Exergames for the elderly: Towards an embedded Kinect-based clinical test of falls risk

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Abstract. Falls are the leading cause of disability, injuries or even death among older adults. Exercise programmes that include a balance component reduce the risk of falling by 40\%. However, such interventions are often perceived as boring and drop-out rates are high. The characteristics of videogames may overcome this weakness and increase exercise adherence. The use of modern input devices, such as the Microsoft Kinect, enables quantification of player performance in terms of motor function while engaging with games. This capability has just started to be explored. The work presented in this paper focuses on the development of a Kinect-based system to deliver step training while simultaneously measuring parameters of stepping performance that have shown to predict falls in older people.

Keywords. Serious games, games for health, accidental falls, balance, fall prevention, step training, aged, Kinect, clinical testing.

Introduction

With increasing age there is a progressive decline in physical function in older people leading to problems such as postural instability and falls [1]. Falls are associated with increased mortality, disability, fractures, fear of falling, to name a few [2]. Stepping is often the last resort in order to avoid a fall. This is defined as changing the centre of mass in relation to the base of support. By taking a proactive or reactive step an individual increases his base of support and regains balance. Physical exercise has been shown to be the most effective intervention to improve balance, stepping behaviour and reduce fall risk on older people [3]. However, compliance to exercise interventions has been reported as poor, partly due to the mode of delivery. These programmes are often perceived as boring and not motivating [4]. The use of video games in physical training (exergames) has shown a positive impact on delivering exercise programs with higher levels of enjoyment and motivation for the elderly [5]. Moreover, the use of modern input devices could allow the determination of a person’s physical performance. Yet, some problems are inherent to the use of video games due to the limitation of available commercial video games which have not been designed for the purpose of providing therapeutic support for the aged cohort [6, 7]. The potential of using this video game technology to accurately perform clinical testing as a tool to assess the effectiveness of
an intervention has just started to being explored [8]. In this paper we describe the development of a hybrid clinical test embedded into game-based stepping exercises using the Microsoft Kinect. This system delivers individually adaptable stepping exercises for older adults and simultaneously measures step performance. The remainder of the paper is structured as follows. Section 1 presents a brief summary of related work in the field of games for lower-limb exercises to serve seniors. 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

Modern input devices, such as the Nintendo Wii Balance Board, Nintendo Wii Motes, and Webcams among others, are now commonly used to enable older adults without much or any computer experience to interact with games as well as to evaluate user performance. For instance, Doyle et al [9] utilised a series of motion trackers and a webcam to deliver balance and strength exercises. The aim of this work was to improve the motor function of the lower limbs, which is essential to avoid falls. In this project, five exercises from the Otago Exercise Programme [10] were delivered and the user performance was remotely monitored by the instructor. This feature allowed the instructor to validate the correct completion of each exercise despite being remotely located from the participant. In the work done by Gerling et al [11], the Nintendo Wii balance board was used for balance training. The game consisted of obstacle avoidance by weight shifting. In this game, the needs and capabilities of the elderly players were taken into consideration resulting in a game with a simplistic interface and adaptive difficulty. One of the problems with this approach is that the use of the Wii balance board still imposes an obstacle on the degree of freedom to be able to perform a wider range of balance exercises suitable for the elderly. In addition to this, the board potentially exposes the older person to an increased risk of falling. To counter the fall risk inherent in a raised platform, Smith et al [12] used a flat dance pad paired with a modified version of the game Dance Dance Revolution. Its main purpose was to provide a tool to exercise the stepping abilities of older adults. Unlike the commercial game, this version has been adapted to a range of stepping speeds including slow responses. More importantly, this work has shown that a custom-made dance pad can be used as a measurement tool to obtain valid step data that discriminate between the groups of recurrent fallers and non-fallers [13].

The work presented in this paper utilises one of the most recent camera-based input devices, the Microsoft Kinect for the Xbox 360 game console. This input device is capable of capturing depth and video without the need of using a game controller or using additional wearable sensors to operate. This feature makes the Kinect ideal for older people not only because they can focus on the exercise rather than the technology, but also because freeing their hands lowers the risk of falling by enabling them to grasp onto something or to lower the impact with the arms in case of a fall.

Furthermore, the proposed system incorporates mechanisms that can resemble clinical tests of motor and cognitive skills for the elderly. This is accomplished by processing relatively accurate information of the positioning of the user’s body in real-time captured with the Kinect. A full body avatar that mirrors the user movements is also displayed as part of user feedback.
The following section sets out the methodology used for conceiving this system and the most relevant aspects that were considered through the design process.

2. Methodology

In order to develop an understanding of the requirements for clinical testing with the Kinect, the technology was explored in order to assess its capabilities and limitations. The resulting criteria was determined according to the following technical aspects: (1) for skeletal recognition the objects should stand between 1.2m and 3.5m depth from the sensor; (2) the built-in skeleton tracking feature in the Kinect could be affected by the presence of objects such as support frames or chairs.

A literature review on existing performance-based tests for predicting falls risk in older people was conducted. The review was aligned to the technical specifications with the purpose of identifying a viable key set of parameters that could be measured.

A number of tests that could be performed without utilising expensive equipment were found; however, most of them were not suitable to be used with the Kinect. Table 1 gives an overview of the identified tests and the reasons for non-selection.

<table>
<thead>
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<th>Tests</th>
<th>Reason to Discard</th>
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<td>Dynamic Gait Index (DGI), Functional Gait Assessment (FGA), Time Up &amp; Go (TUG)</td>
<td>Require distance that Kinect is not able to cover, measures of speed and gait would not be accurate</td>
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<tr>
<td>Berg Balance Scale (BBS), Romberg Test, Clinical Test of Sensory Interaction and Balance (CTSIB), Backwards Release, L/E Chair Stand Test, U/E Arm Curl Test, Multi-Directional Reach Test (MDRT)</td>
<td>Require assistance of physiotherapist or use of support frames. Problematic as Kinect could misunderstand the presence of two people or a supporting frame affecting measurement</td>
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The researchers found the Choice Stepping Reaction Time task (CSRT) [14] feasible to measure the required parameters with the Kinect and suitable for translation into a videogame. More importantly, this test has been validated in more detail in older populations including large prospective cohort studies with falls follow-up [15]. The CSRT task is a composite measure of sensorimotor functions, such as balance and strength, as well as cognitive functions such as attention and central processing speed. It is through these composite metrics that the test is able to combine several dimensions of falls risk. In its original version the CSRT involves the person standing on the two central step panels of a wooden board. One of four surrounding panels (front left, front right, left, right) lights up randomly and the person has to step on this panel as quickly as possible and then return to the centre. The mean reaction time of 20 trials is measured [14]. Recently this test has been designed for a dance pad exergame device and findings indicate that it is valid to determine falls risk in community-dwelling older people [13].

3. Designing the Game

The description of the Kinect-based system is described as follows: the user stands in front of the computer screen/TV and shortly after the system projects an avatar mirroring the person’s movements. A circle with either 6 or 10 symmetrically
distributed sectors is then drawn on the screen surrounding the player’s avatar (Figures 1 & 2). This circle would follow the avatar as long as the user moves. Once the colour of one sector changes to green on the screen the subject is expected to step on it in space and back to the centre as quickly as possible.

As soon as the player returns to the initial position the process starts over. The sequence is selected randomly as well as the time between trials so that the user is unable to anticipate the time and location of the next changing colour sector. The distance between the player and the sectors is determined by the user’s height measured by the Kinect. This feature is important as the adaptation of the test to the user dimensions is significant in terms of step length and fall risk. Thus, the new Kinect-based test of CSRT eliminates this limitation of the original CSRT task.

In addition to this, a ‘Go/No Go’ task was incorporated. For this task 25% of trials come up in a red colour signalling the user to remain centred without stepping. The remaining 75% of trials are conducted as described above.

The system also provides different camera views from various angles for the user. One view shows the user and sectors from above (Figure 1), a second one shows the user from the back and a third from the front. Each of these views result on a different cognitive load for the user when performing the task, thus it can be utilised for testing under diverse cognitive conditions.

It is relevant to mention that the initial version of this system is intended to be used in a lab environment and be operated by a clinician or researcher for the setup of the initial parameters. The parameters to be selected and tuned by the therapist are the following: the radius of the circle (step length in percent of body height), the activity to perform (‘Go’, ‘Go/No Go’), the number of steps to execute per sector and the visual perspective (camera view) the user has onto the game.

Based on the requirements of the CSRT test, the following measurements were incorporated to the Kinect-based system:

- **Decision time (ms):** Time elapsed between the sector turning green and one of the legs initiating a movement.
- **Movement time (ms):** Time elapsed between the leg initiating a movement and the foot touching the green coloured sector.
- **Response time (ms):** Decision Time + Movement Time
- **Validation of ‘Go / No Go’ Activity:** A ‘Go/No Go’ activity is successful when the user meets the ‘Go’ condition (green) and inhibits his/her response during ‘No Go’ trials (red).

Advanced technical features of the Kinect allowed for the incorporation of the following measures as a complement to the original parameters:

- **Validation of Expected Direction vs. Observed direction:** As each sector is strategically located surrounding the player in all directions (front-left, front-right, left, right, back-left & back-right), the user is expected to touch them accordingly.
- **Step Length:** Distance between the leg that stays in the centre of the circle and the leg that touches the green coloured sector.

Following a review of guidelines for building entertainment systems for older adults and previous research with older people, the following aspects were considered throughout the design process:
Table 2. Age-appropriate features, adapted from Flores et al. and Garcia Marin et al. [8, 16]

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<th>Dimension</th>
<th>Implemented Feature</th>
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| **Cognition:** While attention and executive functions are risk factors for falls. Ongoing high levels of attention, memorisation and learning, could cause difficulties when playing, leading to stop activity [7, 11, 17] | Selective attention and response inhibition is assessed by the 'Go/No Go' task  
Number of stimuli: The number of stimuli per trial was restricted to one. |
| **Feedback:** Provide accurate feedback for motivation of player [5, 16]       | Game Views: the feature to select between three different camera views of the user onto the game is provided (Figure 1 & 2) as well as a score after finishing. |
| **Challenge vs. Player Skills:** Providing the appropriate challenge to allow the player to perform activities according to their capabilities [5, 7, 16] | Radius of the circle: This is defined as the distance between the user foot when located at the initial point and the sectors surrounding him/her. The larger the radius the more challenging it is for the user to make an appropriate step. For the game, this value ranges from 10-50% of the body height to enable frailer and fitter individuals to play.  
Between-Trials time: This is defined as the time that the user waits after touching the target sector and a new sector appears. This is randomly selected between 1.5s and 2.5s. |
| **Control:** Establish appropriate relations between movements and display. The elderly player could erroneous learn and adapt movements in real life[18] | Use of full body avatar: in the game, the user is represented by an avatar that mirrors the user movements and the tasks the user is instructed to perform are totally aligned to what the user sees on the screen. |

A comparative review of the available gaming technology was carried out in order to select a suitable developing platform to implement the system. The Microsoft XNA Platform and the Kinect Software Development Kit (SDK) were chosen for the following two reasons: (1) Skeleton tracking and the process of gathering information of joint points are more accurate than the current open source alternatives. (2) The Wider deployment of the game for the XBOX 360 platform for trial purposes, making the prototype exposed and available to a larger audience.

**Figure 1.** Top view with 10 sectors & radius=40%.  
**Figure 2.** Front view with 6 sectors & radius=50%.

4. Conclusion and Future Work

This paper describes a system that uses the Microsoft Kinect depth and motion capture technology to deliver step training to older adults. The game-based system builds on Kinect’s advanced features to allow continuous real time skeletal tracking and feedback. This implementation enhances the user interaction as no game controllers or wearable sensors are required for operation allowing older users with no computer use...
experience to play. More importantly, a set of parameters that can be obtained with the Kinect in order to fulfill the requirements to simultaneously measure clinical data has been identified, making this game potentially useful in clinical practice. The initial version of this game is intended to be operated in a clinical environment in the presence of a therapist. In future versions the system design is thought to assess user performance from home without the help of another person.

The continuation of this work includes a test version that allows the assessment of step performance under the dual task paradigm in order to improve the clinical meaningfulness of the test. Dual tasks have been frequently associated with falls and balance impairments in older people, providing evidence for the importance of specific cognitive functions in postural stability [19]. The next stage of this study will involve the clinical validation of the step parameters, followed by the conduction of controlled trials to determine the responsiveness of the game to a training intervention as these have shown to improve important risk factors of falls in older people [20].

References


