilateral spatial neglect.
- Presence of ataxia or any other cerebellar symptom.
- Presence of behavioral or psychiatric disturbances which would interfere with the treatment.
- Inability to undergo physical therapy due to reduced general health status.

B. Intervention

Each patient underwent 15 sessions of 30 minutes distributed in 3 sessions per week. Apart from the effective sessions, all the subjects participated in a previous learning session to familiarize themselves with the system.

The patients' balance condition was assessed before (week 0) and after the treatment (week 5) to evaluate the improvement with the virtual therapy, and 5 weeks later (week 10) to evaluate if the results lasted. Figure 7. shows the timeline of the study.

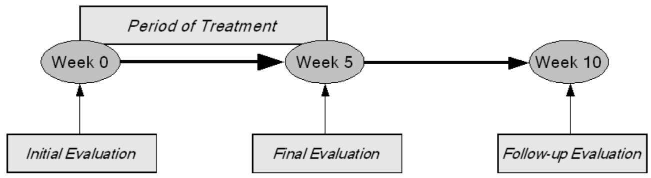


Figure 7. Timeline of the clinical trial. Participants were assessed before and after treatment, and in a follow-up evaluation.

Balance condition was assessed by means of Berg Standing Scale (BBS) [22], Tinetti Balance (TBA) and Tinetti Gait Assessment (TGA) [23]. In addition, a computerized dynamic posturography (CDP) was carried out to measure the stability limits (PSL), control of the medial-lateral balance (PML) and control of the antero-posterior balance (PAP) of the participants. With this aim, the NED/Sve IBV dynamometric platform was used [24][25]. This system compares the stability limits in the ground, medial-lateral and antero-posterior plane with a normal pattern and gives the result as a percentage of it.

Acquired data were computed using a paired Student's t-test by means of IBM SPSS Statistics 15. All statistical analyses were performed considering a significance level of $p<0.05$ (95% confidence interval of the difference).

IV. RESULTS

All the participants finished the 15 sessions. TABLE II. illustrates the numerical values obtained in the different assessments. The same results are depicted in the boxplots of the Figure 8.

None of the patients suffered from side effects like cybersickness or disorientation.

TABLE II. EVALUATIONS OF BALANCE CONDITIONS

Clinical scales	Values[a]		
	Initial	*Final*	*Follow-up*
Berg Balance Scale	46.77±5.246	51.23±3.789	52.38±3.798
Tinetti Balance	14.38±2.219	15.69±0.630	15.69±0.630
Tinetti Gait	9.00±2.121	10.69±1.377	11.38±0.870

Posturography	Values[b]		
	Initial	*Final*	*Follow-up*
Stability Limits	80.15±8.896	82.69±8.645	82.54±9.107
Medial-lateral	83.85±14.611	89.92±11.273	90.85±9.720
Antero-posterior	80.46±9.837	86.15±9.191	87.15±8.971

a. Numerical values are given in mean ± standard deviation; b. Values are given as a percentage of the normal pattern

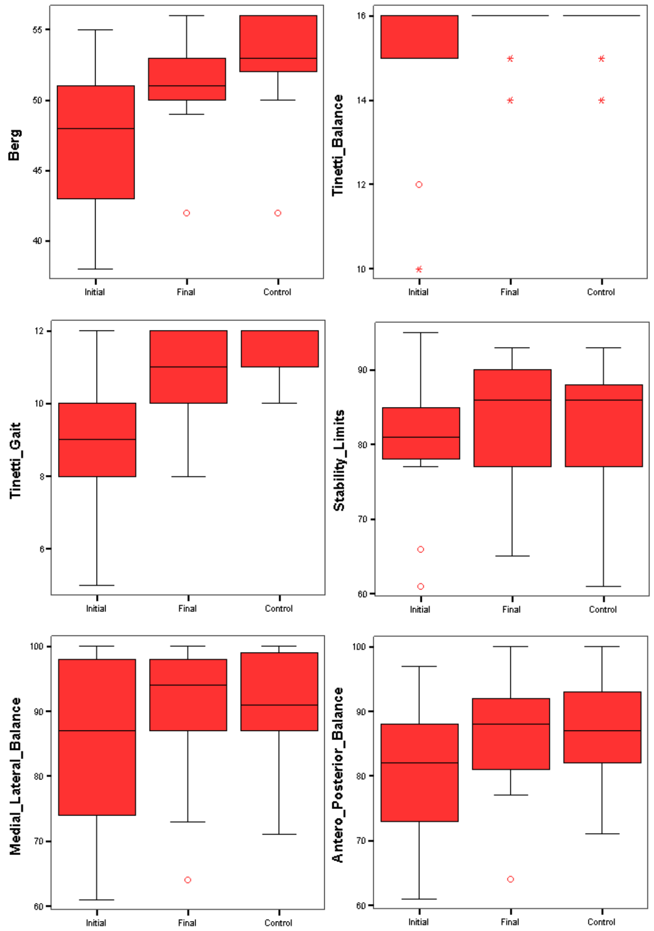


Figure 8. Boxplots of the scores achieved in the assessments of the patients

V. Discussion

TABLE III. shows the numerical results of the paired t-tests between the final and initial assessment and between the follow-up and the final assessment.

In spite of the improvement shown in the final assessment for both scales and posturography, a post-hoc analysis of the patient's scores revealed only significant time effects in BBS (p=0.001), TGA (p=0.000), CDP-ML (p=0.012) and CDP-AP (p=0.008).

In addition, statistical analysis of the follow-up assessment showed significant improvement in TGA (p=0.022), that is, in absence of the virtual therapy.

The significant improvement in the balance scales and in the posturography evidence that the virtual therapy can provide benefits in the balance recovery of patients with ABI. In addition, the achievement remains 5 weeks later and it is supposed to have a positive impact on the patient's gait, which is depicted in the significant improvement in the TGA in the follow-up assessment.

Regarding the patients' impressions, all the participants reported to have a good time during therapy and take interest in the next session. Some of them also became exhausted and even sweaty, but also reported to feel perfectly. Clinical staff declared to have taken control over the system and have integrated it in their daily routine.

TABLE III. Paired T-Tests Between the Final and Initial Assessment and Between the Follow-up and Final assessment

Clinical scales	***Values***		
	Mean	***Std. Dev***	***Significance (2-tailed)***
BBS_i-BBS_f	-4.46	3.620	0.001
TBA_i-TBA_f	-1.31	2.175	0.051
TGA_i-TGA_f	-1.69	1.182	0.000
PSL_i-PSL_f	-2.54	6.385	0.177
PML_i-PML_f	-6.08	7.421	0.012
PAP_i-PAP_f	-5.69	6.408	0.008
BBS_f-BBS_{fu}	-1.15	1.951	0.054
TBA_f-TBA_{fu}	-0.69	0.947	0.022
TGA_f-TGA_{fu}	0	0	NS
PSL_f-PSL_{fu}	0.15	4.079	0.894
PML_f-PML_{fu}	-0.92	6.317	0.608
PAP_f-PAP_{fu}	-1.00	5.831	0.548

i: initial; f: final; fu: follow-up. NS: non-significant

VI. Conclusions and Future Work

The statistical analyses show that the BioTrak system can provide benefits in the balance recovery of patients with ABI.

However, since the participants underwent both traditional and virtual therapy during the study and since the chronicity was not bounded in the inclusion criteria (and then endogenous recovery processes can underlie the functional recovery), new studies are needed in order to prove if the system can provide benefits to traditional therapy for balance recovery. In addition, future work will also focus on validating other exercises of the system and evaluating BioTrak in other pathologies that induce balance disorders.

BioTrak has proven to be a powerful tool for the balance rehabilitation. The system is versatile, valid for multiple pathologies with balance disorders, and adaptable, since the system adapts each patient's dysfunction. It provides game-oriented exercises enhancing patients' motivation, effort and treatment adherence. The session time is spent on rehabilitation, not on configuring the system, allowing therapists to focus on the rehabilitation of patients. Then therapists can provide better care and/or can look after more patients. BioTrak also provides objective data of the patients and makes possible to analytically study the evolution. In addition, the system is oriented to telerehabilitaion: the session can be performed in the patient's home and monitored at a distance.

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