The Effectiveness of Exergaming Training for Reducing Fall Risk and Incidence among the Frail Older Adults with a History of Falls

Amy S.N. Fu¹, PhD, Kelly L. Gao¹, MPT, K.K. Tung¹, DHS, William W.N. Tsang¹, PhD, Marcella M.S. Kwan², PhD

¹ Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong, China
² Rural Clinical School, School of Medicine, The University of Queensland

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Correspondence addresses:
William W.N. Tsang, PT, PhD
Department of Rehabilitation Sciences,
The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
Phone: (852) 2766 6717
Fax: (852) 2330 8656
Email: William.Tsang@polyu.edu.hk
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ABSTRACT

Objective: To use Nintendo’s Wii Fit® balance board to determine the effectiveness of exergaming training in reducing risk and incidence of falls among the older adults with a history of falls.

Design: Randomized controlled clinical trial.

Setting: A nursing home for older adults.

Participants: Sixty older adults aged 65 or above.

Intervention: Participants who lived in a nursing home had six weeks of balance training with either Wii Fit equipment or conventional exercise.

Main Outcome Measures: Physiological Profile Assessment (PPA) scores and incidence of falls were observed with subsequent intention-to-treat statistical analyses.

Results: PPA scores and fall incidence improved significantly in both groups after the intervention, but the subjects in the Wii Fit training group showed significantly greater improvement in both outcome measures.

Conclusions: In institutionalized older adults with a history of falls, Wii Fit balance training was more effective than conventional balance training in reducing the risk and incidence of falls.
Key words: virtual reality; exergame; older adults; falls; balance exercise

List of Abbreviations

COP – Center of Pressure

FAC – Functional Ambulatory Category

PPA – Physical Profile Assessment

SPSS – Statistical Package for the Social Sciences

VR – Virtual Reality

RCT – Randomized controlled clinical trial
Falls are the second leading cause of accidental deaths worldwide,\textsuperscript{1,2} and adults older than 65 suffer the greatest number of fatal falls. Even non-fatal falls can impact on one’s quality of life as a result of severe fall-related injuries and fractures. Moreover, older people who report a fall in the past year are likely to fall again.\textsuperscript{3} Falls can lead to fear of falling,\textsuperscript{4} which may lead to a debilitating spiral marked by loss of confidence and restriction of activity, resulting ultimately in a loss of independence.\textsuperscript{5} Falls have also shown to be a strong predictor of nursing home admission.\textsuperscript{6} Research showed that fall incidence in institutionalized older people are about three times more than those living in the community.\textsuperscript{7-8} A recent study found that 89\% of preventable deaths of nursing home residents were due to falls.\textsuperscript{9} A fall prevention program aimed at this frail elderly population is therefore important. Exercise have been shown to be effective in reducing falls in the community,\textsuperscript{10} however it has failed to reduce the rate of falls or risk of falling as a single intervention in nursing care facilities.\textsuperscript{11}

Virtual reality (VR) and exergaming technologies have been used as an assessment and treatment tool in rehabilitation.\textsuperscript{12,13} Some VR training environments have been enhanced by the addition of video games, increasing participants’ motivation and enjoyment.\textsuperscript{14-16} Nintendo released the Wii Fit\textsuperscript{®} platform that includes a built-in center of pressure (COP) sensor which can enhance yoga, strength training, aerobics, and balance games. The system offers feedback to the participants, enabling them to identify improved balance capabilities.

Although there is some evidence of the effectiveness of virtual reality and the use of video games in enhancing balance control,\textsuperscript{17} empirical evidence in falls prevention particularly with a randomized controlled clinical trial (RCT) design is still lacking.\textsuperscript{18} While there is research on exergaming in patients with chronic stroke\textsuperscript{19} and multiple sclerosis\textsuperscript{20}, but still little research on the effectiveness of the Wii Fit apparatus in the treatment of balance dysfunction among the frail elderly who are at risk of falls. This study was therefore designed.
to investigate the effect of interactive exergaming training exercise on balance control, fall 
risk factors and the incidence of falls among frail elderly persons living in a nursing home.

METHODS

Study Design

This was a single-blinded, RCT with a control group (a conventional balance training 
group) and an intervention group (the Wii Fit balance training group).

Participants

Sixty participants aged 65 or over living in a nursing home were recruited. Each was 
assessed with a Functional Ambulatory category (FAC) of grade 2 or 3. The FAC grade 2 
subjects required manual contact with one person during ambulation on a level surface to 
prevent falling. The manual contact usually consisted of continuous or intermittent light 
touches to assist balance or coordination. The FAC grade 3 subjects could walk on a level 
surface without such contact, but for safety’s sake they required a guard standing by because 
of either poor judgment, questionable cardiac status, or a need for verbal cueing. All of the 
participants were alert and medically stable and able to follow instructions. Each had history 
of falls in the previous year. A fall was defined as “inadvertently coming to rest on the ground 
or other lower level with or without loss of consciousness, and other than as a consequence of 
sudden onset of paralysis, epileptic seizure, excess alcohol intake or overwhelming external 
force”. Residents who had visual problems which might affect their training, who were 
unable to follow instructions or who had any history of seizure, stroke, Parkinsonism or 
uncontrolled cardiovascular disease were excluded.
Approval from the nursing home was obtained prior to conducting the study, and ethical clearance was obtained before the study began from the ethics committees of both the nursing home and The Hong Kong Polytechnic University. Informed voluntary consent was obtained from each participant after thorough explanation.

Procedures

Subjects were randomly assigned to the conventional or Wii Fit balance training group by using a random number produced by the computerized method of minimization (Figure 1). The conventional balance exercise regime used was that developed by Campbell and colleagues specifically for fall prevention among elderly women. It has been shown to be effective in reducing falls incidence in an elderly population. The exercise regime included lower limb muscles strengthening exercises, tandem standing exercises in parallel bars, tandem walking exercises in parallel bars, sideways and turn round walking exercise in parallel bars, stepping exercise, sitting to standing exercise, and half-squats. Subjects were rested for one to two minute between sets. The exercise was organized in one-hour sessions, which were held on three days a week for six weeks. A physiotherapist conducted the whole training regime for all conventional and Wii Fit subjects during this six-week period.

Subjects who were randomized to the Wii Fit balance training group received balance training using a Nintendo’s Wii Fit® balance board. Three balance training games—namely Soccer Heading, Table Tilt and Balance Bubble—were selected. In Soccer Heading, the subjects mimicked soccer players and took turns kicking soccer balls, cleats, or panda heads at each other. Subjects scored a point if their head butted a soccer ball, but lost a point if a cleat hit them and three points if they were nailed by a panda head. To perform these maneuvers the subjects had to shift their body weight left or right while standing on the platform. In the Table Tilt game the subjects tilted a board to roll marbles into holes by
shifting their body weight. They had to carefully manipulate the board to roll the balls into
the holes without dropping a ball off the table. In Balance Bubble the players were required to
steer the bubble through a hazard-filled course, again by shifting their body weight while
standing on the balance board. The farther the subjects leaned, the faster the bubble traveled
in that direction. Subjects progress to the harder mode of the game at their own pace. This
pace was determined through the game’s “star system” that rates the player’s performance on
each individual game. Subjects were rested while each game was being restarted.

These activities exercised various components of the balance control system including
the musculoskeletal components, the sensory system, neuromuscular strategies and
anticipatory control. The Wii Fit training was also for one hour per session, three sessions a
week for six weeks. Since all the participants had history of falls, they were accompanied by
a rehabilitation assistant who provided immediate manual support when necessary during
both the Wii Fit and the conventional balance exercises.

After the six-week intervention period, both groups resumed the routine mobilizing and
strengthening exercises without receiving either the Wii Fit or the conventional balance
training.

Outcome measures

Falls incidence was recorded by the nursing staff according to the aforementioned
definition and reported to the investigator for each subject monthly over the 12-month period
after randomization. Nurses at the nursing home who documented falls were unaware of
subjects’ group allocation.

Fall risk was determined using the short-form physiological profile assessment (PPA)
composed of five validated measures of physiological function. Weighted combinations of
these measures can provide a falls risk score that can predict people at risk of multiple falling
The five measures used were contrast sensitivity, proprioception, quadriceps strength, simple reaction time and postural sway. Visual contrast sensitivity was assessed using the Melbourne Edge Test. Proprioception was measured using a lower limb-matching task. Errors in degrees were recorded using a protractor inscribed on a vertical clear acrylic sheet (60cm x 60cm x 1cm) placed between the legs. Quadriceps strength in both legs was measured isometrically in kilograms while the participants were seated with the hip and knee flexed at 90 degrees. Simple reaction time in milliseconds was measured using a light as the stimulus and a finger-press as the response. Postural sway while subjects stood on foam with double legs and eyes open was measured using a sway meter recording displacements of the body at the level of the pelvis. A research assistant blinded to the subjects’ allocation was responsible for the PPA assessment. Fall risk was assessed before and after the six-week training program.

Statistical Analysis

The data were analysed using version 19 of the Statistical Package for the Social Sciences (SPSS) software package (IBM Corp. 2010) and Stata v12 (StataCorp. 2011). Independent t-tests and chi-square tests were conducted to compare the two groups in terms of age, height, weight, BMI, as well as the distribution of genders and functional ambulation categories. For the PPA z-scores, independent t-tests were used to compare the between-group difference, while paired t-tests were performed to compare the within-group measurements. For the numbers of falls, negative binomial regression models were employed to estimate the difference in rates of falls between the two groups. Additional models adjusted for sex, age and number of falls in previous year before the intervention were used. The intention-to-treat was employed in the statistical analyses and the alpha level was set at 0.05.
RESULTS

All 60 subjects completed the six-week training and the post-intervention assessment (Figure 1). Two subjects from the Wii Fit balance training group and three from the conventional training group could not complete the full year of surveillance due to illness or death, so the completion rates were 93.3% for the Wii Fit group and 90% for the conventional balance training group.

The demographic data are shown in Table 1. There was no statistically significant difference in average age, gender, height, weight, BMI, FAC distribution or number of falls over the previous year between the two groups.

Fall risk

Table 2 presents the means and standard deviations of the five items of the PPA short form and PPA z-scores before and after intervention. Independent t-tests showed that there was no statistically significant difference in the average pre-test PPA values of the two groups. Within both the Wii Fit and conventional balance training groups, paired t-tests showed that there were significant differences in their PPA z-scores before and after the respective interventions. However, independent t-test showed that there was statistically significant difference in the post-test PPA z-scores between the two groups. Subjects who had received the Wii Fit balance training achieved significantly greater muscle strength ($p < 0.001$), faster reaction times ($p < 0.001$), and less body sway ($p = 0.013$) when compared with those who had received conventional balance training (Table 2).

Figure 2 shows the fall risks of the participants between the Wii Fit balance and conventional balance training groups, with the higher the z-score, the greater a person’s fall risk. It also shows the fall risk scores before and after the intervention. Prior to intervention, the mean z-score for both groups was 3.7, in the marked risk category. After training, the
mean z-score of the conventional training group was 3.3 while it was 2.4 for the Wii Fit
training group. The decrease in fall risk was more marked in the Wii Fit training group than
the conventional exercise group ($p = 0.004$).

**Falls**

The overall incidence of falls in the intervention group was 0.54 per person years (range 0-1)
compared with 1.52 per person years in the control group (range 0-3) (Table 2). The
incidence rate ratio (IRR) adjusted for age and sex (common confounders though not
significant in univariate analysis) was 0.35 (95% confidence interval (CI) 0.20 to 064, $p =
0.001$). Inclusion of previous falls in the model resulted in an improved IRR of 0.31 (95% CI
0.17 to 0.57, $p<0.001$).

**DISCUSSION**

**Wii Fit games in reducing falls & fall risk**

This study is the first RCT utilizing Wii Fit balance games or exergame as a training
technique for fall prevention in older adults. The Wii Fit balance training has shown to reduce
falls by 69% compared to the conventional exercise. In terms of fall risk, the Wii Fit balance
training has a 35% improvement in the fall risk z-score, significantly higher than 11% in the
conventional exercise group. The findings echo the results of Campbell and colleagues\cite{22}
whose exercise regime was adopted for the control group of this study.

**Wii Fit games as balance training**

Wii Fit games have been shown to improve balance in patient groups such as those who
suffered chronic stroke and multiple sclerosis,\cite{19,20} but no RCT has been conducted in the
context of fall prevention. Clark and Kraemer\cite{25} reported a case study investigating the
clinical use of Wii games as therapy exercise with elderly nursing home residents at risk of falling. They report that clinical outcomes such as Berg Balance Scale scores, timed up and go test times and dynamic gait index ratings were improved. Another case study was conducted by Hakin and colleagues in a community-dwelling older adults suffering from bilateral peripheral neuropathy. There were improvements found in tests conducted by the computerized dynamic posturography as well as clinical tests.

Rendon and colleagues adopted a RCT design for a total of 40 community-dwelling older adults. The Wii Fit balance group received an intensity of intervention of 3x/week for 6 weeks while the control group received no intervention. The clinical tests using 8-foot Up & Go test and Activities-specific Balance Confidence showed significant improvement in the Wii Fit group. Another RCT was conducted by Jorgensen and colleagues investigating the Wii Fit training on muscle strength and postural control in community-dwelling older adults. The investigators found an 18% increase in maximum muscle strength after the intervention in comparison to the control group who wore shoe insoles. This increase was comparatively higher than ours (14%) possibly due to the younger mean age of their group 75 years and a passive intervention mode in the control group. However, there was no difference in the bilateral static stance in term of COP velocity moment whereas we found a lower body sway area (21.7%) in the Wii Fit group when subjects were standing on a foam with eyes open.

A recent RCT conducted by Cone and colleagues on young healthy adults (18-35 years) using the dosage of six weeks (2-4 x/week, 30-45 min/day). They found that the Wii Fit group achieved better in condition 5 of the sensory organization test (condition where the visual input is occluded with inaccurate somatosensory input) and better spatial and temporal domains in the limits of stability test. The investigators suggested that improved postural control when subjects relied on vestibular input to maintain postural control might be due to the frequent movement of head during the game play. The game also challenged the players
in their reaction time and stability limit and these improvements were being reflected in the limits of stability test.

All of these studies were either single subject case reports or studies recruiting healthy elderly persons. There has been no RCT performed with an elderly population at risk of falls, especially frail elderly persons with functional disability (FAC grade 2 or 3).

Is Wii Fit balance training better than conventional balance training?

The five test items of the PPA short form are i) contrast sensitivity, ii) proprioception, iii) quadriceps strength, iv) reaction time, and v) body sway. In Wii Fit groups, significant improvements after training were observed in reaction time; quadriceps strength and body sway while improvements in reaction time and quadriceps were only found in the control subjects. Any changes in proprioception and contrast sensitivity were not significant. The significantly better performance in these test items observed in Wii Fit group over the conventional exercise group may be explained by the different training modes and environments of the two protocols.

During the Wii Fit training, the trainees had to shift their body quickly in different directions with appropriate timing in order to gain points and not lose in the games. Such training would be expected to strengthen the legs, improve the reaction time in response to external cues, and improve control of body sway. Moreover, exergaming provides real-time performance feedback, cuing stimuli to support error-free learning. Performance feedback as to the status and outcome of a response is generally accepted to be necessary for most forms of learning or skill acquisition, including the learning process that underlies rehabilitation. So the real time visual feedback to the subjects would be expected to enhance the training process compared with conventional training. Moreover, the exergaming environment allows dynamic stimulus delivery and control. This also allows for the presentation of cuing stimuli.
that could be used for “error-free” learning approaches in rehabilitation scenarios. Unlike the participants in Wii Fit group, control subjects only improved in reaction time and quadriceps strength, but not in the postural sway. In the PPA, it assesses the body sway during standing on foam with eyes open. However, the exercise regime designed by Campbell and colleagues\textsuperscript{22} consists of more dynamic balance training, such as tandem walking, sideways and turn around exercises. Due to training specificity, the effect of a more dynamic balance could not be reflected on a static standing assessment.

Study Limitations

We acknowledge the study has certain limitations. Firstly, the difficulty level of the games might be too hard for frailer adults, as they were originally designed for people of relatively younger age. Subsequently, each game lasts only few minutes, so they had to be re-started regularly, which could potentially decrease the efficiency of the training. Although Wii Fit games have been used and accepted by other high fall risk population such as multiple sclerosis, studies often recruited younger age group as in Kramer and colleagues’ study with mean age of 47.\textsuperscript{20} These limitations arose due to the commercial nature of the games, therefore, balance training games targeting the older adults need to be designed specifically for clinical application. Secondly, the amount of rest time in each subject was not recorded. This might result in inconsistency between the two groups in training duration. Thirdly, the physiological outcome measures were only re-assessed post intervention, how much training effect is maintained throughout the follow-up period is not known. However, any deficits in the physiological function would be reflected by number of falls occurred.\textsuperscript{3,23} Finally, as the trial was undertaken in a nursing home setting, we acknowledge our findings may not be generalizable to older people living in the community.
CONCLUSIONS

Wii Fit balance training was demonstrated to be significantly more effective than conventional balance training for reducing falls among the institutionalized, frail, elderly people most at high risk of recurrent falls.

REFERENCES


**Figure Legends:**

Figure 1. Study Flowchart

Figure 2. A scatter plot showing the PPA z-scores pre and post-intervention between the Wii Fit balance and conventional balance training groups
Supplier’s List:

\(^a\) Nintendo, Redmond, Washington, US
Table 1. Baseline characteristics of subjects in both groups. Values are mean ± SD unless otherwise stated.

<table>
<thead>
<tr>
<th></th>
<th>Conventional balance training group (N=30)</th>
<th>Wii Fit balance training group (N=30)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
<td>82.3 ± 4.3</td>
<td>82.4 ± 3.8</td>
<td>0.975</td>
</tr>
<tr>
<td>Gender (Male/Female)</td>
<td>10 / 20</td>
<td>11 / 19</td>
<td>0.995</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.58 ± 0.5</td>
<td>1.55 ± 0.3</td>
<td>0.657</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>59.7 ± 0.5</td>
<td>59.4 ± 0.6</td>
<td>0.542</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.9 ± 0.5</td>
<td>24.7 ± 0.4</td>
<td>0.481</td>
</tr>
<tr>
<td>Functional Ambulatory Category (grade 2 / 3)</td>
<td>16 / 14</td>
<td>14 / 16</td>
<td>0.797</td>
</tr>
<tr>
<td>No. of falls over previous one year (range)</td>
<td>2.2 ± 0.9 (1 - 4)</td>
<td>2.5 ± 1.1 (1 - 5)</td>
<td>0.307</td>
</tr>
</tbody>
</table>
Table 2. Comparison of outcome measurements between the conventional balance training group and Wii Fit balance training group

<table>
<thead>
<tr>
<th></th>
<th>Conventional balance training group (N=30)</th>
<th>Wii Fit balance training group (N=30)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test</td>
<td>Pre-test</td>
</tr>
<tr>
<td>Contrast sensitivity (db)</td>
<td>17.3±1.5</td>
<td>17.3±1.5</td>
<td>17.4±1.6</td>
</tr>
<tr>
<td>Proprioception (degree)</td>
<td>2.6±1.0</td>
<td>2.6±1.0</td>
<td>2.3±1.2</td>
</tr>
<tr>
<td>Quadriceps strength (kg)</td>
<td>4.1±0.4</td>
<td>5.1±0.6a</td>
<td>4.3±0.5</td>
</tr>
<tr>
<td>Reaction time (ms)</td>
<td>346.6±89.0</td>
<td>338.9±87.6a</td>
<td>344.3±77.3</td>
</tr>
<tr>
<td>Postural sway (mm²)</td>
<td>1213.5±390.7</td>
<td>1330.8±510.4</td>
<td>1364.0±372.5</td>
</tr>
<tr>
<td>PPA z-scores</td>
<td>3.7±1.2</td>
<td>3.3±1.2a</td>
<td>3.7±1.0</td>
</tr>
<tr>
<td>No. of falls</td>
<td>2.2 ± 0.9</td>
<td>1.5 ± 0.6a</td>
<td>2.5 ± 1.1</td>
</tr>
</tbody>
</table>

Note. Values are mean ± SD or p values.

*Within group:*

a Denotes a difference at the alpha = 0.01 significance level when compared with the pre-test values.

*Between the two groups:*

b Denotes a difference at the alpha = 0.01 significance level.

c Denotes a difference at the alpha = 0.05 significance level.
Assessed for eligibility (n=82)

Excluded (n=22):  
- No fall in previous year (n=5)  
- Unable to follow instruction (n=4)  
- Visual problem (n=3)  
- FAC grade<2 (n=4)  
- Declined (n=6)

Randomised (n=60)

Wii Exercise Group (n=30)  
Conventional Exercise Group (n=30)

Pre-intervention assessment on PPA

Wii balance exercise X6 weeks,  
3x/ week, 1h/ session  
Received allocated intervention (n=30)

Conventional exercise X6 weeks,  
3x/ week, 1h/ session  
Received allocated intervention (n=30)

Post-intervention assessment on PPA (n=30)

Completed 12 month follow-up on falls surveillance (n=28)  
Did not complete (n=2):  
- Illness (n=2)  
- Death (n=0)

Completed 12 month follow-up on falls surveillance (n=27)  
Did not complete (n=3)  
- Illness (n=2)  
- Death (n=1)
Figure 2. A scatter plot showing the PPA z-scores pre and post-intervention between the Wii Fit balance and conventional balance training groups.