A Groundbreaking Technology in Virtual Rehabilitation to Improve Falls in Older People

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Abstract. Falls are a common alteration in older community dwellers and represent a serious problem for these dwellers. With a high incidence in this type of population and high medical costs to treat them, the traditional sessions need to enrich with low-cost alternatives. Virtual Rehabilitation is a novel research area that provides playful, motivating and customizable environments that are very useful for therapeutic sessions. The sit-to-stand movement is a typical exercise that can reduce fear of falls and lessen fall risks, for this, we have created a groundbreaking technologic system that follows the rules of this exercise. The Neuro Balance (NBAL) system is an accessible tool to support rehabilitation of older people with fall histories. In this study, we have tested NBAL with a user satisfaction questionnaire to analyze the acceptance of our tool. The results showed that NBAL is a satisfactory tool to be tested on neurological patients in a near future.

Keywords: Virtual Rehabilitation · Accessibility · Lower limb disorders Satisfaction · Human computer interaction

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1 Introduction

Falls are often produced by balance alterations in older people, with a high frequency for the elderly aged 80 years or more [1]. Approximately, 30 percent of older people suffer falls at least once a year [2] and this percentage can worsen as age increases, therefore, falls are a really serious problem in this population [3].

Incidence in this community fluctuates from 224 to 809 falls per person-year [4] in developed countries, with around 250,000 falls and 1000 fractures in UK in 2012 [5], and an incidence in Finland of 20.3 in men and 11.7 in women per 100,000 persons in 2011 [6].

Falls in older people may be produced by several causes. Rubenstein [7] indicated that falls are due to accident or environment-related, gait or balance disorders or weakness, dizziness or vertigo, drop attack, confusion, postural hypotension, visual disorder, syncope and other specified causes (arthritis, drugs, alcohol, among others). However, the causes of falls are multifactorial and in consequence, many researchers have carried out studies in order to identify risk factors that increase the likelihood of falling. In [7, 8] identified the following fall risk factors: weakness, balance deficit, gait deficit, visual deficit, mobility limitation, cognitive impairment, impaired functional status, postural hypotension, medication use, etc.

Community-dwelling older adults suffer serious injuries, such as: (1) wrist fractures are produced when people fall forward or backward and they support their body with their hand [9]; and (2) hip fractures are caused by muscle weakness or balance problems which increase the fall risks and incapacity to prevent the impact of a fall on people aged over 75 years-old [10]. Patients with neurological disorders are another group that suffers falls and balance impairments. People with these alterations show not only motor control but also cognitive impairment [11].

Many of the known neurological diseases involve disorders on the lower extremities. These diseases cause biomechanical alterations whose walking pattern becomes difficult on the daily activity of patients. Activities as walking, going up stairs or getting up from a chair can be a challenge for people with these neurological diseases. Some examples of these neurological diseases are Acquired Brain Injury (ABI) [12], Multiple Sclerosis [13], Parkinson’s disease [14] and Guillain-Barre syndrome [15].

Spasticity is a neurological symptom that characterizes these pathologies. Traditional techniques for motor rehabilitation of lower extremities include the use of bandages and orthoses in order to stretch on spasticity. The use of bandages is a technique characterized by prolonged stretching of the lower extremities, heating generation in the affected areas and prolonged pressure on the affected limbs. In [16], the authors performed a study on treatment using lower leg casting with saline injections or with botulinum toxin to measure the effect on the contracture of the calf muscles. Currently, botulinum toxin is useful in the treatment of spasticity [17].

Other traditional techniques to reduce fall risks are based on different intervention programs with a strong relationship between causes and factors of this impairment. These intervention programs are focused on multifactorial interventions, which cover the following areas enunciated by AGS Guidelines in [18]: (1) gait training programs; (2) assistive devices; (3) personalized medication; (4) balance and postural control training [19]; (5) environmental risk; and (6) customizable therapies centered on cardiovascular alterations.

Individualized gait training can be described as the ability to reeducate a patient to walk with lower-limb disorders. Thanks to this intensive intervention programs, older people reduce the percentage of falls per year [20]. Benefits to use assistive devices [21] with the main objective of the reduction of falls are produced due to the incorporation of specific equipment (canes, walkers, etc.) in the therapeutic sessions. Personalized medication in these subjects is focused on the use of psychotropic treatment along with the intervention period [22]. Static and dynamic balance training with specific designed programs reduce risks and fear of falls [23]. Modification of environmental hazards at home such as poor lighting, loose carpets, or bathroom safety can reduce the average of falls in older people [24]. Customizable therapies produced by cardiovascular alterations together with the use of pacemakers and new types of medication can improve this disorder [25]. These customizable therapies are quite expensive in the intervention and follow-up period for the hospitals because it is necessary to focus on the participants in specific motor control and cognitive trainings in the rehabilitation processes [26]. Therefore, it is recommended to look up other types of solutions for reducing direct and indirect costs by using novel low-cost technologies in these therapies.

2 Related Work

Classical motor rehabilitation consists of performing therapeutic exercises with the support of therapists for the recovery of motor, cognitive and/or emotional skills. These skills may have been reduced due to different causes such as a stroke, a surgical intervention in any limb or accidents that lead to injuries. In recent years, the use of devices capable of capturing weight transferences, postural control, body tracking or gestures in conjunction with classic video games or virtual immersion have been promoted for the realization of exercises in motor rehabilitation. In this sense, the repetitive exercises that a patient must execute are supported with a playful environment to improve motivation [27]. This technique of including games in non-recreational activities such as learning or motor rehabilitation is known as Virtual Rehabilitation (VR) [28]. Although VR does not replace the classic one, it is used as an experimental complement in the therapeutic sessions.

VR is being used for rehabilitation of older people with a known history of falls. In [29], the Balance Rehabilitation Unit (BRU) was evaluated on sixty community-dwelling older people from Australia and the results showed that people's balance was significantly improved which it supposes to prevent falls in the elderly. Also, in [30] Tai chi and Balance training with VR were compared in order to determine which of the two trainings has better effects in reducing fall and improve balance and functional mobility in elderly. Tai Chi had the best results; however, the sample size was small and new studies must be conducted on larger samples.

User Satisfaction Evaluation Questionnaire (USEQ) [31] is a questionnaire defined to evaluate usability or user satisfaction with VR systems. USEQ was applied to forty patients with balance disorders after their first session with a customizable VR system. The statistical study performed by the authors [31] identified the six items correlated with each other and suggests that the USEQ is a reliable questionnaire with an adequate internal consistency. Additionally, the patients considered that the USEQ is short, clear and concise.

The high evidence of using VR in this community to reduce the risks of falls per year encourage us to create a groundbreaking and customizable low-cost system with specific Virtual Environments (VE) thanks to the assistance of clinical specialists.

The purpose of our study is to test the satisfaction of the Neuro Balance Application (NBAL) in users without any neurological impairment.

3 Methods

3.1 Participants

The NBAL system was applied to 29 students without any neurological impairment. The participants' age ranged from 22 to 52 years. The student group was composed of six males and twenty-three females. The level of studies of these subjects is university studies. These participants accomplished our inclusion criteria, which are the following: (1) no experience using VR; (2) without traumatological injuries; (3) with a normal comprehension of the instructions of our novel system; (4) a good knowledge of psychological disorders in pathologies with neurological disorders; and (4) acceptance to participate in this experiment. Table 1 summarizes information related to participant's ages.

Table 1. Age summary of the Participants

Gender	μ	Max	Min	σ
Male	32.66	52	22	13.23
Female	23.82	27	22	1.72

3.2 NBAL Description

The NBAL system requires a laptop with Bluetooth support, a projector and two Wii Balance Boards (WBBs). WBBs are an accessory for the Nintendo Wii© used to capture the user's weight transferences and balance; earlier studies suggest that the WBB is a valid and low-cost alternative to professional force-platforms for assessment of standing balance [32]. NBAL does not require additional peripherals or wearables needed to interact with it.

Two WBBs are connected via Bluetooth with a laptop running a program to gather and filter the signals coming from the four force sensors in each platform. This program sends these data through a socket to an application built with Unity game engine. Using the Bluetooth communications instead of connecting the WBB via USB reduces the risks of patient's injuries.

The NBAL system stores users weight thanks to eight sensors of WBBs, this information is obtained at a low level by reading the data of the records of the processing unit of each WBB. This information is obtained in calibration phase in each session to analyze kinetic data such as: (1) vertical, antero-posterior and medio-lateral of ground reaction force (GRF); and (2) center of pressure (CP).

NBAL interfaces consist of a calibration module where the patients or participants must stand on the left WBB, and then they must stand with each foot over each platform matching foot templates placed on them. It is noteworthy that, at first, users are requested to place both feet in the left WBB so the NBAL can accurately detect user´s weight and also determine which the left and right WBBs are. To gather required data for the calibration module, it is necessary that the participants imitate the avatar shown on screen doing the sit-to-stand transition. The main scene of NBAL includes an avatar, a user-controllable object and a throwable object that moves from right to left. To illustrate the EV, suppose toothpaste as the user-controllable object which is composed of two pieces, the tube and the gel. Each of these pieces is controlled by the user's weight exerted by each leg on each platform. Thus, if a user inclines to the right, the toothpaste tube will be lower than the gel, and if the user slopes to the left, the opposite will occur. Additionally, the throwable object that moves from right to left is a toothbrush. Thus, the game goal is that the user keeps both pieces of the toothpaste fitting together when the toothbrush approaches to them. If the toothbrush comes into contact with the toothpaste and the toothpaste pieces are relatively close to each other (they are coupled), then it will be a successful catch. However, if the toothbrush arrives and the pieces are too far from being coupled it will be taken as a mistake. Finally, if the toothbrush does not reach the toothpaste then it is a miss.

3.3 Procedure

The experiment was performed during a Psychology Master´s class corresponding to the basics principles of human behavior found in the VR. The researchers explained to the participants the actions they had to do on each of the stages required to complete a full rehabilitation session. The first stage consisted of standing on the left platform with both feet. The second stage required the participant to put his/her left feet on the template placed on the left WBB while doing the same action simultaneously with his/her right feet and right WBB. In the third stage, the participant was inquired to sit-to-stand as shown as the avatar on the VE. With these three stages which lasted 3 s each, calibration was completed capturing the pressure exerted by the participants over the platforms. The calibration is extremely important because it makes possible customize the therapeutic sessions and thus, the clinical experts will be able to evaluate patients' improvements over time for validations with this type of pathologies.

Then, one of the researches picked all the objects that will be part of session's VE. Finally, the participants imitated the avatar on sitting and standing to try to catch the throwable object while trying to keep the two controllable objects fitting together; this exercise was performed for a period of one minute. The experiment lasted 30 min approximately. Figure 1 shows a participant interacting with NBAL system. Once concluded the experiment, the participants filled USEQ questionnaire to measure user satisfaction when interacting with NBAL.

Later, the students were gathered in groups of 3 to 4 participants in order to propose enrichments of the NBAL system. Among the recommendations made, one of the groups suggested that, using a first-person perspective in the VE could be more natural

Fig. 1. A participant testing the NBAL system

for the patients. Also, using color feedbacks to indicate to the patient how good they were performing training exercises. Before starting a rehabilitation session, another group recommended including a previous training, where the patients could be able to interact freely with NBAL. Additionally, the evolution of patients should be represented as a big picture, showing where they started, where they are and where they will be to reach the final goal in terms of reducing fall risks.

On the other hand, training patients to do the sit-to-stand exercise too fast can lead them to frustration, and could be prevented by taking in count their limits. Another recommendation for the NBAL improvement is to auto-adjust the maximum difficulty patients could handle, challenging them to improve themselves while keeping them away from frustration.

4 Results

A user satisfaction test was conducted with our study group of participants. The evaluation was made in a classroom using the USEQ questionnaire.

4.1 Outcomes

USEQ questionnaire consists of the following items: Q1. Did you enjoy your experience with the system?; Q2. Were you successful using the system?; Q3. Were you able to control the system?; Q4. Is the information provided by the system clear?; Q5. Did you feel discomfort during your experience with the system?; Q6. Do you think that this system will be helpful for your rehabilitation?

Figure 2 shows a set of boxplots for each question of USEQ. The *x* axis represents the number of question and the *y* axis corresponds to the score value from (1-Not all) to (5-All-Very much). The median in the question Q1 was 4 out of 5. With respect to Q2, the capacity of the participants to use the NBAL system successfully has a median of four. Users have different opinions regarding the clarity of NBAL instructions in the question Q4, with a median of 3. At least half of the participants answered with a median of 1 in the question Q5 related to discomfort. Finally, a median of 4 for the question Q5 was obtained in terms of helpfulness of the NBAL system.

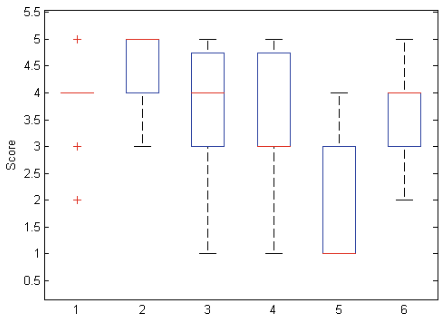

Fig. 2. USEQ participant responses

Figure 3. illustrates the total score of USEQ questionnaire with a median of 24 out of 30. The total score of USEQ is computed as the sum of each answer except Q5 where it is added as 6 minus its value.

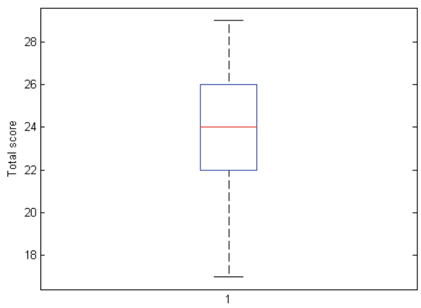

Fig. 3. USEQ total score

Table 2 summarizes the Cronbach's Alpha outcomes. The Cronbach's alpha value for the complete scale was 0.684. Cronbach's alpha was calculated for all six items of USEQ.

Table 2. Score on questions of the USEQ. Corrected item-total correlation [31]. Cronbach's alpha if item is deleted.

	Mean	Std. dev	Scale mean if item deleted	Scale variance if item deleted	Corrected item-total correlation	Cronbach's alpha if item deleted
Q1	3.96	0.73	19.92	9.660	0.158	0.714
Q2	4.58	0.62	19.32	9.310	0.383	0.660
Q3	3.82	0.96	19.92	8.660	0.347	0.664
Q4	3.55	1.05	20.36	7.657	0.389	0.656
Q5	2.00	1.25	19.84	6.057	0.637	0.548
Q6	3.79	0.86	20.24	7.357	0.629	0.570
Total	23.72	3.17				

5 Discussion and Conclusions

We validated a groundbreaking technological system focused on the improvements of fall risks. In our study, we tested the acceptance of the NBAL system by using USEQ. The outcomes produced by USEQ reveals that most of participants enjoyed the interaction with the NBAL system because they rated it with 4 out of 5 according to the question Q1. We think that this result is due to NBAL follows a traditional exercise in the rehabilitation process, the sit-to-stand exercise is suitable for the balance training in order to prevent falls. With respect to success by using NBAL, the participants showed a high score. This outcome indicates that our system was satisfactory because our tool accomplishes the requirements of the sit-to-stand movement. The instructions were simple to follow during the session, for this reason, the outcome of the question Q3 shows a good score. In relation to the question Q4, we can point out that NBAL presents specific visual cues which are focused on textual stimuli produced by NBAL such that the participants can follow the correct movements. We also found that at least half of the participants did not feel any discomfort by using our system because our tool is not invasive and it is possible to customize each session for each participant. Finally, the participants answered that the system can be helpful for the rehabilitation process since our system is based on the sit-to-stand exercise with a playful and motivating manner.

Regarding to the Cronbach's alpha, we can see that the value is inside the marginal limits of acceptance according to Bangor et al. [33]. This result indicates that our system can be tested for patients with neurological disorders.

In a near future, we consider to design a study with older people that have incidents of falls (control group) and ones without fall histories (experimental group). For this, we will validate our system analyzing specific parameters such as: (1) the Berg Balance Scale [34]; (2) the 30 s sit-to-stand test [35]; (3) the Tinneti test [36]; (4) kinetic data such as GRF and COP; and (5) a length of session based on scientific literature.

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