A Virtual Reality Game-like Tool for Assessing the Risk of Falling in the Elderly

Jaime A. GARCIA
UTS Games Studio, University of Technology Sydney UTS, Faculty of Engineering and IT, Sydney, Australia. Email: Jaime.Garcia@uts.edu.au

Abstract. In recent years, the use of interactive game technology has gained much interest in the research community as a means to measure indicators associated with the risk of falling in the elderly. Input devices used for gaming offer an inexpensive but yet reliable alternative to the costly apparatuses used in clinics and medical centers. In this paper, we explore the feasibility of using virtual reality technology as a tool to assess the risk of falling in the senior community in a more immersive, intuitive and descriptive manner. Our VR-based tool captures stepping performance parameters in order to fulfill the requirements of a well-established clinical test for fall risk assessment. The use of virtual reality allows for an immersive experience where elderly users can fully concentrate on the motor and cognitive functions being assessed rather than the technology being used.

Keywords. Serious Games, Games for Health, Accidental Falls, Balance, Fall Prevention, Fall Risk Assessment, Elderly, Virtual Reality, Clinical Testing.

Introduction

With age, the likelihood of falling increases significantly. This is a rather critical problem in the senior community affecting 1 in 3 people every year. Falls can lead to traumatic brain injuries, fractures or even death [1]. Detriments in the mental and physical health can lead to poor balance, loss of muscle mass and strength, slow reflexes, among others. All these major causalities of falling. Clinical assessments consisting of time-based stepping systems have been effectively used in the past as a tool to discriminate between fallers and non-fallers [2]. However, to accurately determine those at risk of falling, assessments require specialized equipment, high levels of precision and the proper administration by a health professional. This makes it costly and difficult to access to seniors who need to be regularly assessed.

A novel approach to counterbalance this issue is the use of interactive gaming technology. Devices such as the Microsoft Kinect, the Leap Motion, the Nintendo Wii Balance Board, among others, allow for the tracking for full body movements in a relatively accurate and inexpensive manner. These attributes make such devices ideal in a clinical setting as they can be used as a means to collect clinical measurements relevant to the problem of falling in the elderly.

In a prior study [3], the authors explored the use of a Kinect-based system to deliver stepping exercises and simultaneously collect stepping performance data. While this study was crucial in determining the potential of using video game technology as a tool to assess the risk of falling in the elderly, it also pointed out that accurate data collection requires fully immersive and reliable tools in order to reduce systematic errors and allow patients to fully concentrate on performing the test.

The work presented in this paper expands on this concept and builds on the immersive nature of Virtual Reality technology in order to offer a more descriptive, meaningful and focusable fall risk assessment tool.

The next section presents a brief summary of related work in the space of gaming technology used to assess the risk of falling in the elderly. In Section 2, the methodology of this study is presented. Section 3 describes the design process and the aspects considered for both clinical assessment and suitability for elder users. Finally, the discussion and conclusions can be found in Section 4.

1. Related Work

In the past decade, the use of gaming technology has gained much interest in the research community as a cost-effective alternative to assess motor and physical functions in the elderly. For example, in the field of falls prevention, systems ranging from mobile apps, Kinect-based games, Wii balance board systems, to name a few, have been used to reproduce well-established tests that assess fall risk factors.

For instance, in the work done by Clark et al. [4], the skeletal tracking capabilities of the Microsoft Kinect are used to collect parameters for the Gait Speed test. The gait test has been shown to be a great descriptor of fall risk in the aged. In this test, individuals are instructed to walk a set distance of 10 meters [5]. Spatiotemporal variables such as step length, foot swing velocity, peak and mean gait speed, and the percentage difference between the peak and mean gait speed are assessed. Collection of data starts once the participant passes the 2 meters mark, and stops at the 8 meters mark. This is to allow for enough space to accelerate to a comfortable walking speed, then decelerate to a full stop. Results showed that Kinect-derived variables were found to be highly reliable, however, many were redundant. The Kinect model showed 15% more variance than the traditional method, which suggests that the Kinect might have introduced a systematic error to the test. This could have been due to the limitation of the Kinect to only be able to track an individual within a 1.5 – 2.5-meter perimeter or the limited framerate of 30hz that the Kinect's infrared sensor imposes.

Similarly, in the work done be Ejupi et al. [6], the Kinect was used to automate the five-times-sit-to-stand (5STS) test to assess leg strength and endurance. This test is based on the premise that a person requires at least two of the three following senses to maintain balance while standing: proprioception, vestibular function, and vision [7]. In this test, individuals are required to stand up and sit down five times without the use of any assistance nor breaks. Time to complete this task is taken and used for diagnosis. In this Kinect-based version, an algorithm was developed to automatically calculate timing and speed-related measurements. Results show that the Kinect-based measures correlated strongly with those collected in a supervised manner. Although this system tackles an important risk factor for falling in the elderly, this approach lacks the immersive factor that engages users limiting their ability to fully concentrate. It is worth mentioning that small distractions in the room can significantly affect the performance of a patient, affecting the reliability of the test.

In the work done by Lubetzky et al [8], the Oculus Rift was used to assess dynamic balance and head mobility through the use of a virtual scenario. In this game-like system, users are fully immersed in a simulated park where balls are thrown at their heads. They must avoid these balls by moving their heads sideways. This is to engage their vestibular system to be able to assess dynamic balance and quantify head movement. Results show trends in measuring head paths, head accelerations, and peak frequencies. While this system was effective in offering a fully immersive experience allowing patients to concentrate and reach a flow-state, this system does not fully exploit the capabilities of VR technology to effectively collect more descriptive parameters associated with the risk of falling in the elderly.

The work presented in this paper utilises the HTC Vive, a virtual reality headset that is capable of capturing body movements in space in a more reliable and immersive manner. These features make this system potentially useful in a clinical setting as it allows for: (1) higher levels of immersion allowing older people to fully concentrate on the activity they are performing, (2) the collection of tempo-spatial parameters that could not be tracked in traditional clinical tests, and (3) the collection of high-precision clinical data in an inexpensive manner.

2. Methodology

In order to gather the requirements for the development of this system, a literature review was conducted on the following topics: (1) proven strategies to assess the risk of falling in the aged cohort; (2) game technologies used to collect motor and cognitive parameters in older people; and (3) game-design guidelines for enjoyable experiences in virtual reality for elderly users. Based on this review, the following system requirements were set out:

1. The system should collect clinical parameters that allow for the fulfillment of a highly-descriptive clinical test to assess the risk of falling in the elderly. Tasks should be meaningful and have a direct alignment to specific descriptors associated with this problem [9]. While there are several clinical tests that assess different factors such as with balance, muscle strength, endurance, among others, this tool should be descriptive enough to allow for a reliable diagnosis of the risk of falling.
2. The system should use state-of-the-art interactive game technology that allows for the collection of tempo-spatial parameters related to the problem of falling in the elderly in a reliable, intuitive and inexpensive manner. The ultimate goal of this research is to explore the feasibility of using game technology as a reliable alternative to the costly apparatuses used in clinics and health centers.
3. The system needs to be fully immersive to eliminate distractions and allow the user to fully concentrate on the motor / cognitive function being assessed [10]. This has been a major factor affecting the collection of reliable data in the past. Users often get distracted, affecting their performance while undertaking these tests. Also, there needs to be a direct connection between the actions being performed and user feedback to avoid the risk of injuries or feelings of frustration [9].

Below, we map the main design elements that were considered based on the system requirements that raised from the academic literature and previous studies.

The Choice Stepping Reaction Time task (CSRT) was selected as prior studies showed that this test it is feasible to measure with inexpensive game input devices and is also suitable for translation into a videogame [11, 12]. More importantly, large prospective cohort studies with falls follow-up have proven the ability of this test to (1) discriminate between fallers and non-fallers and (2) predict falls in the aged cohort [12].

This test requires users to complete a simple stepping task driven by a computer software. Reaction time is measured and used for diagnosis (Requirement 1) [1]. The HTC Vive was selected as the main input device as it facilitates the delivery of fully immersive contents and a natural interaction (Requirement 2 and 3). This is ideal for elderly users with minimal computer literacy, allowing them to focus on the tasks rather than the technology. The following section fully describes the mechanics of our VR-based tool for all risk assessment and the main design considerations.

3. The Virtual Reality Fall Risk Assessment Tool

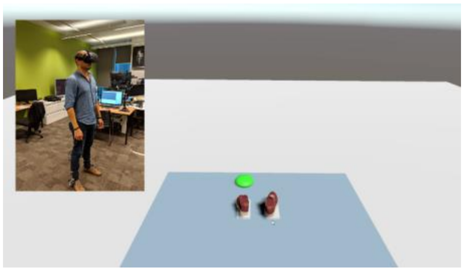

Figure 1. Stepping stimulus being presented to the user.

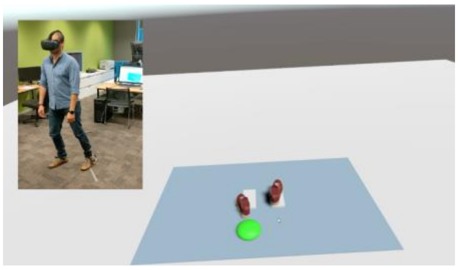

Figure 2. User reacting to stepping stimulus.

In order to interact with our tool, users must wear the HTC Vive head-mounted headset. A virtual scenario resembling an empty room is then presented. This room consists of an exercise area (demarked by a light blue square) with two small white rectangles indicating the starting position of the test. Users can walk freely in this room. To eliminate any distractions, light colours and a simplistic level design were chosen. Two red shoes mirroring the movements of the user's feet are also presented. This helps the user to concentrate on the stepping task and allows them to have a sense of presence in the virtual environment. HTC Vive controllers are attached to the user's lower limbs using a set of elastic bands. This is to allow for the tracking of the foot movements and the animation of the virtual shoes in an unobtrusive manner. The field of view is slighted shifted in a way that the user can see themselves from behind. Previous studies have indicated that this view-mode could offer a more comfortable and immersive experiences [13].

Test mechanics resemble the original CSRT task [2]. Stepping stimuli are presented in the virtual system in the form of a green ellipsoid (or pellet) (See Figure 1). Users are expected to react to this by taking a quick reactive step towards the pellet with the leg that is closest to the stimulus (see Figure 2). As soon as the virtual shoe collides with the pellet, the latter disappears from the screen. Users must then return to the initial position as quickly as possible. Once this is completed, the process starts over in a randomized order and location (front-left, front-right, back-left, back-right, left or right). This is to prevent users from memorizing stepping patterns and instead forcing them to react to the stepping stimuli. The mean reaction time of 36 trials as well as the validation of the correct response is automatically measured by the system and used for the assessment of the risk of falling. This feature is important as one of the main limitations of the original test is that therapists must perform this validation through observation.

At the beginning of the test, therapists are presented with a set of options to adjust the test parameters. This is to allow them to control the cognitive load and physical demand of the test in order to assess users under different conditions. (See Table 1)

Table 1. Current customisable test parameters.

Parameter	Rationale
Number of Stepping Locations	This allows the therapist to select from a 4-location layout (left, front-left, front-right, right) or a 6-location layout for the pellets to randomly appear (left, front-left, front-right, right, back-left, back-right). The original CSRT test uses 4 stepping panels [2]. A newer implementation uses 6 [12]. 6 is our default value.
Number of Steps (per Location)	This is to set the number of repetitions per location. The default value is 6. This is to allow for the collection of 36 stepping events for the diagnosis of fall risk.
Step Length (cm)	This is to adjust the size of the steps that users must take during the test. That is the main limitation in the original test, as the stepping stimuli are located in fixed positions. This allows therapists to explore different spatial configurations by increasing or decreasing the size of the steps [3]. The default value is 40cm.
Time Between Stimuli (ms)	This allows the therapist to set the time users will wait after reacting to a stepping stimulus. This can be used to set the pace of the test. The default value is 2000ms.
View (puppet, top-down, first person)	In order to allow for higher levels of immersion we have included 3 camera views. In the first-person view, the location of the virtual shoes matches the location of the user's feet, hence the user must look down to be able to react to the stepping stimuli. In the top-down view, stepping stimuli are presented as if the user was taking steps on a wall in front of them. While this is at first confusing, studies have shown that participants often find this view-mode very intuitive [13]. In the puppet view, users can see themselves in the virtual world as if they were standing behind themselves. The latter is the default value.
Use of Inhibition (on/off)	This is to increase the cognitive load of the stepping test by forcing participants to inhibit some of their responses. When enabled, red pellets will appear on the screen from time to time. Users must avoid stepping on them. This Go/NoGo paradigm has been successful in discriminating between fallers and non-fallers, as fallers often report longer reaction times [12]. The default value is "off".
Percentage of Inhibition (%)	This setting is used to determine the frequency in which the red pellets will appear. The default value is 25%.
Use of flashing (on/off)	This allows for a more cognitively demanding test, where the green pellets only appear for a split second on the screen. Users are still required to react to this stimulus as if the pellet was still present. This has also been useful in discriminating between fallers and non-fallers. The default value is "off".
Flashing time (ms)	This is used to set the time users will see the pellets on the screen. The default value is 200ms. (Only works when Flashing is enabled).
Wait for users(on/off)	This parameter allows the therapist to set whether the system will wait for the user to respond or it will present a new stepping stimulus after a short period of time. The default value is "off". (Only works when Flashing is enabled).
Wait time (ms)	If Wait for users is enabled. This will set the time the system will wait for the user to respond before spawning a new pellet. The default is 2000ms.

4. Conclusion and Future Work

This paper explores the feasibility of using Virtual Reality (VR) game technology as an alternative to reliably assess the risk of falling in the elderly. The game-like tool builds on the HTC Vive VR headset to deliver fully immersive stepping stimuli and collect indicators of fall risk in an intuitive, inexpensive and reliable manner. This implementation enhances the delivery of the Choice Step Reaction Time test as it allows subjects to fully immerse in the stepping exercises by removing any distractions that could affect their performance.

More importantly, a set of tempo-spatial parameters that could not be obtained in the traditional form of the test have been identified, making this tool potentially useful in the clinical setting. While Virtual Reality technology allows for a fully immersive experience, there are also some limitations and challenges that still need to be addressed. While the HTC Vive controllers offer higher levels of precision in tracking user movements and collection of spatial-temporal data, there is also a limitation in the number of trackers that can be used concurrently. Being able to track only 4 points at the time, makes it difficult for game designers to provide full-body avatars that allow participants to have more sense of presence in the virtual world. This can potentially avoid participants from having feelings of confusion, frustration or even motion sickness.

For the purpose of this lower-limb based stepping test, this technology suffices the requirements of the chosen clinical test.

The next stage of this study will involve the clinical validation of time-based and spatial-based parameters obtained with this tool, followed by the conduction of controlled trials to determine the discriminative validity of our prototype.

References

[1] Stuck, A.E., J.M. Walthert, T. Nikolaus, C.J. Büla, C. Hohmann, and J.C. Beck, *Risk factors for functional status decline in community-living elderly people: a systematic literature review.* Social Science & Medicine, 1999. 48(4): p. 445-469.

[2] Lord, S.R. and R.C. Fitzpatrick, *Choice Stepping Reaction Time: A Composite Measure of Falls Risk in Older People.* Journals of Gerontology Series A: Biological Sciences & Medical Sciences, 2001. 56A(10): p. M627.

[3] Garcia, J.A., Schoene, D., Lord, S.R., Delbaere, K., Valenzuela, T. and Navarro, K.F., 2016. A bespoke kinect stepping exergame for improving physical and cognitive function in older people: a pilot study. *Games for health journal*, *5*(6), pp.382-388.

[4] Clark, R.A., Vernon, S., Mentiplay, B.F., Miller, K.J., McGinley, J.L., Pua, Y.H., Paterson, K. and Bower, K.J., 2015. Instrumenting gait assessment using the Kinect in people living with stroke: reliability and association with balance tests. *Journal of neuroengineering and rehabilitation*, *12*(1), p.15.

[5] Maki, B.E., 1997. Gait changes in older adults: predictors of falls or indicators of fear?. Journal of the American geriatrics society, 45(3), pp.313-320.

[6] Ejupi A, Brodie M, Gschwind YJ, Lord SR, Zagler WL, Delbaere K. Kinect-based five-times-sit-to-stand test for clinical and in-home assessment of fall risk in older people. Gerontology. 2016;62(1):118-24.

[7] Tiedemann, A., Shimada, H., Sherrington, C., Murray, S. and Lord, S., 2008. The comparative ability of eight functional mobility tests for predicting falls in community-dwelling older people. *Age and ageing*, *37*(4), pp.430-435.

[8] Lubetzky AV, Hujsak BD, Fu G, Perlin K. An Oculus Rift Assessment of Dynamic Balance by Head Mobility in a Virtual Park Scene: A Pilot Study. Motor control. 2019 Jan 1;23(1):127-42.

[9] Garcia Marin, J., E. Lawrence, K. Felix Navarro, and C. Sax, Heuristic Evaluation for Interactive Games within Elderly Users, in Conference on eHealth, Telemedicine, and Social Medicine (eTELEMED 2011). 2011: Gosier, Guadeloupe, France. p. 130-133.

[10] Bruun-Pedersen, J.R., Serafin, S. and Kofoed, L.B., 2015, October. Simulating nature for elderly users- A design approach for recreational virtual environments. In 2015 IEEE International Conference on Computer and Information Technology; Ubiquitous Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing (pp. 1566-1571). IEEE.

[11] Garcia, J.A., Pisan, Y., Tan, C.T. and Navarro, K.F., 2014, October. Assessing the Kinect's capabilities to perform a time-based clinical test for fall risk assessment in older people. In International conference on entertainment computing (pp. 100-107). Springer, Berlin, Heidelberg.

[12] Schoene, D., S.R. Lord, P. Verhoef, and S.T. Smith, *A Novel Video Game–Based Device for Measuring Stepping Performance and Fall Risk in Older People.* Archives of physical medicine and rehabilitation, 2011. 92(6): p. 947-953.

[13] Raffe, W.L. and Garcia, J.A., 2018, May. Combining skeletal tracking and virtual reality for game-based fall prevention training for the elderly. In *2018 IEEE 6th International Conference on Serious Games and Applications for Health (SeGAH)* (pp. 1-7). IEEE.