A bespoke Kinect stepping exergame for improving physical and cognitive function in older people: a pilot study

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Abstract

Background: Systematic review evidence has shown that step training reduce the number of falls in older people by half. This study investigated the feasibility and effectiveness of a bespoke Kinect stepping exergame , in an unsupervised home-based setting.

Methods: An uncontrolled pilot trial was conducted in twelve community-dwelling older adults (mean age 79.3±8.7 years, 10 female). The stepping game comprised rapid stepping, attention and response inhibition. Participants were recommended to exercise unsupervised at home for a minimum of three 20-minute sessions per week over the 12-week study period. The outcome measures were choice stepping reaction time (CSRT) (main outcome measure), standing balance, gait speed, five-time sit-to-stand (STS), timed up-and-go (TUG) performance and neuropsychological function (attention: Letter Digit and executive function:Stroop tests) assessed at baseline, 4 weeks, 8 weeks and trial end (12 weeks).

Results: Ten participants (83%) completed the trial and re-assessments. A median 8.2 20-minute sessions were completed and no adverse events were reported. Across the trial period participants showed significant improvements in CSRT (11%), TUG (13%), Gait Speed (29%), Standing Balance (7%) and STS (24%) performance (all $p<.05$). There were also non-significant but meaningful improvements for the Letter Digit (13%) and Stroop tests (15%).

Conclusions: This study found that a bespoke Kinect step training program was safe and feasible for older people to undertake unsupervised at home and led to improvements in stepping, standing balance, gait speed and mobility. The home-based step training program could therefore be included in exercise programs designed to prevent falls.

Introduction

Falls are very common in older people, making fall prevention a major public health priority. There is strong evidence that appropriately designed exercise programs can prevent falls in community-dwelling older people [1, 2]. In this context, exercise interventions that train stepping ability have been found to be most effective in preventing falls by approximately 50%, likely due to improved balance and reaction times in older people living in both community and institutional settings [3]. In recent years, the gamification of exercise programs (also known as 'exergames') has been investigated in its feasibility and effectiveness. Several studies have now demonstrated that it is safe and feasible for community-dwelling older people to engage with exergames [4-9]. In addition to this, it has been shown that exergames including cognitive and motor training, induce comparable improvements in physical function to more traditional forms of exercise delivery [8, 10]. More importantly, studies using stepping exergames have improved both physical and cognitive fall risk factors in older people [7, 11, 12].

Despite the evidence to support exercise as an effective falls prevention strategy among community-dwelling older people, adherence to exercise interventions is often poor [13, 14]. Barriers to exercise participation among older people include lack of time and motivation, boredom, fear of falling, and factors such as inconvenience, inaccessibility, questionable safety and cost [13-16]. In the context of optimizing adherence, the development of enjoyable exercise programs taking into account the needs of older adults that promote participation and engagement are necessary. Exergames have been used to promote physical activity and improve program adherence. Systematic review evidence indicates that adherence to such programs is similar, or slightly better, than adherence to traditional programs in older people [17]. This increased adherence to technology-based programs most likely relates to the fun factor inherent in video games which increases the levels of motivation and engagement when exercising [4].

So far, most studies in this area have used commercial games in supervised settings using the Nintendo Wii, Xbox and PlayStation consoles, that have not been specifically designed for older people [17]. However, factors such as the pace of gameplay, the amount of graphical information, and the instructions on how to use the interface can make it difficult for older people to use these programs without supervision, thus limiting their use as home-based interventions [8, 9, 18, 19]. In order to address these issues, a bespoke Kinect-based exergame was developed to provide a user-friendly stepping exergame for older people to play at home [20]. The main motivation for choosing this system was that it has: (1) an appropriate game design achieved through the use of user-centered design methodologies; (2) three stepping routines that train the ability to take quick steps and avoid obstacles; and (3) an embedded version of the Choice Stepping Reaction Time (CSRT) task [21], a test that has shown to reliably predict falls in older adults. These aspects make this game potentially useful in the clinical practice as: (1) it was purposely designed for the appeal and needs of the aged cohort; (2) it trains specific physical and cognitive functions associated with falls in the elderly; and (3) it allows for a continuous assessment of their health outcomes in order to evaluate their progression. None of these characteristics are available in current commercial games.

The aims of this pilot study were to a) evaluate the feasibility and safety of using the 'StepKinnection' exergame to deliver unsupervised step training exercises in older people's homes; and to b) assess the efficacy of this intervention in improving stepping ability as well as physical and neuropsychological factors associated with falls in older people.

Methods

Participants

The sample comprised older people living in retirement villages and the general community in Sydney. The inclusion criteria were: living independently, aged 65 years or older, able to walk without assistance, fluent in the English language, owning a flat screen television with a HDMI Port, able to watch television from a distance of 3m (with or without glasses) and having sufficient room for system use (1.2 m - 2.5 m). Exclusion criteria were unstable health conditions, blindness, colour blindness, cognitive impairment (Mini-Cog score <3), and inability to step unassisted or walk independently.

The study was approved by the Human Research Ethics Committee at the University of New South Wales (UNSW HREC HC12316) and ratified by the Human Research Ethics Committee at the University of Technology Sydney (UTS HREC 2012-279R). Written informed consent was obtained from all participants prior to their participation in this study.

Intervention

The bespoke Kinect-based system called the 'StepKinnection' game (described in detail in [20]) was used to provide stepping training exercises in the homes of older people. In brief, this system consists of a small computer that connects to participant's home television for display and a Kinect sensor that provides skeletal tracking. A Wi-Fi pocket modem was provided to participants when required to enable transfer of game play data to a secure server.

System installation and instructions on how to use the program were provided to each participant during an initial 30 minute home visit prior to the commencement of the trial. An instructional booklet was also provided to participants. Follow-up home visits were performed with each participant at the end of week 4, 8 and 12 to perform re-assessment measures, encourage program use and resolve any difficulties participants may have experienced. Participants were encouraged to play the game as much as they wished with a minimum recommended dose of three 20-minute sessions per week during the 12 week trial.

The theme of the ‘StepKinnection’ game involved the player traveling around the world looking for treasures, with the accompaniment of traditional music from each country (See Figure 1a). To play the game, participants were instructed to stand in front of the television (approximately 1.5 to 2 meters away) facing the Kinect and use either hands to navigate through the program menu. The main game activity involved making fast, directed steps onto a target (fruit) presented on the television screen (See Figure 1b). As participants performance improved, new levels (represented by different countries) were unlocked. Task difficulty was controlled by decreasing the display time (from 2000 to 1000 ms) and size of the target (fruit), thus requiring faster and more accurate steps. A motor inhibition task was incorporated in the intermediate levels to increase the cognitive complexity of the game; i.e. a lady bug appeared on the screen for which participants had to inhibit their step response (See Figure 1c). In doing so, participants had to selectively attend to some stimuli (fruits) while inhibiting others (lady bugs). Furthermore, in higher levels, participants earned bonus points by stepping on coins that appeared briefly (800 to 1000 ms) in random locations on the screen (See Figure 1d). As means to provide feedback to participants points were accumulated for stepping on the targets (fruits and coins) as well as when inhibiting the step on the lady bugs. Completing each challenge contributed to the player being awarded a trophy.

Outcome Measures

The physical and cognitive function outcome measures were collected on a monthly basis over the 12 week trial period. The assessments (described below) took two hours to administer and were assessed under the same conditions at each time point.

Choice Stepping Reaction Time (CSRT) Test

The Choice Stepping Reaction Time (CSRT) test was the primary outcome measure. It provides a composite measure of sensorimotor functions, such as balance and strength and cognitive functions such as attention and central processing speed [21]. CSRT for step completion (lift off and transfer) was measured in milliseconds using a LCD display step pad [22]. On the screen participants saw a graphical presentation of the four arrows of the mat. The step direction (front left, front right, side left and side right) was indicated by one arrow changing its colour. Participants were asked to step as quickly as possible onto the corresponding arrow of the pad and returned to the centre. The test consisted of 4 practice trials (one trial for each step direction) and 32 test trials with stimuli occurring randomly between 1 and 2 seconds after the participant returned to the centre.

Secondary Outcome Measures

Gait Speed

Usual and fast gait speeds were assessed over a 10m course. To allow for acceleration and deceleration, 2m was provided at either end of a 10-m marked course [23]. The average time in seconds of three trials were collected, at normal speed and at fast speed.

Timed Up and Go (TUG)

The Timed Up and Go test (at usual walking speed) was used to assess participants' mobility [24]. Participants were asked to rise from a chair, walk three metres, turn around, walk back to the chair and sit down. The total time taken in seconds by the person to complete this task was measured with the average time of two trials used for the analysis.

Standing Balance

In this test individuals were asked to perform six progressively difficult stances. For each stance (feet apart, feet together, semi-tandem, near-tandem, full tandem, left/right foot), the participant was required to maintain a balanced position for 10 seconds while holding their arms crossed against their chests. The total time that the participant was able to remain balanced was used as the test measure.

Five times Sit to Stand

This test was used to assess lower extremity functional strength, transitional movements and balance [25]. Participants were required to initially sit with their back against the back of an armless chair. They were then asked to stand up and sit down five times as fast as possible with their arms crossed against their chests. The time taken in seconds to complete the test was used for subsequent analysis.

Letter Digit Substitution Test

This test was used to measure processing speed [26]. This test involves the use of a LCD display paired with a computer running the Psychology Experiment Building Language (PEBL) software [27] and a keyboard. Nine letter-digit pairs are presented on the screen followed by a sequence of 30 letters that appear in random order. For each letter, participants were required to type the corresponding number as quickly as possible using the keyboard. Response time is registered by the computer and the average response time for the corrected trials was used for the analysis.

Stroop Test

The Victoria Stroop task was used to measure executive control by response inhibition [28]. This test requires participants to state a colour under three conditions, while supressing habitual responses related to the conditions. This test involves the use of a LCD display paired with a computer running the Psychology Experiment Building Language (PEBL) software [27] and a custom-made game pad with four coloured buttons matching the test colours (green, red, blue, yellow). In this study, we only used the number of errors made during the colour-word interference task (condition 3) and the efficiency score of inhibition calculated as the ratio of colour-word interference and colour only tasks (condition 3 / condition 1).

Statistical Analysis

Due to the small sample size, non-parametric tests were applied for inferential statistics [29]. Friedman's 2-way analysis of variance (ANOVA) by ranks was used to determine changes over time [30]. Wilcoxon matched-pair signed-rank tests were then applied as post-hoc tests to determine at which time-points differences in test performances were significant [31]. The level of significance was set to 5%. Analyses were conducted using SPSS for Windows (Version 20).

Results

Participant descriptions

The 12 people (10 women and two men) who agreed to participate in the trial had a mean age of 79.3 years (SD 8.7). No participants used a walking aid and four participants reported having difficulty standing for 30 minutes. The majority (N=9) reported that they were in good health, with four suffering from arthritis and two from diabetes. A previous falls history was reported by two participants and one reported a moderate fear of falling. A summary of all health and lifestyle characteristics of the sample are described in table 1.

Safety and adherence

Twenty-three older adults were approached to participate in the study and of these 11 declined to take part: five people had no interest in the project, two expressed interest but could not be contacted for baseline assessment and installation, three were keen to participate in the trial, however, due to previous commitments were unable to do so and one passed away before the intervention started.

Of the 12 participants who completed the baseline assessment, one dropped out before starting the intervention due to family related reasons. One dropped out after one week indicating she was unable to play the game. This was primarily due to the lack of room to play the game and the inability to easily switch input sources on the participant's TV. The remaining 10 participants successfully completed the 12 week intervention with no adverse events reported such as falls, pain or injuries.

For the 10 participants who completed the trial, the median number of sessions completed was 6.2 (IQR=1.6-11.4) and median total game play time was 369 minutes (IQR=93-681). For the trial completers, the median number of sessions completed was 8.2 (IQR=4.2-12.7) and median total game play time was 489 minutes (IQR=251-759). Two participants (17%) achieved the prescribed total recommended dose of 720 mins. The system logs for the 10 trial completers indicated that these participants played: a mean of 2.5 sessions per week with a mean duration of 20 minutes per session in the first month; a mean of 1.6 sessions per week with a mean duration of 16.9 minutes the second month; and a mean of 2.2 sessions per week with a mean duration of 22.3 minutes in the third month.

During the first month, the majority of participants played and unlocked all 16 levels. These levels then remained unlocked but there were no set goals to achieve. When interviewed, one participant said *"you got to have a goal to work towards; otherwise it's more of the same*". It is likely that this could have affected motivation and adherence during the second month. For the third month, an additional 16 new levels were incorporated into the system. This resulted in increased levels of adherence as shown in the results.

Primary Outcome Measure: CSRT

CSRT significantly improved over the trial period (Friedman ANOVA χ^2=16.879, df=3, p=0.001). The most prominent improvement occurred in the first four weeks (Wilcoxon signed-rank Z=-2.803, p=0.005). Significant improvements from baseline were also evident at 8 weeks (Z=-2.803, p=0.005) and 12 weeks (Z=-2.701, p=0.007) (Table 2 and Figure 2).

Secondary Outcome Measures

Table 2 shows the participant scores for the physical and cognitive function scores at baseline and retest time points. Gait speed, fast gait speed, TUG times, standing balance and sit to stand times showed overall significantly improvements over the trial period. Compared to baseline, statistical differences were evident all time points for gait speed, fast gait speed and sit-to-stand times, and at week 8 and week 12 for TUG and standing balance times. The two cognitive measures showed trends for improvement across the trial: digit letter test (χ^2=6.939, df=3, p=0.074) Stroop test (χ^2= 6.236,df=3, p=0.101).

Discussion

The StepKinnection exergame is a custom-built stepping game, designed for older people to use unsupervised in their own home. The results of the present study demonstrate that this program is feasible, safe and effective for older people without major mobility problems or cognitive impairment.

Feasibility and safety of the stepping exergames intervention

The drop-out rate was only 17%, with the two drop-outs (both aged above 90 years) not starting the intervention. The remaining 10 participants were able to play the game, navigate through the menus, change levels of difficulty and perform the stepping routines. Participants indicated that they enjoyed the stepping training and thought it useful for maintaining their health. Across the completers, a median total game play of 8 hours was achieved (68% of the recommended 12 hours). No adverse events related to the intervention were reported which suggests the exergame is a safe mode of exercise for older adults and can be played without supervision at home.

Effectiveness of Intervention

The 12 week intervention with the StepKinnection game at home significantly improved stepping performance as well as several other balance and mobility measures associated with fall risk in older people. Our main outcome measure (CSRT performance) showed an overall significant improvement of 11%, indicating positive changes in participants' central processing speed and movement velocity. The 11% improvement is similar to that found in a previous study that examined the efficacy of an eight week step training intervention that used a dance mat and a modified version of the Stepmania game [32]. Importantly, the mean improvement in absolute terms (123 ms) appears clinically meaningful as it is not too dissimilar to the 150 ms difference in CSRT times reported between recurrent and non-recurrent fallers [21].

The exergame training appears to have generalised beyond stepping performance to other balance and mobility measures. Across the trial period, participants showed significant improvements in TUG (13%), Gait Speed (22%), Standing Balance (7%) and Sit to Stand (24%) performance. These improvements all appear to be clinically meaningful and in line with previous exercise interventions using gait speed [33], TUG [34], and Sit to Stand [35] tests as outcome measures. Although the percentage of improvement in Standing Balance was statistically significant, the effect of the intervention may have been underestimated due to a ceiling effect in that participants were asked to perform the sixth postures for 10 seconds (not for as long as they could) and several achieved this during the retests. The post-hoc tests showed improved performance after one month in most physical measures with maintained improvement for the remainder of the trial.

There were also trends for improved processing speed and selective attention as indicated by the 13% improvement in the Digit Letter and 27% improvement in Stroop test scores at the end of trial. These differences proved not significant due to relatively large variations in change scores, but imply the conflict resolution tasks within the game may have been suitably challenging to induce improvements in cognitive measures that have been consistently associated with falls [36, 37].

Study Strengths and Limitations

Strengths of the study were the automated recording of adherence and the multiple assessments which allowed for monitoring of physical and neuropsychological functioning across the trial period. Being pilot in nature, the study also has limitations. First, the sample was small which may have made it difficult to detect significant changes in the outcome measures, notably the Letter Digit and Stroop tests. However, obtained effect sizes appear to be clinically meaningful. Second, the study would have benefited if dual task, social participation and instrumental activities of daily living assessments were included as outcome measures. Finally, due to study constraints it was not possible to conduct a randomised controlled trial and blinded assessments. Thus it cannot be ruled out that the improvements noted in the participants may have been due to factors other than the intervention including possible investigator bias. Despite this, the findings are encouraging as the improvement observed for the majority of the outcome measures mirror those reported in several previous similar studies [3, 7].

Conclusions

This study found that a bespoke Kinect step training program was safe and feasible for older people to undertake unsupervised at home and led to improvements in stepping, standing balance, gait speed and mobility. Adherence was good in those who commenced the intervention indicating the exergame may have advantages over off-the-shelf commercial games designed for entertaining a younger audience. The home-based step training program could therefore be included in exercise programs designed to prevent falls.

Conflict of Interest

The *StepKinnection* exergame has been developed by Dr Garcia as a commercial product.

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