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Research article

Effect of Flywheel Resistance Training on Balance Performance in Older Adults. A Randomized Controlled Trial

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Abstract

This study aimed to assess the effects of flywheel resistance exercise training on postural stability and mobility in older adults and to investigate whether changes in power are related to improvements in balance. Thirty-six participants were randomly allocated to either a flywheel resistance exercise training group (ETG; n = 18) who underwent 6-weeks of training (2 to 3 days per week) or a control group (CON; n = 18). The average power and Mean Propulsive Velocity (MPV) were computed. Timed up-and-go test (TUG) and postural balance (anterior–posterior (AP) and medial–lateral (ML) center of pressure (COP) excursions) in different tasks were also assessed. Within-group analyses showed a significantly better performance in mobility (TUG, $p < 0.01$) and COP_{AP} with open eyes ($p < 0.05$) for ETG. Between-groups analyses showed significant improvements in TUG (-0.68 [-1.25 to -0.98]) and in COP_{AP} (-2.90 [-4.82 to -0.99]) in ETG compared with CON. Mean power also increased in ETG and the changes were related to those observed in stability (COP; $r = -0.378$, $p < 0.05$). In conclusion flywheel resistance exercise training improved balance and mobility in older adults as well as muscle power.

Key words Strength; mobility; eccentric exercise.

Introduction

Falls are considered a major public health concern and an important cause of morbidity and premature mortality among community-dwelling older adults (Kumar et al., 2016). Athough factors contributing to falls in this population are numerous; balance impairment (balance dysfunction or postural instability) has been strongly associated with falls risk (Rubenstein, 2016). This can be attributed to the progressive age-related decrease of neuromuscular function, including diminished capability of muscle to develop force rapidly and alterations in muscle contractile properties (Hortobágyi et al., 2001). Moreover, this decline could be attributed to the deterioration in the sensory system, leading to reduced muscle strength and capacity for balance recovery (Isner-Horobeti et al., 2013). Numerous authors have reported that during aging, muscle power (determined by slowed contraction velocity) decreases to a greater extent and more rapidly than strength does, contributing to increased risk of falls (Foldvari et al., 2000). Thus, as it is hypothesized that muscle power may be associated with balance performance (rapid generation of muscle force to react quickly to threats to balance), some authors have suggested that this outcome is even more important than strength as a predictor of falls in older adults (Orr, 2010).

Regular exercise is considered to be one of the main preventive measures for the decline in functional ability experienced by older adults and has been shown to be an effective strategy to reduce the number of falls in this population (Sherrington et al., 2008). Further, both muscle strength and power are strong contributors to postural stability (Cadore et al., 2013). Thus, as reviewed by Orr (2010), resistance interventions in older adults have been shown not only to improve neuromuscular activity, strength, power or functional capacity, but also to improve balance (Howe et al., 2011) and reduce the risk and incidence of falls (Gillespie et al., 2012). However, a systematic review showed that progressive resistance training has not been consistently shown to improve balance performance in older adults (Orr et al., 2008). Therefore, scientists and clinicians have focused their attention on finding effective exercise interventions to improve muscle strength and power, and thus improve balance.

Eccentric exercise modalities are classically used to improve muscle strength and power in healthy participants (Naczk et al., 2016) and flywheel inertial devices that also influence the eccentric action, are currently employed for rehabilitation and clinical purposes (Isner-Horobeti et al., 2013) to revert the undesirable effects of aging on the musculoskeletal system in older adults (Raj et al., 2012). These devices are reported to be more effective than traditional free weight training in improving muscle peak power (Chiu and Salem, 2006) and balance (Onambélé et al., 2008) and are considered an effective method for muscle strengthening in older adults (Onambélé et al., 2008; Raj et al., 2012). Improvement of eccentric muscle strength could also be beneficial to reduce fall risk in older people (LaStayo et al., 2003). This seems logical considering that for many tasks that involve a high risk of falls, the majority of the work is performed eccentrically (e.g., stairs descent). Notwithstanding, and despite the importance of the preservation of eccentric strength in older adults with low levels of strength (Hortobágyi, 2003), a limited number of studies have investigated the effects of flywheel resistance training in this population. While some researchers have focused on the use of inertial training (coupling concentric and eccentric actions) to improve strength and postural balance (Onambélé et al., 2008), the uses of these exercise paradigms in interventions completed by older adults are scarce in the literature. For example, in the aforecited study, a limited number of participants (only twelve assigned to the

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inertial load) used a basic isolation exercise (leg extension using the YOYO leg-extensor flywheel) instead of a closed-chain exercise (e.g., squat) that requires simultaneous mobility and stability contributions of numerous structures to ensure optimal functioning. Further, postural stability tests only included a single-leg stance with open eyes. Thus, considering the importance of developing muscle power to improve balance performance in this population (Cadore et al., 2013), the current study was conducted to examine the efficacy of flywheel resistance exercise training on postural stability in healthy older adults and to investigate whether changes in lower-limb power are related to improvements in balance. It was hypothesized that this program would induce improvements in balance and mobility following the intervention period while those receiving usual-care would not demonstrate improvements. Further, in accordance with previous studies (Paillard, 2017), we hypothesiezd there would be a relationship between lower-extremity muscle power and postural performance.

Methods

Participants

The participants included a total of 36 individuals (24 female, 12 male) with a mean age of 65 ± 4 years (Table 1) who had not been engaged in any regular exercise-training program in the previous 12 months. Participants were informed about the design of the study and all provided written informed consent prior to participation. Individuals, who had to be older than 60 years-of-age, were excluded if they had cognitive or functional disorders that adversely impacts skeletal muscle function or manifests in a mobility disorder. The 36 participants who fulfilled the inclusion/exclusion criteria were randomly allocated to either a squat flywheel exercise-training group (ETG; n = 18) or a control group (CON; n = 18) that continued with their typical daily activities that included employment or leisure activities. CON received the usual care from community services and their general practitioner, which may have included medical and allied health management but did not include regular exercise training (Figure 1). Randomization was performed by a member of the research team who was not directly-involved in the recruitment or assessment of participants using a computer generated random allocation data processing program and a 1:1 ratio (ETG:CON). Sample size calculations indicated that with an estimation of 28% change in muscle power and 11% improvement in postural balance performance (Onambélé et al., 2008), 9 participants per group ensured a statistical power of 0.80. The study was approved by the Institutional Review Board and was in accordance with the Declaration of Helsinki.

Table 1. Characteristics of the participants in the study (n= 34).

	Variables	ETG (n=17)	CON (n=17)	*p*
Demographic variables	**Age (years)**	64.4 (3.61)	66.38 (4.85)	.170
	Gender (% males)	41	29	
Body composition	**Body Mass (kg)**	77.17 (13.70)	73.67 (11.46)	.412
	Height (m)	1.64 (.07)	1.62 (.10)	.848
	BMI (Kg/m^2)	28.49 (4.62)	27.74 (3.72)	.596

Values are mean (SD) unless otherwise indicated; BMI: Body Mass Index.

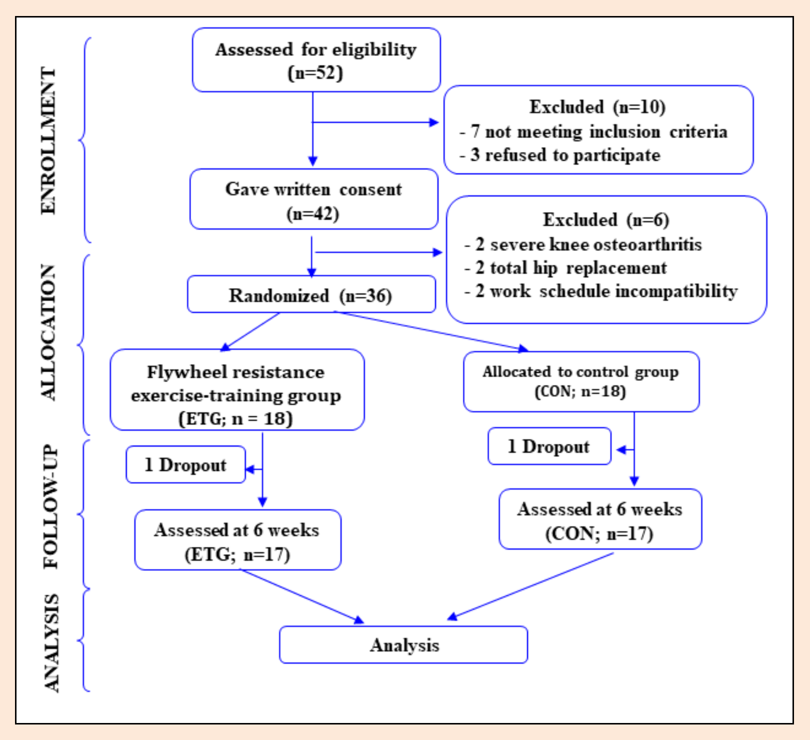

Figure 1. Flow of participants through the trial.

Procedures

Before starting the training program, participants completed two familiarization sessions that consisted of a review of safety guidelines, adjusting a harness to each participant's leg length, and practice with the squat training device (kBox 3, Exxentric AB TM, Bromma, Sweden) equipped with one flywheel with a moment inertia of 0.025 $kg{\cdot}m^{-2}$ (after week 4 a flywheel with a moment inertia of 0.05 $kg{\cdot}m^{-2}$ was used). Similar to procedures reported elsewhere (Fernandez-Gonzalo et al., 2014), participants then underwent six weeks of flywheel resistance training two (week 1, 3, 5) or three (week 2, 4, 6) times a week with at least 48 h of rest between sessions. Participants performed four sets of nine repetitions: two repetitions at the beginning of each set to initiate the flywheel movement and then seven maximal bilateral repetitions accelerating the wheel in the concentric action and, upon completion (when the flywheel strap winds back due to inertial forces), decelerating the wheel by means of an eccentric action. The rest interval between sets was 3 min. Mean Propulsive Velocity (MPV) and average power output were measured during each concentric action and real-time feedback was provided on a computer monitor with the associated software. Research personnel gave verbal encouragement during all repetitions performed.

Measures

Outcome measures were assessed by study personnel blinded to group assignment at baseline and at the end of the intervention period (6 weeks).

Postural stability tests: The test of postural balance consisted of three tasks measured using a force platform (type 9281A, Kistler Instruments AG, Winterthur, Switzerland). Center of pressure (COP) excursions (measured in millimetres) were recorded at a sample rate of 1000 Hz in the anterior–posterior (AP) and medial–lateral (ML) axis in a quiet standing posture with feet shoulder width apart: (a) standing on the platform with the eyes open, (b) standing with the eyes open and performing a cognitive task (backwards counting by threes as fast and as accurately as possible, beginning with a randomly selected number from a range of 100-200), and (c) standing on the platform with the eyes closed. For each condition, three trials of 30 seconds were performed with a rest period of 1 min between trials. During each trial, participants were instructed to keep the hands placed on the hips and to remain as still as possible for the duration of the trial. For data analysis, the average of the three trials in each of the three conditions was used. The intraclass correlation coefficients (ICCs) were determined on a subgroup of 10 participants with a 7-day interval by the same tester. Excellent reliability was found for COP path length with ICC levels of 0.76, 0.78 and 0.83 for open eyes, closed eyes and cognitive task respectively.

Timed up-and-go test: Participants stood from a chair (43 cm of height) without using the hands, traveled a distance of 2.44 m, turned around a cone positioned at the end of the route, returned, and sat down again in the chair. Two trials, with 3 min of rest between trials, were performed and the fastest time was used for analysis (Podsiadlo and Richardson, 1991). The ICC for the TUG test was 0.91.

Power assessment: Mean power and MPV for each repetition were sampled at 100 Hz using an encoder (SmartcoachTM, Smartcoach Europe AB, Stockholm, Sweden) and associated software (Smartcoach® v.3.1.8.0). The mean of the seven repetitions performed during each set for every training session was used for data analysis.

Statistical analysis

Descriptive statistics were calculated for demographic variables and dependent measures. Pairwise t tests were performed at the group level to analyze within-group changes over time. Assumptions for normality were confirmed with the Shapiro–Wilk test. Changes in dependent variables over time within groups and differences between groups at the same times were evaluated using repeated-measures analysis of variance. All data were first log-transformed to reduce bias and then, if logarithmic transformation of the data led to normal distribution, Pearson correlation coefficients were used as a measure of the strength of the association between the changes in power with the balance and mobility outcomes. The results are presented as means ±SD and 95% confidence intervals. As suggested by Cohen, (1988), the threshold values used for the effect sizes (ES, Cohen's d) were >0.2 (small), >0.5 (moderate) and >0.8 (large).

Results

Throughout the 6-week program, two volunteers dropped out for personal reasons (one from ETG and one from CON). Therefore, as detailed in Table 1, statistical analysis was performed with 17 older adults in the ETG and 17 in the CON. There were no significant differences between groups for age ($p = 0.17$), body mass index ($p = 0.60$), or height ($p = 0.85$). The 17 participants in the ETG completed an average of 14 out of the potential 15 sessions over 6 weeks, resulting in a compliance rate of 93%. No harmful effects of the 6-week exercise intervention were noted in the ETG and the CON groups.

Balance assessment

The pretest and postest group mean values, within-group and betwee-group changes (90% confidence limit) for postural balance and TUG performance are depicted in Table 2. Within-group analyses showed significantly better performance in mobility (TUG, $p < 0.01$) and COP_{AP} with open eyes ($p < 0.05$) for ETG, while significant differences (deterioration) were found for COP_{AP} with open eyes in CON group (Table 2).

In the between-groups analysis illustrated in Table 2, ETG showed a significantly better performance in TUG ($p < 0.05$) than CON. A significant change in COP_{AP} (-2.90 [-4.82 to -.99], $p < 0.01$) was also observed in ETG compared with CON. There were no significant between-groups differences in the other balance variables.

Table 2. **Effects of a 6-week flywheel resistance exercise training program on postural balance and mobility in older adults (n=34).**

	ETG			CON				
	Pretest (Mean ± SD)	Postest (Mean ± SD)	P *	Pretest (Mean ± SD)	Postest (Mean ± SD)	P *	P ‡	*Between-group differences (95% CI)*
TUG (s)	6.25 ± 1.38	5.42 ± 0.74	**<0.01***	6.24 ± 1.02	6.08 ± 0.86	.482	**.023**‡	-.68 (-1.25 to -.98)
OE_COP (mm)	13.26 ± 4.45	13.50 ± 3.73	.708	13.70 ± 3.95	14.91 ± 4.29	.099	.309	-.97 (-2.89 to .94)
OE_AP (mm)	6.26 ± 4.11	4.58 ± 1.51	**.050***	6.47 ± 3.02	7.70 ± 3.95	**.028***	**.004**‡	-2.90 (-4.82 to -.99)
OE_ML (mm)	11.48 ± 5.44	11.63 ±3.36	.844	10.79 ± 2.86	11.15 ± 3.20	.461	.819	-.21 (-2.06 to 1.64)
CE_COP (mm)	20.94 ± 6.70	19.74 ± 5.43	.081	18.87 ± 5.30	17.96 ± 3.75	.242	.705	-.40 (-2.51 to 1.72)
CE_AP (mm)	7.34 ± 3.13	6.76 ± 2.61	.337	6.69 ± 2.26	6.83 ± 2.00	.777	.351	-.72 (-2.28 to .83)
CE_ML (mm)	17.89 ± 5.80	17.99 ± 5.84	.920	15.21 ± 4.77	15.05 ±4.05	.479	.635	.57 (-1.86 to 3.01)
CT_COP (mm)	13.85 ± 4.82	14.38 ± 3.69	.382	14.30 ± 5.26	14.56 ± 3.98	.818	.640	.74 (-2.46 to 3.95)
CT_AP (mm)	5.41 ± 1.84	5.27 ± 1.82	.792	6.14 ± 3.40	6.54 ± 2.91	.604	.561	-.54 (-2.41 to 1.33)
CT_ML (mm)	11.06 ± 4.32	11.42 ± 2.79	.630	10.92 ± 3.14	11.31 ±3.15	.826	.632	.56 (-1.81 to 2.93)

TUG: Timed up and go test; COP: center of pressure excursions; OE: Open eyes; CE: Closed eyes; CT: Cognitive Task; AP: antero-posterior axis; ML: medio-lateral axis. Statistically significant differences ($p < 0.05$). * Within-group differences, P value from 1-way ANOVA (time factor). ‡ Between-groups differences, P value from 2x2 (GroupxTime) ANOVA with repeated measurements for the time factor.

Power assessment

As detailed in Figure 2A and 2B, significantly greater MPV and mean power values were found following the intervention in comparison with baseline. ETG participants increased MPV by 48% whereas power output increased by 63% during the 6-week period.

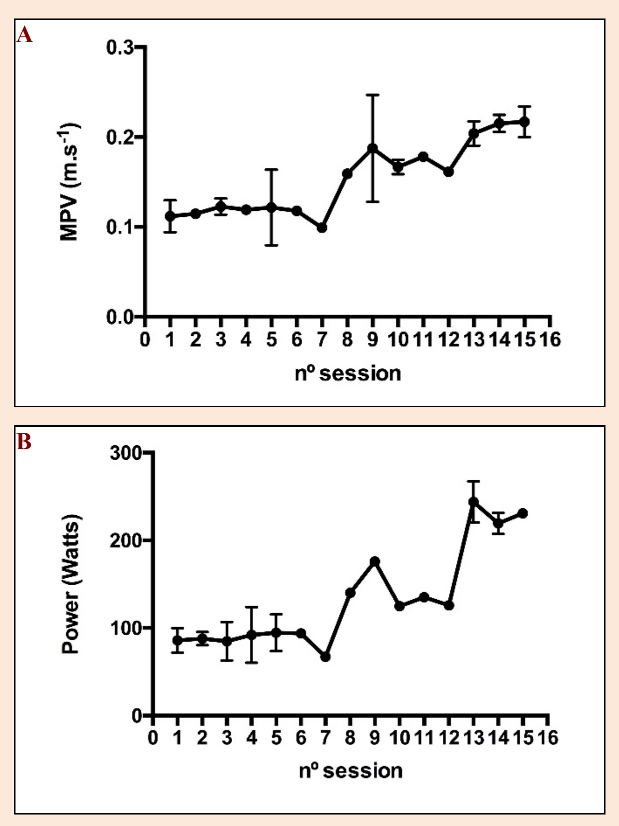

Figure 2. **Mean Propulsive Velocity (A) and concentric power (B) recorded every training session during the 6-week period in the ETG group.**

As detailed in Table 3, Pearson's correlation coefficients between changes in balance outcomes and changes in muscle power after the 6-week intervention were significant for COP both with open eyes ($r^2 = 0.583$, $p < 0.05$), closed eyes ($r^2 = 0.541$, $p < 0.05$) and when performing a cognitive task ($r^2 = 0.618$, $p < 0.05$).

Table 3. **Pearson's correlation coefficients between changes in Mean Power and changes in balance.**

Outcome	Mean Power
Change OE_COP	0.583 *
Change OE_AP	0.337
Change OE_ML	0.457
Change CE_COP	0.541 *
Change CE_AP	– 0.080
Change CE_ML	0.148
Change CT_COP	0.618 *
Change CT_AP	0.144
Change CT_ML	0.342

Correlation is significant at * $p < 0.05$. COP: center of pressure excursions; OE: Open eyes; CE: Closed eyes; CT: Cognitive Task; AP: antero-posterior axis; ML: medio-lateral

Discussion

In the present study, it was hypothesised that, compared with a control group, flywheel inertial training of the lower limb would result in improvements in indices of postural balance and functional mobility. After only 6 weeks, improvements in both mobility (TUG) and balance (COP_{AP} with open eyes) were observed along with improvements in MPV and mean power in ETG participants.

Collectively, these results have a high clinical impact considering the priority placed on reducing falls and mobility deficits in older adults (Gillespie et al., 2012). Recently, Orr (2010) recognized the importance of intervention studies based on balance as a primary outcome, rather than any other outcome. In the current study, 6 weeks of training resulted in a 27% decrease in COP_{AP} (ES = 0.54), which exceeds the improvements reported by different authors following more lengthy traditional resistance exercise programs in older adults (Marques et al., 2016). Further, to our knowledge, only one other study assessed the effect of flywheel inertial loading on strength and balance in comparison with conventional knee-extensors weight training in this population (Onambélé et al., 2008); however, and although those authors reported changes between 16-18% in the COP_{AP} and COP_{ML} displacement in the flywheel-training group, non-significant within and/or between groups differences were reported in these outcomes.

Results of the current study showed significant changes in COP_{AP} (-2.90 [-4.82 to -.99], $p < 0.01$) with open eyes, which contrast with the aforementioned study where the main difference in the magnitude was observed in the ML direction. While differences in the methodologies used in the assessment of balance make it difficult to compare these results, a possible explanation for the discrepancies could be attributed to the muscles activated in each exercise. It is important to note that when recovering from postural threats, older adults tend to rely more on hip strategies (hip and knee extensions) for balance control (Hess et al., 2006), which are the most activated with inertial systems. Thus, the squat modality may have more greatly impacted other synergistic muscles (e.g., hip abductors and adductors or ankle plantarflexors and dorsiflexors) that have a greater influence on balance, especially on the COP_{AP} (Orr et al., 2008). However, as in the Onambélé study (Onambélé et al., 2008), changes in COP_{ML} were not found. One justification given by the authors for this lack of effect was that COP displacement is a very difficult parameter to improve. In our opinion, the employment of different positions on the device could lead to a greater activation of additional musculature and it may be hypothesized that this could also imply improvements on this ML axis.

In addition to these results, a 13% improvement in mobility (TUG; ES: 0.60) was found. Previous studies involving eccentric-based training in older adults found increments in functional tests ranging from 5–29 % in TUG (Raj et al., 2012; LaStayo et al., 2003; Mueller et al., 2009), and only a few studies have focused on the use of inertial paradigms to improve mobility and balance in older adults (Onambélé et al., 2008). These authors showed improvements in functional ability of the lower body that are essential in helping maintain independence and reducing the risk of falls. These improvements could also be attributed to the improvements in muscle power as changes in this outcome are considered a strong predictor of performance of daily living activities in older adults (Radelli et al., 2018). In any case, flywheel resistance training seems to be effective to promote changes in both balance and mobility in older adults and this appears to be related to the greater muscle force produced during eccentric exercises in comparison with concentric muscle actions, which may be attributed to neural adaptations, including increased recruitment and synchronization of motor units (Kamen and Gabriel, 2010), leading to better synchronization (Semmler et al., 2002) or reduced co-activation (Cadore et al., 2013).

Another interesting finding in our study was that power output increased (63%) after only 6-weeks of training. These results are even better than those recently obtained after a 12-week protocol in stroke patients, which could be attributed, according to the authors and as stated above, to neural adaptations (Fernandez-Gonzalo et al., 2016). We also aimed at determine whether changes in balance outcomes are related to improvements in power. It was previously shown that muscle power is related to balance in older adults (Orr, 2010). Thus, in the current study, the improvements in muscle power were accompanied by changes in COP both with closed eyes ($r^2 = 0.583$, $p < 0.05$), with the eyes open ($r^2 = 0.541$, $p < 0.05$) and performing a cognitive task ($r^2 = 0.618$, $p < 0.05$). One possible interpretation for this relationship is related to balance recovery strategies and compensatory postural actions (Paillard, 2017). When an adverse situation affects postural balance, the individual needs to develop force rapidly to control the center of mass and recover stability; therefore, increased power output may be especially important for the older adult in recovering balance (Pereira et al., 2012). It has been reported that fallers have considerably lower leg power than non-fallers (Foldvari et al., 2000) but, in agreement with our results, improvements in muscle power may also be associated with balance performance (Orr, 2010).

Only a couple of studies have examined the contribution of muscle power to balance performance, suggesting that it can be an indicator of balance deficits and falls risk (Bean et al., 2008). In older adults, higher leg velocity was also associated with functional balance test outcomes (Bean et al., 2008). Further, exercises that are performed with a high speed promote greater improvements in functional task performance of healthy older individuals (Pereira et al., 2012), highlighting the relevance of limb velocity in older adults (Bean et al., 2008). In our study, MPV also increased from $0.12\ m\cdot s^{-1}$ to $0.22\ m\cdot s^{-1}$, probably due to exercises with this paradigm could offer maximal voluntary resistance during both concentric and eccentric actions. Increasing the velocity component of peak power improved the performance of many functional tasks in previous studies (Sayers and Gibson, 2014) and this may have clinical consequences as aging is associated with a decline in neural processing which can diminish the ability for rapid force development and therefore limit the response to postural challenges (Orr, 2010).

There are some limitations to this study and therefore the results should be interpreted with caution. First, the lack of effect in some outcomes may indicate that an insufficient training dose was utilized to induce adaptations or failed to strengthen key postural control muscles. As reviewed by Orr et al., (2008), balance performance is more likely to improve in longer-term versus shorter-term studies that can contribute to the need to achieve a minimum volume and/or duration to elicit gains. This may have a double interpretation in the present study as improvements in COP_{AP} were observed after only 6 weeks but the response in other key contributors to maintaining balance control, such as COP_{ML}, was not as clear. These inconsistent effects may be due not just to an inadequate or ineffective dose of training, but also to the variability in sample size or even the lack of statistical power to detect between-group differences as previously suggested (Orr et al., 2008). However, considering that eccentric exercise is sometimes associated with adverse effects (e.g. muscle damage with symptoms of delayed onset muscle soreness), we decided to use a careful and safe progression of eccentric training intensity. Further, since older women tend to show a more pronounced preservation of eccentric strength than men (Hortobágyi, 2003), perhaps the larger number of men in the ETG group biased the results.

Conclusion

Despite these limitations, the results of the current study highlight the potential benefits of the training conducted by the ETG group. Flywheel resistance exercise training improved balance and mobility in older adults but also muscle power generation that may be a limiting factor in the control of balance. Therefore, this can be considered an appropriate form of activity to be used as a rehabilitation tool for improving functional capacity in older adults. A greater understanding of eccentric training-induced adaptations on these outcomes would further contribute to evidence-based practice in this population.

Acknowledgements

This study was also registred with the trial number: ACTRN12617001166369. The authors declare that they have no conflict of interest. The experiments comply with the current laws of the country in which they were performed.

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Key points

- There was inconsistent or no evidence to support the benefits of inertial training on balance and mobility.
- Flywheel resistance exercise training improved balance and mobility in older adults.
- This technology can be used as a rehabilitation tool for improving functional capacity in older adults.
- Exercise programs that require less time are highly desirable.

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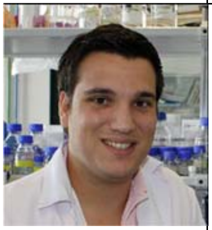

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