Developing an exergame for unsupervised home-based balance training in older adults
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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2016

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

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Chapter 7

Exergames for unsupervised balance training at home: a pilot study in healthy older adults

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Gait and Posture 2016; 44, 161-167
ABSTRACT

Exercise videogames (exergames) are gaining popularity as tools for improving balance ability in older adults, yet few exergames are suitable for home-based use. The purpose of the current pilot study was to examine the effects of a 6-week unsupervised home-based exergaming training program on balance performance. Ten community dwelling healthy older adults (age: 75.9 ± 7.2 years) played a newly developed ice skating exergame for six weeks at home. In the game, the speed and direction of a virtual ice skater on a frozen canal were controlled using lateral weight shifts, which were captured using Kinect. Sway characteristics during quiet standing in eyes open (EO), eyes closed (EC) and dual task (DT) conditions were assessed in time and frequency domain before, and after two, four and six weeks of training. Balance was also evaluated using the narrow ridge balance test (NRBT). Multilevel modeling was applied to examine changes in balance ability. Participants played 631 (±124) min over the intervention period and no subjects dropped out. Balance in terms of sway characteristics improved on average by 17.4% (EO) and 23.3% (EC) after six weeks of training (p<0.05). Differences in rate of improvement (p<0.05) were observed between participants. No intervention effects were found for quiet standing in DT conditions and on the NRBT. In conclusion, the pilot study showed that unsupervised home-based exergaming is feasible in community dwelling older adults, but also that participants do not benefit equally from the program, thereby emphasizing the need for more personalized exergame training programs.

Keywords: Balance ability, exergames, Fall prevention, Home-based training
7.1 | INTRODUCTION

Older adults experience a decreased ability to maintain, achieve and restore balance during activities, often referred to as age-related deterioration of postural control [1]. Impaired postural control is among the leading causes of falls [2], and falls are the primary cause of injury in older adults, resulting in substantial disability and mortality [3].

Over the last decade, exercise videogames (exergames) have gained popularity as a tool for improving balance ability [4,5]. Exergames are computer games that are controlled through whole body movements. An advantage of these games is that repetitive movements are trained as functional movements within the game [4]. This replicates daily life, where maintaining balance is also embedded in goal-directed tasks [6]. Moreover, because the movements are goal-directed, an external focus of balance control is applied, which has been suggested to improve learning [7].

Advances in the gaming industry have led to affordable exergaming platforms for individual use in the home environment with ever-increasing precision [4]. Their usage may improve the willingness of older adults to train balance, which is often compromised by barriers such as fear of falling, lack of motivation, the effort and costs of traveling and a preference for the privacy of the home environment [8,9]. Exergames hold the potential to take down many of these barriers. A recent review article [4] showed that nine exergame intervention studies report improvements in balance control, as measured using a wide range of clinical and instrumented balance tests. The dynamics of the postural control system can be characterized by measures based on Center of Pressure (COP), which have been found sensitive for identifying age- and task-related differences in postural steadiness [10] and fall risk [11]. In particular, measures related to the velocity and the magnitude of the COP displacements and frequency domain-based measures are reported to be sensitive for detecting age-related differences in balance ability [10,12].

Few elderly already play exergames in their homes, primarily because current commercially available exergames, such as Wii fit (Nintendo, Kyoto, Japan) and Kinect adventures (Microsoft, Redmond, USA) target a younger population. Studies that adopted such games for training balance in older adults therefore all used supervised training sessions, often performed in a clinic [5]. Several research groups developed their own exergames for supervised balance training and reported positive findings regarding the effect of exergames on balance control, as indicated by improved limits of stability, COP sway area, reaction time, narrow walk time and step timing [13-15]. To our knowledge, only the group of Schoene et. al., conducted an unsupervised exergaming pilot study, in which older adults played a step game for eight weeks [15]. We developed an exergame that is controlled completely using bodily movements and consists of affordable consumer electronics, thereby enabling community dwelling older adults to train balance in their home environment without supervision. The game runs on a mini-PC which connects to any modern television and is controlled using Kinect (Microsoft, Redmond, USA). The user controls the speed and direction of a virtual ice skater on a frozen canal by shifting his or her bodyweight in both lateral directions. The rationale behind this training paradigm is that recent studies showed that age-related deterioration in lateral weight shifting abilities is associated with fall risk [11,16,17]. Training lateral weight shifting is thus expected to improve balance ability and reduce fall frequency.
The effects of an exergame training program performed by community dwelling older adults without supervision on balance ability are largely unknown. Therefore, the general aim of this study was to examine the effects of a 6-week unsupervised home-based exergaming training program on balance performance in community dwelling older adults. In addition to a clinical measure of balance, the Narrow Ridge Balance Test [18], we studied COP characteristics before, during and after the exergame training program, and examined whether the rate of improvement of balance ability was comparable between subjects and whether the effects of the game on balance ability were related to balance ability at the start of the trial.

7.2 | METHODS

7.2.1 | Participants
Ten community dwelling older adults (5 men, 5 women, age 75.9 ± 7.2 years) participated in this study. Participants had to be able to walk independently for at least 15 min (self-reported). Exclusion criteria included self-reported neuromuscular, orthopedic or cognitive impairments that affect balance ability, and recent (<1 year) hip or knee replacement surgery. All subjects provided written informed consent. The research was approved by the Medical Ethical Committee, University Medical Center Groningen (METc nr. 2014/204), in accordance with the ethical standards of the declaration of Helsinki.

7.2.2 | Procedure and instrumentation
The current study used a custom-made exergame, suitable for unsupervised use in the home-environment of participants. The participants stood in front of their television with their feet at shoulder width, and controlled a virtual ice skater by repeatedly swaying their center of mass in lateral directions while keeping their feet on the ground. Increasing sway amplitude and/or sway speed resulted in a higher in-game skating speed, and steering was done by leaning towards the desired direction to go to. Two modes were available for playing: ‘endurance’ and ‘coordination’. The goal of the ‘endurance’ mode was to skate as far as possible within a given time limit, which could be set by the participant at one, three or five min. The skating track consisted of a frozen Dutch canal (Figure 1). The goal of the ‘coordination’ mode was to complete a track with a given length as fast as possible, but without hitting obstacles, which included ice holes and bridges. The length of the track was self-selected: 300, 600 or 1500 m and the corresponding number of ice holes was 12, 35 and 120 respectively. The number of bridges was zero at the 300 m track and between one and ten at the longer tracks. Hitting an object resulted in a virtual fall, decreasing the score.

Participants played the game three times 30 min per week for six weeks. Improving high scores resulted in achieving medals, and every second week new tracks of equal difficulty were uploaded. The exergame was installed on a Gigabyte Brix GB-BXA8-5545 mini-PC (Gigabyte, New Taipei City, Taiwan) connected via HDMI to the television of the participant. Kinect, interfaced with the mini-PC, and OpenNI SDK 2.2 were used to capture the movements of the participants [19].
Balance ability was measured at the participants’ home before and after the intervention period, as well as after two and four weeks of playing, by measuring sway characteristics for 45 s during quiet standing in eyes open (EO), eyes closed (EC) and dual task (DT) conditions, and using the Narrow Ridge Balance Test (NRBT), which is a clinical balance test during which the subject stands on one leg on ridges of decreasing width [18]. Quiet standing was performed barefoot on a MatScan® 3150 Pressure Mat System (Tekscan, South Boston, USA), which records the COP position at 100Hz. For the EO condition, subjects were instructed to stand still with arms at the sides, while looking at a visual reference positioned two meters in front of them. The procedure was repeated under EC and DT conditions. The DT consisted of the Brooks spatial memory task [20], which required the subject to memorize the positions of numbers on a grid, which were provided using an audio file. Measurements were performed twice, and averaged for each condition.

![Figure 7.1 | Screenshot of the exergame and a participant playing the game in her home. The avatar is controlled through bodily movements of the participant.](image)

### 7.2.3 Data processing

NRBT mean and maximum scores were computed. The COP position data were analyzed using Matlab 2013b (The Mathworks, Natick, USA). The first five and last ten seconds were cut from the COP position data, leaving 30 seconds of data per trial. The resultant distance (RD) time series were given by

\[
RD_n = \sqrt{AP_n^2 + ML_n^2}
\]  

(7.1)

where AP and ML are the time series of the anterior-posterior and medio-lateral distances from the mean COP respectively, \( n \) is the sample index, where \( n=1, 2 \ldots , 3000 \). Data were filtered using a 3rd order Savitzky-Golay filter with a window frame of 21. The following outcome measures were computed: summed distance in AP (APDIST) and ML direction (MLDIST), mean sway velocity (MVELO), root
mean square distance (RDIST), total power of RD (POWER), 95% power frequency (95%PF) of RD [see 10] and sway area (SAREA). SAREA was approximated by dividing the COP ML-AP path diagram in 72 segments of the pressure mat, each 5° in size. The maximum radius of the sway path was computed for each segment, and these 72 consecutive points defined, together with the origin of the COP path diagram, 72 triangular segments of which the area was summed [21]. To describe the intensity of the training, the lateral sway frequency of the Kinect trunk marker [19] was computed during exergaming.

7.2.4 | Statistical analysis
Multilevel modeling [22,23] was applied (MLwiN v 2.29.0.0 software, University of Bristol, UK) to study changes in balance ability. A two-level hierarchical model was constructed. Level 1 holds the phase (baseline and after two, four and six weeks) of measurements, which were nested in level 2; the participants. A separate model was built for each outcome measure. First, an empty model was defined, which describes the effect of the grand mean that underlies all observations. To test whether individual participants differ from each other in terms of the selected balance outcome measure at baseline level, the intercept was set at random. Whether a change to a more complex model was warranted, was assessed by subtracting the deviance statistic of the new model from the empty model. The deviance statistic follows a chi-squared distribution with a number of degrees of freedom equal to the difference in number of parameters. To test whether the intervention had an effect on balance performance, the intervention variable (phase) was added to the model as an explanatory variable. Significant improvement of the model indicates an intervention effect, which was computed for each measurement phase individually. Finally, to assess inter-individual differences in rate of improvement, the slopes of all measurement phases were set at random. A typical model would look as follows:

$$APDIST_{ij} = \beta_0 + \beta_1 T_{ij} + \beta_2 T_{ij} + \beta_3 T_{ij} + \beta_4 T_{ij} + e_{ij}$$

(7.2)

where $\beta$ represents the fixed part of the model, consisting of the intercept ($\beta_0$) and the intervention effect ($\beta_1, \beta_2, \beta_3$) at each time of measurement (T2, T3, T4), while $i$ and $j$ represent level 1 (phase) and level 2 (subject) respectively. $e_{ij}$ is the residual (or error) term. Effect sizes were quantified by comparing the regression coefficients of the post-intervention measurement with the baseline measurement [24]. As a post-hoc test, it was examined whether including the balance performance at baseline further improved the model. To this end the participants with a relatively low performance on the NRBT at baseline (scoring <1; which was achieved by six participants) were included as a dummy variable after which the model was evaluated again. Post-intervention changes in task performance on the Brooks spatial memory task were evaluated using a paired $t$-test. A significance level of $p<0.05$ was used for all analyses.
7.3 | RESULTS

Participants played on average 631 ± 124 min over a period of six weeks with a mean sway frequency of 0.43 (± 0.11) sways per second. No drop-outs and adverse effects were reported. Table 1 displays the variables of the multilevel models constructed for the instrumented balance tests and the NRBT. The multilevel models improved for all outcome measures when including a random intercept in the models, indicating that participants showed differences in balance ability at the start of the program. When adding the measurement phase to the models, main intervention effects were found for DISTAP and POWER in EO condition (Table 1). When observing individual phases, intervention effects were found after four weeks for all measures in EO and EC condition, except for MLDIST and 95%PF in EO and EC conditions and SAREA in EC condition. After six weeks, effects were found in EO condition on APDIST, MVELO, RDIST and POWER and in EC condition on RDIST and SAREA (table 1). Analysis of effect sizes showed that after six weeks sway characteristics improved on average with 17.4% and 23.3% for EO and EC conditions respectively. No significant intervention effects were observed on the NRBT or in DT condition. However, task performance on the Brooks spatial memory task improved over the six weeks period. Setting the slopes at random significantly improved the models in EO condition for MLDIST, MVELO, SAREA and POWER, in EC condition for all measures and in DT condition for APDIST, MLDIST, SAREA and POWER, indicating that participants showed different rates of improvement. For illustration purposes, Figure 2 shows the scores of all subjects on MVELO and POWER in all three conditions, revealing an improvement over time in EO and EC conditions. Figure 3 shows that the scores of a single subject on all measures display a similar trend for each condition. The post-hoc test performed to examine the effect of the balance performance at baseline on the intervention did not result in significant improvements to the model, except for the outcome measure POWER in EO condition, POWER, MLDIST and SAREA in EC condition and SAREA in DT condition.
<table>
<thead>
<tr>
<th>Measures</th>
<th>Baseline</th>
<th>2 weeks</th>
<th>4 weeks</th>
<th>6 weeks</th>
<th>Effect random intercepts</th>
<th>Intervention effect</th>
<th>Effect random slopes</th>
<th>Deviance empty model</th>
<th>Deviance final model</th>
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<td></td>
<td>Coeff ± SE</td>
<td>Coeff ± SE</td>
<td>Coeff ± SE</td>
<td>Coeff ± SE</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>APDIST (mm)</td>
<td>282.6 ± 34.0</td>
<td>-28.5 ± 15.8</td>
<td>-44.1* ± 22.8</td>
<td>-54.3** ± 25.7</td>
<td>***</td>
<td>*</td>
<td></td>
<td>482</td>
<td>429</td>
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<tr>
<td>MLDIST (mm)</td>
<td>126.9 ± 20.8</td>
<td>2.0 ± 14.5</td>
<td>-10.4 ± 13.8</td>
<td>-12.6 ± 17.2</td>
<td>***</td>
<td>*</td>
<td></td>
<td>447</td>
<td>392</td>
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<tr>
<td>MVELO (mm/s)</td>
<td>11.1 ± 1.4</td>
<td>-0.8 ± 0.6</td>
<td>-1.6* ± 0.9</td>
<td>-1.9* ± 1.0</td>
<td>***</td>
<td>*</td>
<td></td>
<td>226</td>
<td>166</td>
</tr>
<tr>
<td>EO RDIST (mm)</td>
<td>4.7 ± 0.5</td>
<td>-0.5 ± 0.4</td>
<td>-0.8* ± 0.3</td>
<td>-0.7* ± 0.5</td>
<td>***</td>
<td>*</td>
<td></td>
<td>137</td>
<td>95</td>
</tr>
<tr>
<td>SAREA (mm²)</td>
<td>85.7 ± 19.6</td>
<td>-10.7 ± 11.7</td>
<td>-25.8* ± 11.1</td>
<td>-15.2 ± 10.3</td>
<td>***</td>
<td>*</td>
<td></td>
<td>429</td>
<td>373</td>
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<tr>
<td>POWER</td>
<td>5.9 ± 1.3</td>
<td>-1.3 ± 1.0</td>
<td>-2.3** ± 0.9</td>
<td>-1.9* ± 1.1</td>
<td>***</td>
<td>*</td>
<td></td>
<td>199</td>
<td>156</td>
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<tr>
<td>95%PF (Hz)</td>
<td>1.6 ± 0.2</td>
<td>-0.1 ± 0.1</td>
<td>-0.01 ± 0.1</td>
<td>-0.2 ± 0.2</td>
<td>***</td>
<td>*</td>
<td></td>
<td>48</td>
<td>27</td>
</tr>
<tr>
<td>APDIST (mm)</td>
<td>679.2 ± 163.2</td>
<td>-117.0 ± 95.8</td>
<td>-186.7* ± 121.2</td>
<td>-156.3 ± 102.9</td>
<td>***</td>
<td>*</td>
<td></td>
<td>586</td>
<td>533</td>
</tr>
<tr>
<td>MLDIST (mm)</td>
<td>228.6 ± 61.2</td>
<td>-2.8 ± 28.1</td>
<td>-35.3 ± 22.4</td>
<td>-43.9 ± 21.6</td>
<td>***</td>
<td>*</td>
<td></td>
<td>533</td>
<td>438</td>
</tr>
<tr>
<td>MVELO (mm/s)</td>
<td>25.2 ± 6.2</td>
<td>-3.4 ± 2.96</td>
<td>-6.3* ± 4.0</td>
<td>-5.5 ± 3.4</td>
<td>***</td>
<td>*</td>
<td></td>
<td>327</td>
<td>265</td>
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<tr>
<td>EC RDIST (mm)</td>
<td>7.1 ± 1.1</td>
<td>-0.6 ± 0.6</td>
<td>-1.2** ± 0.5</td>
<td>-1.1* ± 0.5</td>
<td>***</td>
<td>*</td>
<td></td>
<td>195</td>
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<tr>
<td>SAREA (mm²)</td>
<td>345.7 ± 154.3</td>
<td>-71.5 ± 80.8</td>
<td>-122.4 ± 95.3</td>
<td>-145.7* ± 85.1</td>
<td>***</td>
<td>*</td>
<td></td>
<td>584</td>
<td>479</td>
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<tr>
<td>POWER</td>
<td>16.5 ± 5.6</td>
<td>-4.5 ± 3.7</td>
<td>-6.1* ± 3.5</td>
<td>-5.2 ± 3.8</td>
<td>***</td>
<td>*</td>
<td></td>
<td>312</td>
<td>224</td>
</tr>
<tr>
<td>95%PF (Hz)</td>
<td>2.1 ± 0.2</td>
<td>-0.1 ± 0.2</td>
<td>-0.2 ± 0.2</td>
<td>-0.2 ± 0.2</td>
<td>***</td>
<td>*</td>
<td></td>
<td>60</td>
<td>22</td>
</tr>
<tr>
<td>APDIST (mm)</td>
<td>277.9 ± 47.9</td>
<td>-2.7 ± 38.4</td>
<td>-31.8 ± 38.7</td>
<td>-6.6 ± 25.0</td>
<td>***</td>
<td>*</td>
<td></td>
<td>504</td>
<td>456</td>
</tr>
<tr>
<td>MLDIST (mm)</td>
<td>111.9 ± 18.5</td>
<td>2.3 ± 6.78</td>
<td>-5.6 ± 14.1</td>
<td>5.1 ± 6.4</td>
<td>***</td>
<td>*</td>
<td></td>
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<td>362</td>
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<tr>
<td>MVELO (mm/s)</td>
<td>10.6 ± 1.8</td>
<td>0.0 ± 1.3</td>
<td>-1.0 ± 1.4</td>
<td>-0.1 ± 0.8</td>
<td>***</td>
<td>*</td>
<td></td>
<td>240</td>
<td>190</td>
</tr>
<tr>
<td>DT RDIST (mm)</td>
<td>3.9 ± 0.5</td>
<td>0.6 ± 0.4</td>
<td>-0.0 ± 0.4</td>
<td>0.4 ± 0.3</td>
<td>***</td>
<td>*</td>
<td></td>
<td>130</td>
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<tr>
<td>SAREA (mm²)</td>
<td>74.5 ± 21.3</td>
<td>-4.6 ± 15.1</td>
<td>-4.3 ± 16.9</td>
<td>13.5 ± 11.3</td>
<td>***</td>
<td>*</td>
<td></td>
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<tr>
<td>POWER</td>
<td>4.7 ± 1.3</td>
<td>0.4 ± 1.1</td>
<td>-1.0 ± 0.9</td>
<td>0.6 ± 1.0</td>
<td>**</td>
<td>*</td>
<td></td>
<td>203</td>
<td>163</td>
</tr>
<tr>
<td>95%PF (Hz)</td>
<td>1.6 ± 0.2</td>
<td>0.0 ± 0.3</td>
<td>-0.1 ± 0.1</td>
<td>-0.2 ± 0.1</td>
<td>**</td>
<td>*</td>
<td></td>
<td>59</td>
<td>35</td>
</tr>
<tr>
<td>MNNRBT</td>
<td>1.5 ± 0.5</td>
<td>0.2 ± 0.3</td>
<td>0.3 ± 0.3</td>
<td>0.5 ± 0.2</td>
<td>***</td>
<td>*</td>
<td></td>
<td>156</td>
<td>100</td>
</tr>
<tr>
<td>MANRBT</td>
<td>2.1 ± 0.7</td>
<td>0.3 ± 0.3</td>
<td>0.4 ± 0.5</td>
<td>0.4 ± 0.2</td>
<td>***</td>
<td>*</td>
<td></td>
<td>169</td>
<td>101</td>
</tr>
</tbody>
</table>

Coeff = coefficient, at baseline the baseline value is reported, and after 2, 4 and 6 weeks the change relative to the baseline is reported. EO = eyes open; EC = eyes closed; DT = dual task; APDIST = summed sway distance in AP direction; MLDIST = summed sway distance in ML direction; MVELO = mean sway velocity; RDIST = root mean square sway distance; SAREA = sway area; POWER = total power; 95%PF = 95% power frequency; MNNRBT = mean Narrow Ridge Balance Test score; MANRBT = Maximal Narrow Ridge Balance Test score; *p<0.05; **p<0.01; ***p<0.001.
Figure 7.2 | Scores on MVELO and POWER for all participants in all three conditions over time. The colored lines and black dashed line represent the individual participants and their mean scores respectively. MVELO = mean sway velocity; POWER = total power; EO = eyes open; EC = eyes closed; DT = dual task. Note that in EC condition, the y-axis scaling was changed to ensure that intervention effects in EO and DT conditions remain visible. Note that POWER is here unitless.
Figure 7.3 | Balance scores on all outcome measures of one participant over time. To fit the graphs in one figure, all values were divided by the mean score on each outcome measure.

APDIST = summed sway distance in AP direction; MLDIST = summed sway distance in ML direction; MVELO = mean sway velocity; RDIST = root mean square sway distance; SAREA = sway area; POWER = total power; 95%PF = 95% power frequency.

7.4 | DISCUSSION

The present study examined the effects of a home-based unsupervised exergame balance-training program on balance ability in community dwelling healthy older adults. The results showed that sway characteristics in EO and EC condition improved after four weeks of training. No intervention effects were found on the NRBT or during quiet standing in DT condition. The rate of improvement differed significantly between subjects, and was not explained by balance ability at baseline. All participants adhered to the program.

Our findings suggest that unsupervised exergaming at home for six weeks is feasible in independently living healthy older adults. The effects on sway characteristics in EO and EC condition were significant for most outcome measures. This result concurs with the majority of other exergame studies, which report positive effects on balance ability [4,5]. The current study additionally shows that the positive effects of exergaming on balance ability also apply when training independently at home. Schoene et al. examined the effect of an exergame involving home-based step training on stepping performance and functional mobility and reported improvements on Choice Stepping Reaction Time task and the Physiological Profile Assessment ranging 21-38%, [15], which is in line with the results of the current study.

The significant improvements on SAREA concur with effects found in [25], in which the effects of 12 weeks of balance training, yoga and Tai Chi on postural control of older adults were evaluated. Effects on sway distance measures on the other hand were not in line with [26], who reported an absence of these effects after four weeks of weight-shifting training. The current study showed no effects on
MLDIST and 95%PF. Previous studies that examined the effects of physical exercise on postural control were also unable to find significant training effects on MLDIST [27] during quiet standing, while 95%PF has, to our knowledge, not been used in exercise intervention studies for training balance [27]. 95%PF could be interpreted as an estimate of the extent of the frequency content of the time series [10] and the absence of an intervention effect implies that although the POWER changed, the frequency content remained similar.

The results of the present study indicate that participants did not benefit equally from the exergame. The MVELO, as shown in Figure 3, for instance improved on average by 11.9% over six weeks in EO and EC condition, but the range was -18 to 43%. Seven out of ten people improved on this measure. No intervention effects were found in the DT condition, but a significant post-intervention improvement on the cognitive task was found, indicating that the possible gain in attentional capacity was allocated to the cognitive task rather than to the motor task [28]. Possibly, subjects prioritized the cognitive task, yet due to the lack of a cognitive-task-only measurement, this could not be verified.

The current study had several limitations. First, the included number of participants was low, as is typical for a pilot study, thereby naturally reducing the statistical power. Second, the primary outcome measures included measures based on COP sway characteristics during quiet stance rather than directly measuring falls, which was an unsuitable method given the small sample size and the high measurement frequency (every second week). The measures used in the current study are suitable for assessment of postural steadiness and fall risk [10-12], however the relationship between improvements on standing balance tasks after an exercise program, and the actual decrease in number of falls is largely unknown [27]. Third, the data could not explain why not all participants responded to the training. Possibly, the ability to improve balance was compromised by the relatively good physical fitness of the subjects. Older adults with reduced mobility might benefit more from the program, but since this was a pilot study, we did not want to include older adults with reduced mobility yet. Alternatively, the self-selected training intensity might have been too low for some participants. Future studies should therefore include measures of physiological functioning such as heart rate and oxygen consumption, or report the perceived exertion after each training. In addition to the present frequency- and amplitude-based measures of postural sway, additional measures focusing more on dynamics of postural sway in terms of variability and stability characteristics at different time scales (e.g. minutes, days) could provide information on how balance improves over time. For instance, efforts have been made to use pattern recognition techniques for quantification of balance control during exergaming [29].

We observed that participants benefitted unequally from the pilot program, which underlines the importance for individualized gameplay settings, such as intensity and duration. As there is a tradeoff between feasibility and intensity in an unsupervised training setting, it is important to quantify balance ability during exergaming and adapt the difficulty of exergames to individual balance ability, generally known as dynamical difficulty adjustment (DDA) [30].

In conclusion, the unsupervised use of exergames by older adults in their home situation is feasible and can offer a useful tool to improve balance ability in this population, thereby accommodating independent living of senior citizens. This study however showed that exergames are not equally beneficial for all elderly. Future research should therefore focus on developing training programs that adapt to individual needs, so to provide an exergame experience that optimally improves balance ability.
Conflict of interest
The authors declare that they have no competing interests

Acknowledgements
This work was supported by INCAS³ and has been performed on behalf of research center SPRINT. INCAS³ is supported by the Province of Drenthe, the Municipality of Assen, the European Fund for Regional Development and the Ministry of Economic Affairs, Peaks in the Delta. This project is financially supported by the Northern Netherlands Provinces Alliance, Course for the North. The exergame was developed by Meint Span and Maarten Stevens (8D Games, Leeuwarden, The Netherlands).
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