Efficacy of Nintendo Wii Training on Mechanical Leg Muscle Function and Postural Balance in Community-Dwelling Older Adults: A Randomized Controlled Trial

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Background. Older adults show increased risk of falling and major risk factors include impaired lower extremity muscle strength and postural balance. However, the potential positive effect of biofeedback-based Nintendo Wii training on muscle strength and postural balance in older adults is unknown.

Methods. This randomized controlled trial examined postural balance and muscle strength in community-dwelling older adults (75 ± 6 years) pre- and post-10 weeks of biofeedback-based Nintendo Wii training (WII, n = 28) or daily use of ethylene vinyl acetate copolymer insoles (controls [CON], n = 30). Primary end points were maximal muscle strength (maximal voluntary contraction) and center of pressure velocity moment during bilateral static stance.

Results. Intention-to-treat analysis with adjustment for age, sex, and baseline level showed that the WII group had higher maximal voluntary contraction strength (18%) than the control group at follow up (between-group difference = 269 N, 95% CI = 122; 416, and p = .001). In contrast, the center of pressure velocity moment did not differ (1%) between WII and CON at follow-up (between-group difference = 0.23 mm/s, 95% CI = −4.1; 4.6, and p = .92). For secondary end points, pre-to-post changes favoring the WII group were evident in the rate of force development (p = .03), Timed Up and Go test (p = .01), short Falls Efficacy Scale-International (p = .03), and 30-second repeated Chair Stand Test (p = .01). Finally, participants rated the Wii training highly motivating at 5 and 10 weeks into the intervention.

Conclusions. Biofeedback-based Wii training led to marked improvements in maximal leg muscle strength (maximal voluntary contraction; rate of force development) and overall functional performance in community-dwelling older adults. Unexpectedly, static bilateral postural balance remained unaltered with Wii training. The high level of participant motivation suggests that biofeedback-based Wii exercise may ensure a high degree of compliance to home- and/or community-based training in community-dwelling older adults.

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FALLS in the elderly population are not only associated with morbidity and mortality but are also related to poorer overall physical functioning and early admission to long-term care facilities (1). The risk of falling increases as people get older (2–4) and major causes for this elevated risk are associated with reduced lower extremity muscle strength (5,6) including loss of rapid force capacity (rate of force development [RFD; 5]) that, among other factors, contribute to impaired postural balance (7). To counteract this age-related decline in physiological function, specific types of exercise and training can be employed to achieve substantial improvements in the neuromuscular system of older adults (8,9) and very old frail individuals (10,11) in order to reduce the risk and incidence of falls (12).

Traditional balance and muscle training regimes have included tilting boards, foam plates, tai chi, dumbbells, and resistance-training machines among others (13). However, a general problem with many of these exercise interventions is that they are monotonous, often resulting in poor training compliance, which in turn prevents participants from reaching their full physiological and/or rehabilitative potential (14,15). In addition, the effect of traditional rehabilitation programs is often limited because participants typically return to their initial baseline values when examined at 1- or 2-year follow-up (16). A major disadvantage of traditional
rehabilitation exercise could be the lack of biofeedback (instantaneous physiological feedback) to the user during the act of exercise. The use of biofeedback in exercise-based intervention protocols has previously been proven useful (17–19) and appears to be an important and relevant psychological motivating factor for participants undertaking training (20,21) not only due to the instant feedback on current performance, but also for tracking longitudinal training improvements (22). Hence, the development of biofeedback-assisted rehabilitation programs seems a promising tool in the future rehabilitation of older people.

One of the most recent forms of biofeedback-based exercise involves the Nintendo Wii console (which is commercially available across the globe) connected to a pressure-sensitive Wii board (Nintendo Wii, Nintendo Co. Ltd., Minami-ku Kyoto, Japan), where the user interacts and controls a virtual character by moving his/her own body while standing on the Wii board. The Wii board detects the center of pressure of the user and displays it onto a TV screen or initiates movements of the virtual character displayed on the screen (eg, steering a downhill skier through successive gates). This enables the user to perform complex balance tasks involving extensive neuromuscular co-ordination and exertion of substantial muscle force accompanied by instantaneous online biofeedback (ExerGame).

To the best of our knowledge, no previous randomized controlled trial (RCT) study has examined the potential efficacy of Nintendo Wii training on key physiological variables related to postural stability in community-dwelling older adults. So far, the Wii system has been used in a few non-RCT experiments (21), pilot studies (20,23), case reports (24), short communication reports (25), and study protocol presentations (26).

We, therefore, performed a randomized, blinded, controlled trial in community-dwelling older adults in order to (a) determine if Wii training could lead to improvements in their mechanical lower limb muscle function, static postural balance, and functional performance, respectively and (b) explore the motivational effect of Nintendo Wii training in this study sample.

**Methods**

**Study Participants and Design**

Community-dwelling older adults were recruited by the principal author through advertisements in local newspapers, senior citizens’ clubs, and senior society organizations in Aalborg, Denmark. Inclusion criteria were as follows: more than 65 years of age, self-reported balance to be poor to average (on a discrete scale: good, average, poor), and capability of understanding verbal instructions. Exclusion criteria were as follows: orthopedic surgery within the previous 6 months, acute illness within the previous 3 weeks, physiotherapy within the previous month, and poor visual acuity (not capable of seeing the visual features on the TV screen). All participants provided written informed consent, and the study was approved by the Ethics Committee of the North Jutland Region of Denmark.

The study was carried out as a randomized, observer-blinded, controlled parallel-group trial with an intervention period of 10 weeks. Participants were stratified on sex and randomly assigned by computer-generated random numbers in permuted blocks to either participation in a Nintendo Wii exercise program (WII) or daily use of ethylene vinyl acetate (EVA) copolymer shoe insoles (control, CON) for 10 weeks. All participant allocation procedures were handled by the laboratory’s chief nurse who was not involved in any other parts of the study. The participants in CON served as a control group, as several studies have shown that EVA insoles do not have any measurable effect on postural balance (27,28). The use of EVA insoles was intended to make CON participants believe that they were engaged in an active treatment. For this purpose, CON participants were explicitly informed (orally and via written material) that the use of insoles was expected to increase sensory inputs from the feet to the central nervous system, resulting in an improved postural balance. This active approach was chosen to control the placebo effect known to exist for medical sham treatment (29). Participants were baseline tested at the Geriatric Research Clinic at Aalborg Hospital, Denmark, prior to randomization (PRE) and again after 10 weeks of intervention (POST). All test procedures were performed by the same experienced researcher, who followed a standardized assessment protocol, and was blinded to each participant’s group allocation.

**Interventions**

Wii training was performed 2 times a week for 10 weeks, with sessions lasting approximately 35±5 minutes. All sessions were supervised by a trained physiotherapist. Each training session was designed to include an initial balance exercise sequence (2/3 of total session’s duration) followed by a muscle exercise sequence (1/3 of session’s duration). The participants could choose freely between five different balance exercises (table tilt, slalom ski, perfect 10, tight rope tension, penguin slide) during the exercise sequence for postural balance (~45 minutes), whereas a single exercise (standing rowing squat) was used in the subsequent sequence of muscle conditioning (~25 minutes). In each session, two participants rotated between exercises and pauses, each of ~10 minutes’ duration. On average, training sessions in total lasted 70±10 minutes.

The participants in CON were instructed to wear the EVA insoles in their shoes everyday for the entire duration of the trial. They were interviewed by phone on three occasions (weeks 3, 6, and 9) by the physiotherapist in charge of the training to check that problems with the EVA insoles had not emerged.
Outcome Measures

Primary outcomes.—Maximal isometric contraction strength (maximal voluntary contraction [MVC]) of the leg extensors was measured (1000 Hz) using a static adjustable leg press apparatus (Leg Force, Newtest, Finland). The participants were seated in the leg press with their knees at an angle of 120° and asked to press as hard and as fast as possible (ie, by exerting maximal RFD) against a fixed, strain gauge instrumented footplate using both legs for approximately 3 seconds. Online feedback of the produced force was provided to the participant on a personal computer screen following each contraction. The analogue strain gauge signal (leg extension force) was sent through an amplifier and subsequently digitally converted at 1 KHz using a 14-bit, 8-channel analog-to-digital converter and then stored in a personal computer. During subsequent offline analysis, the force signal was digitally filtered using a fourth-order Butterworth filter (cutoff frequency = 20 Hz; Matlab 7.13, Mathworks). Methodological details on the calculations of MVC and RFD are given elsewhere (30). Acceptable test–retest reproducibility has previously been demonstrated for the assessment of maximal isometric muscle strength in lower limb muscles in middle-aged and older adults (31,32). Prior to all PRE- and POST-testing, participants were asked to perform a series of three to five submaximal leg press maneuvers to get accustomed to the apparatus. After a small pause, the participants performed three maximal trials (which later were averaged into a mean value) separated by a 30-second rest.

Postural balance capacity was assessed by analyzing the center of pressure velocity moment (CoP-VM; mm²/s) recorded (100 Hz) using an instrumented force plate (Good Balance, Metitur, Finland). The vertical ground reaction force signal from the force plate was sent through an amplifier and subsequently processed using a 24-bit, 3-channel analog-to-digital converter and stored in a personal computer. The force signal was initially filtered online by the internal processing software (Good Balance) using a 3-point median filter and secondly on an infinite impulse response filter (cutoff frequency = 20 Hz) to remove any high-frequency noise content in the signal. Methodological details on the calculation and reliability of CoP-VM (mm²/s) have been reported elsewhere (32,35). Postural balance testing comprised two successive 60-second trials (analyzed data collapsed into mean values) separated by a 30-second rest period (36). Participants were asked to remove their shoes prior to all sway recordings and remain in a relaxed standing position with arms folded across the chest and focusing on a visual target positioned 3 m away. The distance between the participant’s medial calcaneus and first metatarsal head were measured to ensure identical foot positions during PRE- and POST-testing, as control of this variable influences the reproducibility of the obtained data (37). Also, the time of day was controlled because this parameter has significant influence on postural balance capacity in elderly adults (33). The light intensity in the test room was controlled at 25 lux. Room temperature was 22°C, and the noise level never exceeded 55 dB during testing.

Secondary outcomes.—Prespecified secondary outcomes comprised of rapid force capacity (contractile RFD), the Timed Up and Go (TUG) test, Short-form Falls Efficacy Scale-International (FES-I), 30-second repeated Chair Stand Test, and a measurement of training motivation (5-point Likert scale). The RFD value was derived from the MVC trials (30). The TUG test is an established test of agility and has been validated on older adults (38). The FES-I is a 7-item questionnaire of fall efficacy in older people during various daily activities (39). The 30-second repeated Chair Stand Test indicates the level of functional strength and endurance in the lower extremity muscles in combination with postural balance (40). At 5- and 10-week time points, the WII participants completed a small survey with three statements (on a 5-point Likert scale) regarding their motivation toward WII training. The statements were as follows: (a) “I find the Nintendo Wii training both fun and motivating,” (b) “I would like to continue using Nintendo WII training in my own home,” and (c) “I would like to continue using Nintendo Wii training in a nearby seniors’ center.”

Adverse events.—Immediately after the POST-tests, all participants were asked if they had experienced any adverse events throughout the intervention period. Also, the physiotherapist involved in the WII training was instructed to report any adverse events that might have occurred during the period of intervention and testing.

Statistical analysis.—All except one participant in the WII group were included in the efficacy analysis (n = 57). The person excluded reported dizziness and uncomfortable feeling during the POST-test. Differences between baseline and follow-up for primary and secondary end points were investigated for normality by examination of histograms and q–q plots. Pre-to-post intervention changes and between-group differences were analyzed using an analysis of covariance model adjusting for gender, age, and baseline level of various outcome variables. In order to examine potential group differences in baseline variables, two-tailed unpaired t-tests were also performed. Missing data were imputed with the use of last observation carried forward in accordance with recommended guidelines (41). A sensitivity analysis using a similar statistical approach to that mentioned earlier was performed by excluding the five individuals, who never received a single session of Wii training. SPSS version 18 was used to perform all statistical analyses, using a significance level of 5%.

In order to obtain a statistical power of 80%, 29 participants were needed in each group to detect at least a pre-to-post 15 mm²/s difference in group mean CoP-VM delta.
(pre-to-post) changes between WII and CON assuming an SD of 20 mm²/s. The values mentioned earlier were based on a pilot study.

RESULTS

Participant Characteristics

Enrollment took place from the beginning of May 2011 to the end of June 2011 when the sample size goal was reached. Baseline (PRE) and follow-up (POST) measurements were performed at the end of June 2011 and at the beginning of September 2011, respectively. Of the 212 people screened for eligibility, 154 (73%) were ineligible or did not wish to participate; thus, 58 underwent randomization with 28 assigned to Wii training (WII), whereas 30 served as CON (see route diagram in Figure 1). In the WII group, five individuals never showed up for training (cf. Figure 1). Thus, Wii training was never started nor completed by 18% of the participants. The remaining participants (82%) took part in 76.7% of the scheduled training sessions. There were no differences in baseline characteristics between WII and CON (Table 1).

Primary end points.—Leg press MVC improved from 1,470 to 1,720 N in WII (+250 N; +17%) and decreased
Table 1. Baseline Characteristics of Study Participants (group mean ± SD)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Wii (n = 28)</th>
<th>CON (n = 30)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>75.9 ± 5.7</td>
<td>73.7 ± 6.1</td>
<td>.15</td>
</tr>
<tr>
<td>Female sex, n (%)</td>
<td>19 (68)</td>
<td>21 (70)</td>
<td>.86</td>
</tr>
<tr>
<td>Body mass index</td>
<td>26.4 ± 4.1</td>
<td>25.9 ± 4.2</td>
<td>.64</td>
</tr>
<tr>
<td>Medical preparations (n)</td>
<td>3.2 ± 3.1</td>
<td>4.1 ± 3.5</td>
<td>.35</td>
</tr>
<tr>
<td>Diagnoses related to Neurological impairment (n)</td>
<td>6</td>
<td>5</td>
<td>.65</td>
</tr>
<tr>
<td>Pulmonary/heart impairment (n)</td>
<td>18</td>
<td>22</td>
<td>.46</td>
</tr>
<tr>
<td>Musculoskeletal impairment (n)</td>
<td>19</td>
<td>17</td>
<td>.38</td>
</tr>
<tr>
<td>Physical activity/wk (h)</td>
<td>4.1 ± 2.5</td>
<td>4.0 ± 2.1</td>
<td>.83</td>
</tr>
<tr>
<td>Fall incidents within last 6 mo (n)</td>
<td>7</td>
<td>9</td>
<td>.88</td>
</tr>
<tr>
<td>MVC (N)</td>
<td>1469.9 ± 689.6</td>
<td>533.4 ± 650.9</td>
<td>.58</td>
</tr>
<tr>
<td>RFD (N/s)</td>
<td>3266.6 ± 2272.1</td>
<td>3704.9 ± 2627.7</td>
<td>.41</td>
</tr>
<tr>
<td>CoP-VM (mm²/s)</td>
<td>22.2 ± 14.8</td>
<td>20.7 ± 13.1</td>
<td>.35</td>
</tr>
<tr>
<td>TUG test (s)</td>
<td>10.2 ± 3.8</td>
<td>11.0 ± 3.1</td>
<td>.81</td>
</tr>
<tr>
<td>FES-I (short) score</td>
<td>11.3 ± 3.5</td>
<td>11.3 ± 4.3</td>
<td>.68</td>
</tr>
<tr>
<td>30-s Chair Stand Test (n)</td>
<td>11.4 ± 3.8</td>
<td>11.2 ± 3.0</td>
<td>.98</td>
</tr>
</tbody>
</table>

Notes: MVC = maximum voluntary contraction; RFD = rate of force development; CoP-VM = center of pressure velocity moment; TUG = Timed Up and Go test; FES-I = shortened Falls Efficacy Scale-International; CON = controls.

Secondary end points.—PRE-to-POST changes in secondary outcomes were greater in WII than in CON for RFD (p = .03), TUG (p = .01), short FES-I (p = .03), and 30-second repeated Chair Stand Test (p = .01; Table 2). In relative terms, the difference at post-intervention between WII and CON participants was 24.6% for RFD, 13.4% for TUG, 4.9% for Short FES-I, and 7.7% for the 30-second repeated Chair Stand Test.

Psychosocial assessments on a 5-point Likert scale in the WII group at weeks 5 and 10 showed that participants who continued with the Wii program either agreed or strongly agreed with the statement that Wii training was fun and motivating (Figure 3). A similar trend was observed for statements 2 and 3, and in addition, the data showed a split opinion within the WII group as to wanting to continue using Wii training in their own home or at a nearby seniors’ center (Figure 3).

Table 2. Pre-to-Post Changes in Secondary End Points (Mean ± SD)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Wii (n = 27)</th>
<th>CON (n = 30)</th>
<th>Between-Group Difference</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE</td>
<td>POST</td>
<td>PRE</td>
<td>POST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RFD (N/s)</td>
<td>3266 ± 2271</td>
<td>4143 ± 2831</td>
<td>3704 ± 2627</td>
<td>811</td>
<td>65; 1556</td>
</tr>
<tr>
<td>TUG test (s)</td>
<td>10.3 ± 3.8</td>
<td>9.0 ± 3.2</td>
<td>11.0 ± 5.0</td>
<td>−1.4</td>
<td>−2.5; −0.4</td>
</tr>
<tr>
<td>FES-I (short)-score</td>
<td>11.3 ± 3.5</td>
<td>10.5 ± 3.0</td>
<td>11.3 ± 4.3</td>
<td>−1.2</td>
<td>−2.2; −0.1</td>
</tr>
<tr>
<td>30-s Chair Stand test (n)</td>
<td>11.5 ± 3.8</td>
<td>13.3 ± 3.2</td>
<td>11.2 ± 3.0</td>
<td>1.1</td>
<td>0.3; 2.0</td>
</tr>
</tbody>
</table>

Notes: Data are presented as pre- and post-intervention means and standard deviations (SD). Absolute between-group difference, 95% confidence interval (CI), and p values are derived from an analysis of covariance, adjusting for gender, age, and baseline level. RFD = rate force development; TUG = Timed Up and Go test; FES-I = shortened Falls Efficacy Scale-International; CON = controls. The means were computed with reference gender = female and baseline RFD = 3,000; TUG = 10; FES-I = 10; and 30-s Chair Stand Test = 10.
Adverse effects.—No adverse events were reported by the participants or the physiotherapist involved in the Wii training during the study period.

Discussion

The main and novel finding in this study was that 10 weeks of biofeedback-based Nintendo Wii training in community-dwelling older adults resulted in a significant improvement in selected physiological outcomes related to lower body mechanical muscle function, where there was an increase of approximately 20% not only in maximal muscle strength (MVC) but also in the capacity for rapid force generation (RFD). Unexpectedly, static postural balance (CoP-VM) remained unaffected following Wii training. Yet, Wii training led to substantial improvements in functional performance (TUG, Short FES-I, and 30-second repeated Chair Stand) compared with nontrained controls. In terms of exercise adherence, the participants who engaged in Wii exercise reported the training to be highly motivating and indicated interest in continuing such exercise activities in their own home or at nearby seniors’ centers.

To our best knowledge, this study is the first RCT to utilize biofeedback-based Nintendo Wii exercise in community-dwelling older adults. Only a few other studies have examined the Nintendo Wii console as a training device in older adults (21) primarily reporting pilot data (20,23), case findings (24), short communication reports (25), or study protocols (26). The Wii training performed in this study was expected to result in improved postural balance accompanied by gains in mechanical muscle function (increases in MVC, RFD). We assumed a positive stimulus on postural balance based on the expectation that the Wii exercises would impose challenges to postural balance control, since the game playing exercises require participants to perform rapid yet controlled shifts in center of pressure position in a variety of directions. It should be recognized, however, that previous non-RCT studies in middle-aged women and older individuals have reported improved (21,23) as well as unaltered (20,25) postural balance with Wii training. These deviating results may be a result of small sample sizes, lack of strict control groups and/or insufficient randomization procedures, or use of subjective balance scales. Biofeedback-based training involving postural balance exercises on a conventional force plate with visual feedback of center of pressure excursion has previously been shown to lead to improved postural balance and reduced fall incidence in older adults (17–19). In this study, the evaluation of postural balance by means of static bilateral testing might not have been sufficiently challenging to the participants to allow detection of potential improvements in postural balance. The Wii training comprised highly dynamic balance exercises, and the possibility exists therefore that the use of more dynamic and challenging balance test modalities could have revealed improvements in postural balance in the WII group. Thus, future studies in well-functioning older adults should employ more challenging postural balance tests to minimize potential ceiling effects on postural balance outcome variables.

Very limited data exist on the potential effect of Nintendo Wii training on mechanical muscle function in older adults. Nitz and colleagues (23) reported a 14% improvement in quadriceps MVC for the right leg and a 17% improvement for the left leg, respectively, following 10 weeks of Nintendo Wii training in 10 women (30–58 years of age). As a novel finding, this study demonstrated a substantial gain (~20%) in rapid force capacity (RFD) of the leg extensors following biofeedback-based Wii training, which was accompanied by a corresponding increase in maximal muscle strength (MVC). This improvement in mechanical leg muscle function as a result of Wii training was likely to be the result of training-induced gains in neuromuscular function, which may have involved an adaptive increase in lower extremity muscle size as well (42,43). Notably, the observed improvements in mechanical leg muscle function could potentially represent a reduction in the risk of falling, as impaired mechanical muscle function in the lower extremities consistently has been identified as one
of the primary risk factors for fall accidents in older adults (6,7,44).

For a given exercise-based intervention program to be successfully implemented in everyday living as well as in senior citizens’ clubs and senior society organizations, it is essential that older people find it feasible, motivating, and enjoyable. Likewise, ensuring that the intervention is integrated with social activities in elderly communities is expected to result in greater long-term sustainability of an intervention. This study showed that older adults engaged in Wii exercise found this modality of biofeedback-based training feasible, motivating, and enjoyable, which is in line with previous reports (20,21).

Some potential limitations may be observed with this study. Five dropouts in the WII group emerged prior to the initial training session, which suggests that the study participants could have benefited from receiving more thorough information about the conditions of the study prior to enrollment. Second, the participants recruited for this study could be characterized as fairly well-functioning in terms of both postural balance and musculoskeletal function. Thus, the current findings may not be generalized to include other elderly population’s, that is, frail individuals or very old adults. Third, training for a longer period than 10 weeks could have resulted in detectable pre-to-post differences in postural balance in the WII group. Finally, during the study period, participants in WII and CON did not receive equal amounts of personal attention (ie, examiner interaction), which might represent a limitation for the results observed in CON.

As a methodological strength of this study, an RCT design was used that followed well-established consort guidelines (41) and involved combined evaluation of various biomechanical, physiological, and psychological outcome measures. Such combined biopsychological approaches might be useful in the future examination of exercise-based interventions in older adults, when seeking to facilitate a more successful and sustainable implementation of various forms of physical exercise as a tool for fall prevention and rehabilitation in this particular population.

CONCLUSIONS

Ten weeks of biofeedback-based Nintendo Wii training, which involved both balance and strengthening exercises, led to significant improvements in maximal isometric leg muscle strength, rapid force capacity, and functional performance in community-dwelling older adults. However, static bilateral postural balance remained unaffected. The latter finding, however, might reflect a potential ceiling effect related to the type of testing used to evaluate postural balance. The high level of participant motivation suggests that Nintendo Wii training may result in a high degree of compliance and adherence to home- and/or community-based training, however, these aspects of effectiveness need to be explored in future studies.

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