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The Braking Force in Walking: Age-related Differences and Improvement in Older Adults With Exergame Training

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The purposes of this present research were, in the first study, to determine whether age impacts a measure of postural control (the braking force in walking) and, in a second study, to determine whether exergame training in physically-simulated sport activity would show transfer, increasing the braking force in walking and also improving balance assessed by clinical measures, functional fitness, and health-related quality of life in older adults. For the second study, the authors developed an active video game training program (using the Wii system) with a pretest-training-posttest design comparing an experimental group (24 1-hr sessions of training) with a control group. Participants completed a battery comprising balance (braking force in short and normal step conditions), functional fitness (Senior Fitness Test), and health-related quality of life (SF-36). Results show that 12 weeks of video game-based exercise program training improved the braking force in the normal step condition, along with the functional fitness of lower limb strength, cardiovascular endurance, and motor agility, as measured by the Senior Fitness Test. Only the global mental dimension of the SF-36 was sensitive to exergame practice. Exergames appear to be an effective way to train postural control in older adults. Because of the multimodal nature of the activity, exergames provide an effective tool for remediation of age-related problems.

Keywords: exergame training, aging, braking force, functional fitness, quality of life

Falls are a major public health problem, contributing to significant morbidity and mortality among older adults. Indeed, approximately 30% of people over 65 years of age living in the community report falling each year, above 50% report fear of falling, and 38% report avoiding activity due to fear of falling (Gillespie et al., 2009; Zijlstra et al., 2007). Preservation of balance and walking ability in the elderly is fundamental to maintaining functional independence. In fact, previous studies have shown that the limitations of mobility and functional losses observed in older adults result in dependence in daily activities, participative limitations and social insulation, and institutionalization; and these limitations generally cause a decrease in quality of life (Metz, 2000; Yeom, Fleury, & Keller, 2008). Fall prevention programs are an important public health strategy; consequently, there is a general need to develop effective and practical exercise programs that improve balance, functional fitness, and health-related quality of life in the elderly.

In the past decade, a substantial number of studies have shown that some exercise interventions including strength, flexibility, and balance training (Hauer et al., 2001); Tai Chi (Wong, Lin, Chou, Tang, & Wong, 2001); or combinations of these activities (Shumway-Cook, Grubner, Baldwin, Liao, 1997; Skelton & Dinan, 1999) have improved lower limb strength, balance, and functional ability. In addition, these interventions have been shown to reduce the risk of falls and fear of falling (Howe, Rochester, Jackson, Banks, & Blair, 2007; Sherrington et al., 2008) and also improve health-related quality of life (Cassilhas et al., 2007).

Recent investigations have studied the potential effects of exergame training programs. Exergames combine entertaining video games with significant physical exercise by using physical input devices that require physical responses, and they have seen a rapid growth in popularity and use among the elderly (CNC, 2010). Exergame systems require participants to produce discrete, controlled movements to and beyond their base of support in response to visual targets. This interaction with the game generates real-time visual and spatial feedback that may promote better body control and be useful for fall prevention (Reed-Jones, Dorgo, Hitchings, & Bader, 2012). Finally, the exergame systems also provide a wide range of motivating tasks that require several different modes of physical activity and varying task difficulty (Maillot, Perrot, & Hartley, 2012). An additional advantage of exergames (such as the Nintendo Wii Fit with Balance Board [Nintendo, Kyoto, Japan]) is that they offer an alternative to standard balance exercise training and they allow the recording of balance measurements.

It has been demonstrated that exergames generate both physiological demands for increased energy expenditure (Graves et al., 2010; Guderian et al., 2010) and cognitive challenges (Anderson-Hanley et al., 2012; Maillot et al., 2012). Exergaming increases motivation during exercise training due to its enjoyable and challenging nature, which could support long-term adherence for exercising balance (Graves et al., 2010; Nitz, Kuys, Isles, & Fu, 2009). Other authors have evaluated the potential balance benefits after several sessions of exercises with video game training. Some of these studies established the reliability and validity of exergames, particularly the Wii Balance Board, as providing safe, adaptable and low-cost balance training and testing for older adults (Agmon, Perry, Phelan, Demiris, & Nguyen, 2011; Reed-Jones et al., 2012; Yamada et al., 2011; Young, Ferguson, Brault, & Craig, 2011). Other studies used a pretest-training-posttest design and identified benefits to balance and mobility in the elderly. Nitz et al. (2009) found improved balance and lower limb muscle strength in 10 women aged 30–58 years after 30-min sessions twice weekly for 10 weeks; although changes in touch, vibration, proprioception, cardiovascular endurance, mobility, weight change, activity level,

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and psychosocial variable (i.e., well-being) were not significant. Clark and Kraemer (2009) conducted a single-subject design study with a patient aged 89 years diagnosed with an unspecified balance disorder and a history of multiple falls. After six 1-hr treatment sessions using the Nintendo Wii bowling simulation, the patient showed improvement on the Berg Balance Scale, the Dynamic Gait Index, the Timed Up and Go Test (TUG) and the ABC Scale. The authors suggested that this exergame intervention may have decreased fall risk for this individual. However, this study only focused on a single participant, so it is necessary to treat the author's conclusions with caution. Recently, Dougherty, Kancel, Ramar, Meacham, and Derrington (2011) showed that the use of the Wii Balance Board three times a week for 10 min significantly improved balance and potentially decreased the risk of falls, as measured by the Berg Balance Scale. Additionally, the Wii Fit 'Age' recorded before and after the entire intervention decreased. In summary, there is evidence that exergames can improve balance as measured by general clinical assessments of balance.

Despite an increasing interest in the general benefits of exergames for balance, little evidence is available on the direct transfer effects of exergames on specific biomechanical measures of balance. Transfer effects refer to the generalization of learning from the training task to an untrained task. To our knowledge, only one study has examined the effects of exergames training on such a measure in older adults with a pretest-posttest design. Lamoth, Caljouw, and Postema (2011) found after a six-week intervention period that healthy elderly adults showed improved postural control from a video game-based exercise program designed to improve balance. Postural control was measured with an accelerometer during quiet standing with feet parallel and in tandem stance. However, in spite of the encouraging results of this study, there is a need for more research on the effects of exergame training on the biomechanics of posture. In the literature, many measures have been used to assess the balance and postural capacity of older adults, including clinical measures (e.g., TUG, Berg Balance Scale) and biomechanical parameters (e.g., body sway, gait variability). Many studies highlight the link between these measures and the risk of falling (Hatch, Gill-Body, & Portney, 2003). However, these measures are distal to the situations actually encountered by seniors. One of the central consequences of aging and the fear of falling is a reduction in the step size when walking. That is why in the present research we propose a biomechanical measurement which is based on the braking force in walking. This is less traditional but more proximal to the biomechanical origins of falls. Before specifically examining the effects of exergame training, we study the effect of age on this recent measure.

We embedded our examination of the braking force within a multidisciplinary approach that also looked at functional fitness and psychological aspects of well-being. We believed that an approach which would consider psychological, functional, and postural dimensions at the same time would permit a better understanding of the benefits of exergames in fall prevention. This multidisciplinary approach was intended to integrate objective information about biomechanical performance with subjective information related to the psychological limitations that might affect execution of the performance in the real world. To our knowledge, no study has examined the benefits of exergames with such a multidisciplinary approach.

The main purpose of the present research was to determine whether exergame training in physically-simulated sport activity would show transfer, improving the braking force as well as clinically-assessed balance, functional fitness, and health-related quality of life in older adults. The braking force has been the focus of several studies in the field of biomechanics, highlighting its relevance in the study of falls in the elderly (Chastan, Westby, et al., 2009; Chastan, Do, et al., 2009; Chong, Chastan, Welter, & Do, 2009). In the standing posture, postural balance is maintained as long as the subject is able to confine the projection of the center of mass (CoM) within the postural basis. This condition cannot be maintained while walking because the CoM is cyclically outside the postural basis. However, to maintain successful walking it is necessary to avoid accidental falls by maintaining postural balance. The process of balance control during walking is therefore different from that during upright posture maintenance. In a gravitational field, all objects are attracted to the ground, so walking actually involves controlled falls. The characteristics of this fall, or more precisely the strategy to control the fall, can be studied from the characteristics of the vertical velocity of the CoM. It has been shown that in unaffected young adults the fall of the CoM during the single stance phase of walking is braked before the swing foot hits the ground. For patients with disorders of balance, as in unmedicated Parkinson's patients, the fall of CoM is stopped mechanically by the contact of the swing foot. In other words, in unaffected individuals, there is an active brake of the fall of CoM; whereas in the Parkinson's patient, the brake is passive. When Parkinson's patients are medicated, active braking reappears (Welter et al., 2007; Chastan, Westby, et al., 2009; Chastan, Do, et al., 2009). This improvement is accompanied by a decrease in balance problems. In patients with balance disorders that are not improved by drug treatments (e.g., progressive supranuclear palsy patients; Chastan, Westby, et al., 2009; Chastan, Do, et al., 2009), braking of the fall of CoM remains passive. These studies suggest that the braking involves the development of coordinated muscle activity to counter the force of gravity.

The aims of this research were twofold. They were (a) to identify the differences in age on the braking force and (b) to determine whether the age-related impairment can be reduced via exergames that elicit multimodal involvement. Our first step was a preliminary experiment to confirm that there are age-related differences in the braking force. During CoM fall, muscles that resist the force of gravity play a significant role (these muscles include the foot extensor muscle, quadriceps, and gluteus). However, strength and resistance in these muscles decreases significantly with aging (Roubenoff, 2000; Runge, Rittweger, Russo, Schiessl, & Felsenberg, 2004). We measured the braking force in 35 younger adults and 34 older adults in the initial stride of a walk, both with a normal step length and a shorter-than-normal step length. We found that the braking force in both step lengths was significantly lower in older adults. Once we established in the preliminary experiment that the braking force was impaired in older adults, we moved to the main experiment where we studied the effect of exergames training on the braking force as well as functional fitness and health-related quality of life in older adults.

Preliminary Experiment: Age Differences in the Braking Force

Method

Participants. Potential participants were contacted through flyers posted in town halls, universities, and community senior centers in the region of Paris, France. Sixty-nine participants divided into two age groups (20–35, 65–80) took part in the experiment. There were 35 participants in the younger group (17 women, 18 men) and 34 in the older group (22 women, 12 men). Each participant completed a questionnaire about their health history, level of education, and physical activity level (1 = never, 2 = sometimes in a year, 3 = once a month, 4 = once a week). All potential subjects also rated their health on a five-point Likert-type health scale (1 = very bad, 2 = bad, 3 = fair, 4 = good, 5 = excellent); those who rated their health as very bad or bad were excluded. Participants with neurological or motor impairment including requiring walking aids were also excluded from the cross-sectional study. Descriptive statistics for these measures are given in Table 1. There were no significant differences between the two groups in level of physical activity and years of education. They gave their informed consent and were not compensated for their participation. Data collection took place in the laboratory.

Apparatus. The braking force was measured with a pressure platform (Zebris FDM Version 1.5 [Zebris Medical GmbH, Achen, France] 54 cm × 62 cm, with 8,064 0.8 cm^2 force sensors arranged in a square matrix). WindFM software (Zebris Medical GmbH, Achen, France) provided pressure and vertical force resultants under each foot. Data were recorded online with an Intel personal computer (Intel, Santa Clara, CA). Analysis of recording offline was realized with software developed for this purpose, which extracted the time and magnitude of the braking force.

Test Procedure. The balance control of the subject was measured by the braking force on the fall of the CoM during the single-support phase of walking; more precisely, during the first step of a gait initiation paradigm (Welter et al., 2007). Figure 1 shows an example of the variation in the resultant vertical forces under each foot. The onset of the movement of gait initiation starts at t0. Between t0 and foot-off (FO) is the phase of anticipatory postural adjustments that prepares the execution of the step (Brenière, Do, & Bouisset, 1987). The plots indicate that the force under the starting foot (gray line in the figure) increases then decreases (i.e., there is first a loading and then an unloading). The force under the stance foot (black line in the figure) shows the reverse (i.e., there is first an unloading and then a loading). Between FO and foot contact (FC) is the swing phase. The plot shows a decrease in the force under the stance foot shortly after the FO, then an increase. We measured the magnitude of the positive change between the minimum and the force at FC. This difference in force represents the braking force (BF). Given that the higher the velocity the greater the step length and the braking force will be, we decided to study two different step lengths: normal and shorter-than-normal. The two step lengths were determined according to the subject's height; 20% for the shorter-than-normal step and 35% for the normal step. The subject was asked to always

Table 1 Means of Demographic, Health, and Exercise Variables for Younger and Older Participants

	Younger Participants		Older participants			
	M	*SD*	*M*	*SD*	*t*	*p*
Age (years)	27.09	3.89	68.65	5.28	3.80	.00
Self-rated health	4.31	0.67	3.94	0.54	2.51	.01
Years of education	16.20	2.27	15.94	3.08	.39	.69
Body mass index (kg/m^2)	22.79	4.21	24.33	4.13	1.54	.13
Physical activity	3.31	0.93	3.06	1.07	1.05	.29

Note. M = mean; *SD* = standard deviation.

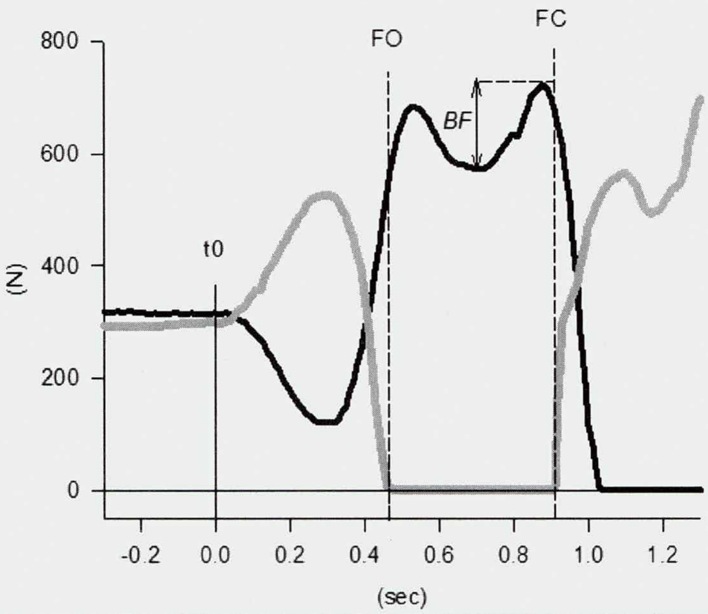

Figure 1 — Plots of the braking force. Typical traces of vertical ground reaction force (in newtons) of starting foot (gray line) and of stance foot (black line). t0: Onset of gait initiation movement; FO: foot-off; FC: foot-contact; BF: braking force.

start with the preferred leg. Six repetitions for each step condition were recorded for each subject.

Results and Discussion

We carried out MANOVA with age group as the independent variable and with two dependent measures: the braking force in both a normal step and in a shorter-than-normal step. There was a significant effect of age group: *Wilk's* = 0.63, $F(2, 68) = 19.04$, $p < .000$, $\eta^2 = .366$. Then, we carried out ANOVA on each measure; the effect of age group was significant for both (Table 2). These results reveal that older participants have a lower braking force magnitude than younger participants, both for normal and shorter-than-normal steps.

The results show an age-related decrement in the braking force, consistent with a balance control deficit in the older adults. The balance control deficit, in turn, could generate vulnerable behaviors in risk situations. These results are the first to show a decline in braking force among seniors. However, it will be important to compare these results to those with more traditional measures, such as the TUG or body sway. Moreover, given the relatively small size of the sample, one should be careful about generalizing the results. Such results would serve to validate the use of braking force in the assessment of balance and posture. With a view to proposing effective means of remediation against the risk of falling, it is relevant to consider training programs that might specifically improve postural control abilities. As we argued in the introduction to this work, exergames have many characteristics that could actively solicit antigravity muscles and thus affect the braking force. If an exergame training program enhances lower-body muscle strength, and therefore the braking force while improving postural coordination among older participants, then exergames could become a leisure activity of considerable benefit.

Main Experiment: Effect of Exergame Training on Balance, Functional Fitness, and Health-related Quality of Life

In our preliminary experiment, we established that the braking force is lower in older adults. The purpose of the main experiment was to determine whether exergame training in physically-simulated sport activity would show transfer, increasing the braking force and also improving balance as assessed by clinical measures, functional fitness, and health-related quality of life in older adults. We developed an active video game training program using a pretest-training-posttest design comparing an experimental group with 24 1-hr training sessions with an untreated control group.

Method

Participants. Potential participants were contacted through flyers posted in town halls and community senior centers. People responding were contacted by phone and they provided an estimation of their physical activity, video game use, and health status. Sixteen independently-living older adults (12 women, 4 men, between 65–78 years) divided into two groups (8 in training group and 8 in control group) recruited from the region of Paris, France, volunteered to take part in this longitudinal intervention study during 14 weeks. None reported falling in the previous 12 months. We included only those individuals who reported never playing video games, who lived a sedentary lifestyle, and who rated their health as fair or better. The study included pretraining (first week) and posttraining (fourteenth week) sessions for assessment and, for the training group, the 24 training sessions. Each participant was required to have a medical certificate permitting the practice of physical activity and to have satisfactory scores in the Mini-Mental State Examination (Folstein, Robins, & Helzer, 1983), the Geriatric Depression Scale (Yesavage et al., 1982-1983), the Falls Efficacy Scale (Kempen et al., 2008), and the Modifiable Activity Questionnaire (MAQ; Kriska et al., 1990). Descriptive statistics for these measures are given in Table 3. The groups did not differ on any of these measures. It should also be noted that the 16 participants were a subset of the 32 reported by Maillot et al. (2012). That report was concerned with changes in cognitive function as a result of exergame training. The 16 for whom results are reported here were those for whom braking force measures of balance were obtained. The psychosocial measures of quality of life have not been previously reported. The measures of functional fitness were previously reported; the results for the subset of 16 are reported here because they are directly relevant to balance.

Measures. The impact of the training program was evaluated by performance on the braking force, a functional fitness battery, and psychosocial variables reflecting health-related quality of life.

Braking Force. We used the same index as in the preliminary experiment.

Functional Fitness. Functional fitness was evaluated with the Senior Fitness Test (SFT; Rikli & Jones, 2001), which measures the underlying physical parameters associated with functional ability and identifies whether an older adult may be at risk for loss of ability to perform functional movements such as walking, stair climbing, and standing up. Height (m) and body weight (kg) were measured to calculate body mass index (BMI, kg/m^2). We used only tests from the SFT directly related to balance control. The *Chair-Stands Test* measures muscle strength for the lower body by the number of full stands that can be completed in 30 s with arms folded across the chest.

Table 2 Comparison on Braking Force According to Step Length Between Younger and Older Participants

	Younger Participants		Older Participants			
	M	***SD***	***M***	***SD***	***F***	***p***
Braking force: short step (N)	125.46	43.79	73.13	43.13	25.00	.00**
Braking force: normal step (N)	222.57	74.00	118.11	69.11	36.67	.00**

Note. M = mean; *SD* = standard deviation; ** $p < .01$

Table 3 Means of Demographic, Health, Exercise, and Subjective Well-Being Variables for Control and Training Groups

	Control		Training			
	M	*SD*	*M*	*SD*	*t*	*p*
Age (years)	74.00	2.14	74.13	4.73	.07	.94
Self-rated health	3.75	0.71	3.63	0.52	–.40	.69
Years of education	11.25	2.87	11.50	1.69	.21	.83
Body mass index (kg/m^2)	26.75	3.22	26.38	4.57	–.19	.85
MMSE	29.50	0.53	29.13	0.99	–.94	.36
FES	19.12	1.73	21.50	3.96	1.55	.14
GDS	5.88	3.27	7.25	2.55	.93	.36
MAQ (hr/week)	0.69	0.69	0.72	0.66	–.11	.92

Note. M = mean; *SD* = standard deviation; MMSE = Mini-Mental State Examination; FES = Falls Efficacy Scale; GDS = Geriatric Depression Scale; MAQ = Modifiable Activity Questionnaire.

The *6-Minute Walking Test* (6MWT) evaluates cardiovascular fitness performance by the number of meters walked in 6 min. The *8-Foot Up-and-Go Test* evaluates motor agility and balance by the number of seconds required to get up from a seated position, walk 8 feet (2.44 m), turn, and return to seated position.

Psychosocial Variables. Health-related quality of life was evaluated using the Medical Outcomes Survey Short Form 36 (SF-36). It is a multipurpose, short-form health survey with 36 questions. It yields an eight-scale profile of functional health and well-being scores, as well as psychometrically-based physical and mental health summary measures (physical functioning; role physical; bodily pain; general health; vitality; social functioning; role emotional; and mental health), two global scores (physical and mental health), and an additional item measuring health transition (Ware et al., 1995). A French version of the form was used (Leplège, Ecosse, Verdier, & Perneger, 1998). In our analyses, we used the two global scores.

Procedure. Sixteen participants were randomly assigned (using sealed envelopes) to two groups: eight participants were assigned to the exergames training group and the other eight participants were assigned to a no-training, no-contact control group. A doubled blind experimental plan was used where neither the participants nor the experimenter knew if they were in the control or experimental group. Participants in the training group completed two 1-hr exergame sessions per week over a period of 12 weeks, resulting in total training time of 24 hr. For the exergame training, we used the Nintendo Wii, a video game console with motion-sensitive technology, with the Wii Remote, the Wii Nunchuk, and the Wii Balance Board. The video game display was a projector projected on a portable screen 76 cm in height and 102 cm in width. A complete description is given in Maillot et al. (2012). Each training session was divided into two periods: the first playing in pairs in the Wii Tennis or Wii Boxing game and the second playing alone using the Wii Balance Board with the Wii Soccer Headers, the Wii Ski Jump, the Wii Hula Hoop, and the Wii Marbles games. The tennis and boxing games were chosen for their aerobic load and because they allow wide freedom of movement. Other games with the balance board were chosen according to the various postural adjustments they demand (forward/backward, left/right, global rotation). For all games, participants were asked to progressively increase their activity level and challenge to improve their performance in the games. At the end of every session, each participant completed two trials in the slalom ski game. We chose this game task as our measure of exergame learning because it requires substantial postural control, and improvement would be evidence that the program trains balance control generally. For this balance task, the participants 'slalomed' by shifting their weight to alternate between blue and red doors shown on the display as quickly as possible. The performance score is a function of the time to complete the course and the number of doors cleared. The best score from the two trials of the balance task was recorded to follow the learning of the Wii balance game. At the end of the training program, the participants completed a questionnaire that measured their subjective impression of the program. Six questions were asked, two in the form of five-point scales on the similarity between the exergame session and conventional forms of physical activity (1 = very much, 2 = much, 3 = relatively, 4 = not much, 5 = none) and on the difficulty of the training sessions (1 = very easy, 2 = easy, 3 = reachable, 4 = difficult, 5 = very difficult); the other four were yes-no questions on whether their body knowledge had improved, whether they would like to continue an exergames practicum, whether they would like to begin a program of physical activity, and whether they would like to acquire an exergame game console. The participants in the control group committed themselves not to modify their sedentary lifestyle and not to begin playing video exergames or engage in any other new physical activity over the 14 weeks of the study.

Results

The first step in the analysis was to verify that the training and control groups were equivalent at the outset of the program. To compare the pretraining scores on both physical and psychological measures for those who would later be assigned to the training and control groups, *t* tests were used. Among the 17 comparisons, none was significant.

The second step in the analysis was to characterize compliance and the accessibility of, and interest in, the training. All participants completed the study through the posttest. The number of completed sessions for the eight trained participants ranged from 20 to 24 (M = 23.25). Overall adherence was 96.88%, with 186 out of a possible 192 sessions completed by participants (eight participants for 12 weeks with two sessions per week). The final questionnaire indicated that the exergame training was manageable for older persons (75% agreed) and seemed comparable to other physical activity (87.5% of results ranged between very much and relatively). All participants reported that they would like to continue with exergame activity, however only 25% contemplated acquiring a game console. Finally, 87.5% of participants thought that their body knowledge improved with the training program and 50% were considering beginning a program of physical activity.

Participants showed significant improvement in performance across training sessions on the Wii Ski Slalom balance score: $F(23, 161) = 10.61$, $p < .001$, $\eta^2 = .60$. Follow-up tests using Tukey's Honestly Significant Difference (HSD) test showed significant improvement from the first session to the sixth session in the Ski Slalom balance task.

The central step in the analysis was to determine whether the training regimen resulted in greater change in the trained group than the untrained controls. We calculated the change score by subtracting the pretest score from the posttest score for each measure. First, we explored the possibility of test-retest improvement in the control group using one-group *t* tests to test the observed change against zero. There were four significant changes (Chair Stands, 8-Foot Up-and-Go, Social Functioning, Mental Global score), but these were negative changes from pretest to posttest rather than improvements. To determine whether the change was significantly greater in the trained group than in the controls, we carried out a MANOVA with all the measures within a set as dependent variables. When the overall difference between treatment and control was significant, we carried out *t* tests on each of the component measures using the modified Bonferroni correction to protect against an inflated chance of a type I error (Holm, 1979). The first set of comparisons was for the physical measures of braking force and of balance-related functional fitness. The descriptive and inferential statistics for those change scores are given in Table 4. Physical improvement was significantly greater in the training group: *Wilks's* $\Lambda = .09$, $F(5, 10) = 18.11$, $p < .001$, $\eta^2 = .901$. Follow-up tests showed that greater improvement in the training group than the controls was observed for all the physical measures except the braking force in shorter-than-normal step condition (although there was an improvement in the normal step condition). The second set of comparisons was for measures of quality of life, for which descriptive and inferential statistics are given in Table 4. The effect of group was significant: *Wilks's* $\Lambda = .07$, $F(10, 5) = 6.43$, $p < .001$, $\eta^2 = .928$. Follow-up tests showed that improvement for only two of these measures was significantly greater in the training group than in the control group (i.e., the score of social functioning and the mental global score; Table 4).

Finally, to estimate the relations among balance, functional fitness, and quality of life, we intercorrelated change scores and the differences between the pretest score and the posttest score. There were four subsets of variables. We averaged the z scores for the measures in each subset. We combined the two measures representing balance ability (i.e., the braking force in the normal step condition and the 8-Foot Up-and-Go [from the Senior Fitness Test], which is recognized as a clinical test of dynamic balance. Then, we combined the two measures of muscle strength and endurance (the Chair Stands task and the 6MWT) as a functional fitness subset (from the Senior Fitness Test). Finally, we used the two global scores from the SF-36. Therefore, the four components we correlated were (a) balance component (i.e., normal step condition and 8-Foot Up-and-Go), (b) functional fitness component (i.e., Chair Stands and 6MWT), (c) global physical health component (i.e., physical functioning,

Table 4 Comparison of Pretest-Posttest Change Scores on Objective and Subjective Evaluation for Training and Control Groups

	Control		Training			
	M	*SD*	*M*	*SD*	*t*	*p*
Balance and functional fitness						
Braking force: short step (N)	6.62	17.05	16.28	25.84	.88	.39
Braking force: normal step (N)	–6.55	12.41	28.41	43.60	2.18	.04*
Chair stands (number)	–2.00	1.20	26.63	1.19	7.76	.00**
8-Foot Up-and-Go (s)	0.72	0.44	–1.07	0.74	–5.92	.00**
6MWT (meters covered)	2.11	23.94	55.54	39.75	3.26	.00**
Quality of life (SF-36)						
Physical functioning	0.13	1.25	0.25	2.55	.12	.90
Role physical	0.25	1.91	–0.63	1.99	–.90	.39
Bodily pain	–0.38	1.06	0.50	2.20	1.01	.33
General health	–0.38	2.07	1.13	1.89	1.52	.15
Physical Global Score	–0.38	2.92	1.25	5.31	.76	.46
Vitality	–1.13	1.46	0.63	2.82	1.56	.14
Social functioning	1.25	1.28	–0.88	1.64	–2.89	.01*
Role emotional	–0.63	1.30	0.13	0.99	1.30	.26
Mental health	0.88	2.03	2.25	2.25	1.28	.22
Mental Global Score	–1.75	2.05	4.25	2.71	4.99	.00**
Health thinking	0.00	0.00	0.25	0.71	1.00	0.33

Note. M = mean; *SD* = standard deviation; N = newton; 6MWT = 6-Minute Walking Test. For Chair Stands, a positive mean corresponds to an improvement between pre- and posttest. For 8-Foot Up-and-Go, a negative mean corresponds to an improvement between pre- and posttest. All *p* values smaller than $p = .05$ remain significant after Bonferroni correction.*$p < .05$; **$p < .01$

role physical, bodily pain, general health), and (d) global mental health component (i.e., vitality, social functioning, role emotional, mental health). The correlations between the components are shown in Table 5. The results show that improvements in balance were significantly associated with improvements in functional fitness and mental health. Similarly, improvements in functional fitness were significantly associated with improvements in mental health.

Table 5 Correlations Among Balance Component, Functional Fitness Component, Physical Health Component, and Mental Health Component

Component	1	2	3	4
1. Balance	—			
2. Functional fitness	.76*	—		
3. Physical health	.18	.04	—	
4. Mental health	.67*	.70*	.34	—

Note. * $p < .05$.

Discussion

The purpose of the main study was to assess the potential of exergame training based on physically-simulated sport play as a mode of physical activity that could have benefits not only on balance, but also on balance-related functional fitness and health-related quality of life for older adults. The training program was modeled on programs of physical activity and balance prevention that had previously shown strength and flexibility benefits.

We found that the biomechanical measure related to balance, the braking force in a normal step, improved significantly after training. With the same step length, the velocity of the CoM fall was decreased significantly with training, suggesting more active control of balance by trained participants. We also found that clinical measures of balance and measures of balance-related functional fitness as measured by the SFT improved as a result of training. These changes in performance show that the program improved lower limb strength, cardiorespiratory resistance, and motor agility in trained participants. The significant improvement in the ski slalom task is consistent with the improvements in these more basic components, although we cannot rule out the possibility of task-specific learning.

These findings on balance and functional fitness scores were not surprising since the activities included in the exergame training involved considerable lower limb balance requirements and body weight resistance workouts that could be expected to produce these results. In the first component of each training session, the participants realized wide movements in unlimited space via the tennis and boxing games. These aerobic activities directly challenged the cardiorespiratory and muscular resistance of the participants (Miyachi, Yamamoto, Ohkawara, & Tanaka, 2010). In the second component, using the balance board games required finer movements eliciting weight transfer at progressively greater levels of difficulty, either in the anterior-posterior axis, the lateral axis, or 360 degrees. Moreover, whatever the nature of the motor responses, each action was associated with visual feedback that allowed systematic adjustments of performance. Thus, the properties of the exergame system are probably responsible for observed improvements (Reed-Jones et al. 2012).

A parallel hypothesis was that the exergame exercises would produce gains in performance on the Wii tasks themselves. Participants showed significant and substantial gain over the course of 24 hr of practice across 12 weeks in the slalom balance task, which challenged a variety of balance control abilities. This improvement showed that this senior population (which was sedentary and new to exergames) could benefit from this system of balance training (Maillot et al., 2012; Nitz et al., 2009; Williams et al., 2010). This conclusion is bolstered by the high level of exercise adherence and the questionnaire reports that participants appreciated and would like to continue exergame activity. The subjects were highly motivated to exercise balance because they found gaming challenging and enjoyable. Results of this study show that healthy older adults can benefit both specifically and generally from a balance-focused video game-based exercise program.

During gait initiation in healthy adults, postural control is reflected by an active reversal of the CoM fall, or braking, which occurs before the swing contacts the ground (Chong et al., 2009; Welter et al., 2007). Active control of the fall of the CoM requires effective solicitation of muscles countering the force of gravity (Chastan, et al. 2010). Age-related deficits in muscle strength and endurance of the lower limbs are likely to be responsible for the reduced magnitude of the braking force in older adults. The results of this study show that the braking force is affected by age but can be improved with training in exergames. This training also shows an improvement in several measures of functional capabilities such as lower limb strength (i.e., chair stands). The correlational analyses showed strong relationships among the components of balance control and balance-related functional fitness. Consequently, the results suggest that the improvement on measures of braking force is related to the improvement of balance-related functional fitness.

Finally, concerning the effect of the program on perceived health-related quality of life, results were mixed. Only the global mental dimension was sensitive to exergame practice. This result demonstrates that 12 weeks of training caused a reduction in activity limitations due to mental health among the trained participants. During the four weeks that preceded the posttest, trained participants reported greater vitality to carry out activities of daily living and fewer limitations related to fatigue and perceived pain related to the age in their social relations. Moreover, the results of correlational analyses show that while balance and functional fitness components improve with the program, these improvements are accompanied by an improvement in perceived mental health. These results suggest that the program has a multidimensional impact. To our knowledge, this is the first study to demonstrate the effectiveness of exergame training program in seniors on biological, psychological, and social variables simultaneously. The results warrant further investigations in the areas of exergames. Beyond improvements in clinical measures of balance already reported in the literature, this study highlights the range of benefits from postural exergame training in terms of biomechanical changes. However, given the small size of the sample, it is important to be cautious in generalizing the results.

This study had several limitations. One limitation of this interpretation is that we are simply comparing our results with the existing empirical literature rather than including a conventional treatment group in our study, which included only physical activity and not exergames. It would be necessary to carry out another intervention study that included a nonexergame balance training group to determine how much of the exergame benefits are due to the balance exercises with video games. Another limitation is present in the number of measures used. This study showed that the braking force is sensitive not only to age, but also in training. It would be interesting to use this new measure with more conventional measures such as the TUG or body sway. This would validate the relevance of the braking force in reducing the risk of falling and fear of falling.

Conclusion

Mobility is a key factor in functional independence, decreasing the risk of falls and improving the quality of life (Guralnik et al., 2000). Decline in mobility is directly related to lifestyle. Thus, the more sedentary the lifestyle, the more mobility is likely to be affected. Our results show that training engenders an improvement of active control of stepping. In aging, the shortening of steps is frequently observed, compensating for a lack of postural control. The stability of a normal step improved with training, which could reduce the need for shortened steps. In view of the results of this study, exergames appear to be an effective way to train postural control in older adults. This new regimen could thus be developed to promote an active lifestyle and could provide a reduction in the barriers to physical activity for older, more sedentary adults.

Given the multimodal nature of the activity, exergames provide an effective tool for remediation of age-related problems. Indeed, it appears it would be appropriate to extend the investigation to more vulnerable populations, such as Parkinson's patients. Recent studies suggest that the braking force is a significant factor in falls in Parkinson's patients (Chastan, Westby, et al., 2009; Chastan, Do, et al., 2009). Other studies show that Parkinson's patients are able to benefit from transfer with virtual reality video gaming (dos Santos Mendes et al., 2012). This may extend to improvements in balance. In summary, our study shows that healthy older adults can benefit from a video game-based exercise programs to improve balance, and that subjects were highly motivated to carry out the exercise that leads to improvements in the quality of life. The study provides a starting point for future research exploring the generalizability of the observed benefits.

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