Annual Review of Cybertherapy and Telemedicine 2012
B.K. Wiederhold and G. Riva (Eds.)
IOS Press, 2012

doi:10.3233/978-1-61499-121-2-108

Balance Recovery Through Virtual Stepping Exercises Using Kinect Skeleton Tracking: A Follow-Up Study With Chronic Stroke Patients

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Abstract. Stroke patients often suffer from hemiparesis, which affects their balance condition and consequently their self-dependency and quality of life. Balance rehabilitation can be a long and tedious process. Virtual rehabilitation systems have been reported to provide therapeutic benefits to the balance recovery of stroke patients while increasing their motivation. This paper presents a follow-up study involving chronic stroke patients to evaluate the clinical effectiveness of a virtual stepping exercise using skeleton tracking through a low-cost Kinect depth sensor.

Keywords. Balance recovery, virtual rehabilitation, skeleton tracking, acquired brain injury, BioTrak system

Introduction

Balance complications are common amongst patients with hemiparetic acquired brain injury (ABI) patients. The balance disorders are among the most disabling dysfunctions since they can affect and even prevent the performance of the activities of daily living. The balance recovery requires the hierarchical recovery of multiple deficits including perceptive, musculoskeletal, and cognitive components of posture in order to achieve maximum functionality in terms of the patient's self-dependency. For this reason, traditional neurorehabilitation programs focus on the balance recovery since the initial stages of the rehabilitation process. There is proven clinical evidence that the recovery of this skill has been associated with a favorable functional outcome [1]. However, the balance recovery process can last for years and can become tedious and meaningless.

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In the last years some studies have reported the clinical benefits of virtual reality (VR)-based systems in the balance recovery of ABI patients, from chroma-key systems [2] to force platforms [3]. At present, the off-the-shelf depth sensors, such as the Microsoft® Kinect [4], provide therapists with a low cost and non-invasive body tracking that can easily fit in the clinical setting. We have integrated the Kinect skeleton tracking in the BioTrak system [5] and in this paper we present a follow-up study involving stroke patients to evaluate the clinical effectiveness of a reaching exercise in standing position that uses VR technology and skeleton tracking.

1. Methods

1.1. Participants

89 patients that were attending a holistic rehabilitation program in a large metropolitan hospital were potential candidates to take part in the study. Inclusion criteria were: 1) age ≥ 18 and ≤ 75 years; 2) chronicity > 6 months; 3) Brunel Balance Assessment [6]: section 3, levels 7-12; 4) Mini-Mental State Examination [7] > 23. Exclusion criteria were: patients with 1) severe dementia or aphasia; 2) cerebellar symptoms. After inclusion/exclusion criteria 15 chronic stroke patients (Table 1) were recruited from the total pool.

Table 1. Characteristics of the participants

Scale	Initial assessment
Gender (n)	
Male	8
Female	7
Age (years)	51.87±15.57
Etiology (n)	
Ischemic stroke	10
Hemorrhagic stroke	5
Hemiparesis side (n)	
Left	7
Right	8
Chronicity (days)	483.47±241.59

1.2. *Instrumentation*

BioTrak is a modular VR system that provides, among others, exercises for the balance rehabilitation in both standing and sitting position. For this study the BioTrak setting consisted of a 42” LCD screen, a standard computer, and a depth sensor (DS). Only the stepping exercise in standing position was evaluated. This exercise immerses the participants in a virtual scenario and represents their feet by means of two virtual shoes. The positions of the participants’ feet are estimated by the DS and then transferred to the virtual scenario. During the training sessions, different items rise from the floor around a central circle. The participants are required to step on the items with one foot before they disappear while maintaining the other foot inside the circle. After that, the participants have to return the extended foot within the circle before they can step on a new item. Specifically, the reaching exercises in standing position train the one-leg standing strategies and the balance control in the swing phase of the gait cycle and in the step strategies (Figure 1).

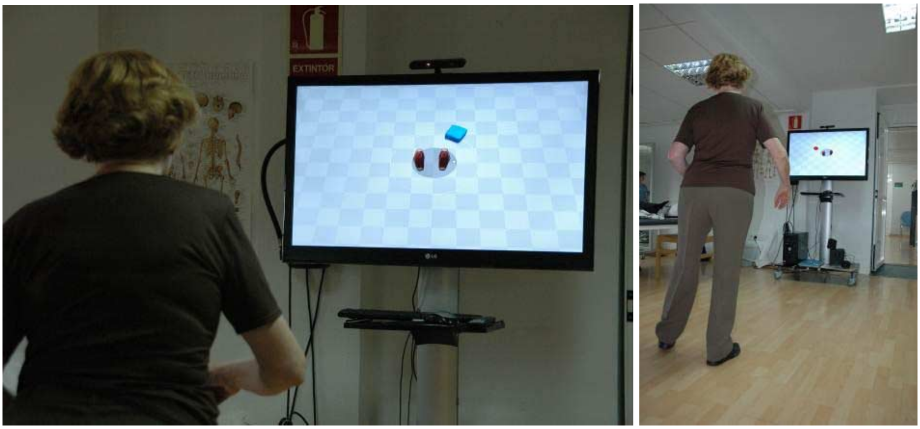

Figure 1. Photograph of a patient testing the system. The patient's feet are estimated by the skeleton tracking and transferred to the virtual world, where two shoes represent them. The objective of the exercise is to step on the items that randomly rise from the floor around the patient.

1.3. Intervention

Each participant underwent 20 sessions of 45 minutes each, which consisted of 6 6-minute repetitions with 1-minute break among them, from 3 to 5 sessions per week. All the participants were assessed with the Berg balance scale (BBS) [8], the balance subscale of the Tinetti performance oriented mobility assessment (POMAb) [9] and the Brunnel balance assessment (BBA) [10] at the beginning (initial assessment), at the end (final assessment), and 1 month after treatment (follow-up assessment).

2. Results

Statistical analyses of the within-subject (time) effect showed significant differences between the initial and final assessment in the BBS ($p<0.01$) but not in the POMAb ($p=0.08$). A post-hoc analysis of the BBS scores showed significant improvement during the treatment ($p<0.01$) but not during the follow-up ($p=0.162$). Regarding the BBA a chi-square test also showed statistical significance in the percentage of participants (26.6%) that increased their score during the treatment (chi-square=2.5, $p<0.01$) but no further increases were detected during the follow-up.

Table 2. Results of both scales expressed in number of participants

Scale	Initial assessment (A_i)	Final assessment (A_f)	Follow-up assessment (A_{fu})	Significance
BBS	49.00±6.12	51.73±3.99	52.13±3.60	$A_i<A_f$ ($p<0.01$)
POMAb	14.60±2.56	15.40±0.74	15.53±0.74	NS
BBA				$A_i<A_f$ ($p<0.01$)
Level=7	1	0	0	
Level=8	1	1	1	
Level=9	0	0	0	
Level=10	0	0	0	
Level=11	2	1	1	
Level=12	11	13	13	

3. Conclusions

The experimental results showed that the virtual training had a significant time effect in the balance recovery of stroke patients, which is coherent with our previous studies [5]. With regards to the BBS and the BBA, the participants improved significantly between the initial and the final assessment. The improvement in the BBS is especially interesting since it is greater than the minimum detectable change established for chronicity ranging from 6 months to 17 years [11]. However, no significant differences were detected in the POMAb, even though a slight tendency towards significance was detected (p=0.08). Although these results must be taken into account considering the limitations of the study (non-controlled) and the characteristics of the final sample, the chronicity values support the potential benefits of the training even in chronic stages, similarly to recent evidence [12]. The skeleton tracking using a low-cost DS provided similar accuracy to other more expensive tracking systems and made the patients' interaction, and consequently their rehabilitation, possible. The therapists highlighted its easy and speed of use. Future studies will include usability questionnaires to deeply evaluate these aspects.

Acknowledgements

The authors wish to thank the staff and patients of the Hospital NISA Valencia al Mar, and José Antonio Gil for his early work. This study was funded in part by Ministerio de Educación y Ciencia Spain, Projects Consolider-C (SEJ2006-14301/PSIC), "CIBER of Physiopathology of Obesity and Nutrition, an initiative of ISCIII" and the Excellence Research Program PROMETEO (Generalitat Valenciana. Conselleria de Educación, 2008-157).

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