Improved muscle strength, muscle power and physical function after flywheel resistance training in community dwelling older adults. A randomized controlled trial.

Abstract

This study aimed to examine whether flywheel resistance exercise training improved muscle strength, muscle power and physical function in older adults. Thirty-six older adults (64 ± 5 years) were randomly allocated to either a flywheel resistance exercise training group (ETG; n = 18) or a control group (CON; n = 18). Subjects in the ETG underwent 6 weeks of resistance training on a flywheel squat device (4 sets of 9 maximal repetitions). Isokinetic concentric (60°/s and 240°/s) and eccentric (120°/s) knee extension and flexion peak torques and mean power were measured. Physical function was assessed by the 30 second Chair Sit-Stand Test (CST) and walking speed. After the intervention within-group analyses showed significantly greater flexion torques and mean power with the dominant leg (concentric at 60˚/s and 240˚/s and eccentric at 120˚/s; all d >0.7, p<0.05) and improvements in CST (d >0.8) in the ETG group, while no substantial differences were found in CON group. Significant between group differences in knee flexion torque both concentric (at 60˚/s: η^2=0.168 and 240˚/s: η^2=0.112) and eccentric (at 120˚/s: η^2=.103) with the dominant leg were also found in favour of the ETG group. There was also significantly better performance in the CST test for the ETG (η^2=0.207). There were significant associations between changes in strength and changes in mean power in the ETG. Changes in physical function outcomes were also observed. In conclusion, flywheel resistance exercise training is an appropriate form of activity for improving strength and functional capacity of older adults.

KEYWORDS: Strength; mobility; physical function, inertial training; elderly

INTRODUCTION

Aging is accompanied by significant changes in the musculoskeletal system (e.g., decreased muscle mass, muscle weakness, and reduced gait speed), which often leads to a deterioration in the performance of daily activities (15,21). Impaired mobility and reduced physical capability in older adults is often related to a lack of physical activity, which is the most prevalent risk factor associated with functional decline and loss of independence (1). Loss of muscle power is also considered a powerful predictor of functional disability in older adults (38). Physical exercise is essential to mantain mobility and can inhibit the effects of aging on functional capacity in older people (38). It has been shown that physical exercise interventions improve functional capacity and the ability to perform daily acitivities in older adults (12), however, the implementation of these programs remains inadequate. There is still a need to define exercise prescription strategies to improve the functional capacity in this population (5).

Strengthening of the lower-limb muscles in older adults may improve the ability to perform activities of daily living and improve functional mobility (3). The benefits of strength-based interventions in reversing age-related decline in muscle mass and physical function have been confirmed, and these strategies are well tolerated by older adults (27). Indeed muscle power output preservation is considered one of the main strategies for counteracting age-related decrease in muscle mass (30). There is evidence that eccentric strength is maintained with age in older adults (33) and it is recognised that eccentric muscle contractions are intrinsic to many daily activities. This has led some authors to suggest that eccentric exercises provide additional benefits above standard exercises in this population (14). It has been suggested that strength-training regimes that incorporate a combination of concentric and eccentric muscle loading would be an effective way to improve functional status and could lead to better strength gains in older adults, when compared to standard strength exercises (7,12,14). Devices such as isokinetic machines or eccentric ergometers, may allow eccentric resistance-training programs in older adults with reduced strength (33).

There is greater acceptance of eccentric-based protocols for clinical purposes (18) and previous studies in older adults found improvements in maximal strength (improvements ranging from 8 to 60%) (16,18,22,26,28,29), and clinically meaningful improvement in functional mobility (16,22,28,37). However, many of the programs previously used have been performed using costly equipment or needed clinician support to facilitate the exercise load. To address these challenges, inertial flywheel devices have emerged as an alternative to gravity dependent weights, allowing participants to produce greater force, power, and improve muscle mass and neural adaptations, than traditional strength training programs (10,24-26). It has been suggested that inertial flywheel devices are particularly effective for training the lower-limb muscles in older people (26), which of course is essential for daily activities in older adults (35).

To date only one study, using a flywheel eccentric exercise-based intervention, has been completed in older adults (26). Onambélé et al. (26), tested peak power in knee extension and unilateral isometric knee extension, however, these authors did not test the relationship between muscle power and improvements in functional capacity. Moreover, Onambélé et al. (26) employed a leg-extension machine in their study, which is biomechanically different from normal functional activities, such as walking or chair rising. There is, therefore, little support in the literature to justify the inclusion of these exercise modalities when aiming to improve functional abilities (i.e., sit-to-stand or walking ability) in older adults. Gluchowski et al. (12) also highlighted the need to assess whether exercises focusing on eccentric actions may lead to functional improvement in this population, we therefore conducted this study to examine whether flywheel resistance exercise training improves muscle strength, muscle power and physical function in older adults. We hypothesized that this type of training would result in increased muscle force and power, and that these adaptations would be accompanied by improved sit-to-stand ability and walking speed performance.

METHODS

Experimental Approach

The study was a 2-site, single-blinded, parallel group, randomised controlled trial, designed to determine the effect of flywheel resistance exercise training on muscle strength, muscle power and physical function in older adults. Further, the study aimed to investigate whether changes in strength and mean power were related to improvements in physical function. Participants included in the experimental group participated in a 6-week flywheel resistance-training program. Parameters that were assessed before and after the intervention included: isokinetic concentric (60°/s and 240°/s), and eccentric (120°/s) knee extension, flexion peak torques and mean power, and physical function was assessed by means of the 30 second Chair Sit-Stand Test (CST) and walking speed over 5 metres.

Subjects

Fifty-two community-dwelling people were recruited from the local community via announcements in daily newspapers, and were successfully screened for inclusion into the study (Fig.1). Thirty-six older adults (24 female, 12 male) with a mean age of 64 ± 5 years and a body mass index of 28 ± 4 Kg/m^2 (Table 1) were included. Participants had to be older than 60-years of age and not have engaged in any regular exercise in the previous 12 months. Subjects were informed about the design of the study and all provided written informed consent. Subjects were excluded if they self-reported any co-morbid condition that would impact skeletal muscle function or mobility (e.g. severe rheumatoid or osteoarthritis, cardiac or respiratory conditions). The 36 subjects who fulfilled the inclusion/exclusion criteria were randomly allocated to either a flywheel resistance exercise training group (ETG; n = 18) or control group (CON; n = 18). The CON group continued with their typical daily activities that included employment or leisure activities and received usual care from the community services and their general practitioner. Usual care might include medical and allied health management, but did not include regular exercise training. Randomization was performed by a member of the research team, who was not directly involved in the recruitment or assessment of subjects, using a computer generated random allocation program and a 1:1 ratio (ETG:CON). The a priori sample size calculation needed to detect an 8% change (clinical meaningful change) in maximal eccentric (ECC) isokinetic torque at 60°/s (10) indicated that 12 subjects per group ensured a statistical power of 90% with an alpha level of 0.05. An additional six subjects were recruited to each group to allow for attrition. The study was approved by the Institutional Review Board at the XXMASKEDXX and was conducted in accordance with the Declaration of Helsinki.

<<FIGURE 1 ABOUT HERE>>

<<TABLE 1 ABOUT HERE>>

Procedures

Flywheel resistance exercise training

Before the training program, subjects completed two familiarization sessions on the flywheel squat device (kBox 3, Exxentric AB TM, Bromma, Suecia). During the squat, subjects stood on the platform with the feet shoulder width apart and knees slightly flexed. From the standing position, after an initial submaximal repetition to initiate the flywheel movement, the performer descended by flexing the hip and knee joints simultaneously (i.e., by an eccentric muscle action). When returning to the starting position subjects extended the hip and knee joints by a concentric muscle action. The subjects were instructed to push with maximal effort through the entire concentric action and to then resist the pull of the flywheel by performing an eccentric muscle action. The knee started at approximately 15 degrees and reached a maximum flexion of approximately 140 degrees.

Subjects from the ETG underwent 6 weeks of flywheel resistance training, twice (week 1, 3, 5) and 3 (week 2, 4, 6) times a week, with at least 48 hours rest between sessions. The flywheel squat device, was equipped with a flywheel with a moment inertia of 0.025 kg_m^2 for 4 weeks then increased to 0.05 kg_m^2 for the following two weeks (Table 2). After a brief standardized warm-up, 4 sets of 9 maximal repetitions were performed (the rest interval between sets ranged from 2 to 3 min). Each set consisted of two repetitions at the beginning to initiate the flywheel movement and then seven maximal bilateral repetitions accelerating the wheel in the concentric action and, upon completion, decelerating the wheel by means of an eccentric action. Research personnel gave verbal encouragement during all repetitions performed.

<<TABLE 2 ABOUT HERE>>

Measures

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

Strength and Power Testing

To estimate strength and power gains in response to the flywheel exercise training programme, isokinetic concentric (at an angular velocity of 60 and 240°/s) and eccentric (at an angular velocity of 120°/s) knee extension and flexion peak torques and mean power were measured in both legs using an isokinetic dynamometer (Biodex System 4, Biodex Medical Systems, Shirley, NY). Isokinetic data for peak torque and mean power were obtained at a sample rate of 100 Hz using the Biodex System 4 Advantage software. Before testing, each subject had a familiarization session to orient them to isokinetic testing. In the warm up activity subjects performed 3-4 submaximal contractions of increasing intensity (from 50% to 90%) for each of the isokinetic contractions and then rested for 1 min between the warmup and the beginning of the test.

Each subject was seated in an upright position and stabilised at with straps at the shoulders, waist and thighs as per manufacturer's guidelines. Each subject's seat position was recorded so that it could be replicated during subsequent testing. The order of isokinetic strength testing for all subjects was standardised as follows: five maximal concentric and eccentric knee contractions at 60°/s were performed first, followed by concentric and eccentric knee contractions at 240°/s. Finally, five eccentric contractions (120°/s) were performed. A rest period of 3 min was given between each type of contraction and a 1 min rest between speeds. Subjects were given verbal encouragement and visual feedback of the torque signal at each repetition. The highest value obtained of all maximum efforts was used as the peak torque value (N_m) and mean power output (W) for each muscle action and speed mode and was chosen for further analysis.

Functional capacity

Physical function was assessed before and after the training period by means of two functional tests based on daily activities. All subjects received instructions about test procedures and were familiarized to each test.

The *30 second Chair Sit-Stand Test* (CST) (31) is considered an important functional evaluation clinical test which is able to measure lower body strength and has been related to the most demanding daily life activities. The test consists of standing up and sitting down from a chair (with a seat height of 0.40 m), starting with the back in an upright position and the arms folded across their chest, as many times as possible within 30 seconds. The test was measured by the same evaluator and was timed to the nearest 0.1 second by using an electronic stopwatch.

Walking speed has been also shown to be an indicator of disability in older adults (36). Subjects walked as fast as possible for 5 metres in a quiet corridor, without the use of any aids, wearing comfortable shoes. The main outcome was walking speed (metres/second, m/s) assessed through gait analysis using a photocell system (Racetime 2; Microgate, Bolzano, Italy). All functional tests were performed with continuous verbal encouragement by the same researcher.

Statistical analysis

Descriptive statistics were calculated for demographic variables and dependent measures. The normality of the data was evaluated by the Kolmogorov–Smirnov test, for non-parametric distribution, differences between groups at baseline, and after treatment were tested using Mann–Whitney's. The statistical analyses addressed two questions relative to the flywheel resistance exercise mode. Within group pre- to post-training effect (ETG vs CON) was tested using a paired-samples t-test. Pre- to post-training between group comparisons were examined using repeated measures ANOVA, followed by Bonferroni's post hoc test, to determine the time effects and the interaction effect (time × group). Moreover, effect sizes were calculated, and the threshold values for Cohen's effect size (ES) statistics were: trivial (0.0 – 0.19), small (0.2 – 0.59), moderate (0.6 – 1.1), large (1.2 – 1.9), and very large (> 2.0) as suggested by Hopkins et al. (13). Partial eta (η) squared between groups (0.01 = small effect, 0.06 = medium effect, and 0.14 = large effect) were also performed to assess the relative magnitude of the differences between groups. Spearman's correlation coefficients were used as a measure of the strength of the association between the changes in muscle strength and muscle power, and changes in the functional capacity outcomes. All descriptive analyses were conducted using a statistical package (SPSS 17.0, Chicago, USA) using a significance level of p<0.05.

RESULTS

There were no significant differences between groups for age (p=0.131), body mass index (p=0.550), or height (p=0.848). The 18 subjects 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 were noted in the ETG group after the 6 weeks exercise intervention.

Strength assessment

Table 3 demonstrates the effects of the intervention on isokinetic knee extension and flexion peak torque. Subjects in the ETG exhibited significantly greater flexion and extension torques at 60˚/s and flexion torques with the dominant leg at 240˚/s after the intervention. Within-group analyses showed a significantly better eccentric torque during the knee flexion at 120˚/s, while no substantial differences were found in CON group (Table 3). Moderate ES (all d > .722) were observed for all these outcomes.

<<TABLE 3 ABOUT HERE>>

Significant between group differences in the knee flexion torque both concentric (at 60˚/s and 240˚/s) and eccentric (at 120˚/s) with the dominant leg were also found in favour of the ETG group. Table 3 outlines the eta-squared measures of effect size between groups. Large effects in favour of the ETG group were observed for knee flexion concentric torque at 60˚/s (η^2=.168) and 240º/s (η^2=.112) and medium effect for knee flexion eccentric torque at 120˚/s (η^2=.103).

Functional capacity

The pre-test and post-test group mean values and within-group ES for functional capacity are outlined in Table 3. Significant differences in the CST test (*d*=0.8) were observed in the ETG subjects. Over the course of the study there were no significant within group changes in functional capacity for subjects in the CON group. Between group analyses revealed that those in the ETG displayed significantly better performance in the CST test than those in the CON group (η^2=0.207).

Power assessment

Mean power (W) values during the isokinetic knee flexion and extension are reported in Table 4. Within-group analyses showed a significant improvement in the power achieved both in flexion and extension at 60˚/s and 240˚/s but also in eccentric flexion at 120˚/s with the dominant leg ($p<0.01$). Most of these improvements represented a moderate treatment effect (all $d > 0.6$).

<<TABLE 4 ABOUT HERE>>

Correlations between changes in strength and power measures and changes in functional capacity

As detailed in Table 5, there was a significant correlation between changes in muscle strength and muscle power and changes in walking speed after the 6-week intervention for concentric (at 60˚/s and 240˚/s) flexion peak torque in the dominant leg and walking speed. Significant association between changes in concentric mean power with changes in the physical function outcomes were also observed (Table 5 and Figure 2). Moreover the knee flexion eccentric peak torque was correlated with the changes in the CST test (Figure 2). Further, the changes in eccentric mean power were significantly correlated with the changes in the CST test ($r^2 = 0.299$, $p<0.05$, Figure 2) and the changes in walking speed ($r^2 = -0.406$, $p<0.01$, Table 5).

<<TABLE 5 ABOUT HERE>>

<<FIGURE 2 ABOUT HERE>>

DISCUSSION

In the present study, we hypothesised that flywheel inertial exercise training would result in improvements in muscle strength and power and thus, improvements in physical function. Following a 6-week program, peak torque for concentric knee flexion at speeds of 60 and 240°/s significantly improved in subjects in the ETG. Peak torque for eccentric knee flexion at 120°/s was also improved in this group (ES: 0.72; $p<0.05$). CST increased by 15% and maximal walking speed by 5% for the ETG. Collectively these outcomes represent considerable clinical impact, and should help mitigate muscle and mobility deficits in older adults (38).

Previous studies have suggested that isoinertial resistance training could lead to improvements in the isokinetic concentric-eccentric torque of limb extensors in this population group (2). Bruseghini et al (2) reported a 5% improvement in maximal isokinetic concentric torque at 60°/s together with a 5% improvement in maximal isokinetic eccentric torque at 120°/s, which is lower than the results reported in the present study (21% and 22% respectively). In the current study, within-group analyses showed a significant improvement in knee extension torque, but only at 60˚/s. This is consistent with previous studies suggesting that concentric peak torque is lower at higher algular velocities (20). Previous authors attributed these differences to the reductions both in muscle fiber size and number, especially type II fibers in the elderly (20). Moreover, and despite the limited comparable data on flywheel resistance exercise protocols in older adults, Fernandez-Gonzalo et al. (10) conducted a pilot study assessing the efficacy of a flywheel resistance exercise programme (8-weeks) in individuals suffering from chronic stroke (63.3 ± 8.1 years). Similar to the current study, these authors reported a 3-6% increase in the isokinetic knee extension concentric torque (60°/s) and a 7% increase in the eccentric torque (90°/s) for the affected leg. (10) The identified changes could be explained, at least in part, by neural adaptations, such as increased motor unit recruitment and reduced co-activation (4) or better synchronization of motor unit discharge (34).

There is evidence that eccentric strength is preserved in older adults and that this could be related to an impairment in the capacity to fully activate muscles under concentric conditions (32). Ochala et al. (25) suggested the preservation of eccentric strength was due to an increase in muscle passive and active stiffness. It seems that the better muscular output observed in the current study could be explained by the tension developed by muscle fibers and in the perimuscular structures which it has been suggested is higher in eccentric modes of exercise (14). Therefore, the efficacy of this training paradigm is possibly mediated by the capacity to achieve higher forces during eccentric muscle action, which, in turn, could be attributed to the recruitment of additional motor units (19).

The gains in strength and power demonstrated in the current study were significantly correlated with the changes in functional capacity, and previous work has shown that eccentric-based exercises positively influence physical performance relevant to daily living activities. Leszczak et al. (17), for example, examined the effects of an 8-week eccentric program and reported that walking speed (ES=0.31), 8-ft timed up-and-go test (ES=0.29) and the CTS test (ES=0.48), improved post-intervention, which supports the findings from our study. Raj et al. (28) also assessed the effects of eccentric training on functional capacity in older adults and reported improvements in walking speed (ES=0.62; 5%). Further, Gault et al. (11) reported improvements in maximal walking speed (ES=0.31, 5%), comparable to that reported by Dias et al. (7) in the 6m walk test (12%) or the chair-rising tests (15%), after a 12-week eccentric-focused resistance training program in older adults. All of which is in agreement with previous results after flywheel resistance training in stroke patients (9). These authors found that the improvements in muscle force and power after this training method resulted in improvements in gait performance after the intervention (CST; ES=0.34, 17%), which agreed with the findings reported in our study (CST; ES=0.77, 15%).

There are some limitations to this study, for example subjects were all healthy older adults, therefore, the generalisability is limited. Moreover, since the preservation of eccentric strength seems to be mediated by the gender (i.e., women tend to show a more pronounced preservation), our results may be slightly biased as we had more women. The training program was designed for individuals who are new to eccentric exercise and cautious progression of the eccentric training was advised. This may have impacted on the results as the lower initial load, duration and training frequency may not have been a sufficient load to stimulate the muscles and cause the expected adaptations. Moreover, the differences in technical execution could explain, at least in part, why between-group improvements were observed in one side only. It is common to observe asymmetrical weight shifting between the left and right limbs at the end of a squat, with the majority of participants shifting from the right to the left (6). Another possible explanation for these differences could be lower limb asymmetries at baseline (greater flexion peak torques observed in the left leg at 60˚/s and at 240˚/s). Despite these limitations, it can be concluded that flywheel resistance exercise training is an appropriate form of activity to increase isokinetic knee flexion, concentric and eccentric torque and for improving the functional capacity (CST) of older adults.

PRACTICAL APPLICATIONS

The results of this study show that flywheel resistance exercise training (2-3 times/week) has the potential to enhance muscle strength, muscle power and physical function in older adults. Clinicians and care givers could implement the reported exercise strategies to prevent or attenuate the functional decline associated with aging, subjects need minimal supervision, therefore, these protocols could be implemented in rehabilitation settings as a safe and viable method to promote physical function adaptations.

ACKNOWLEDGMENTS

The authors declare that they have no conflict of interest and that the results of the present study do not constitute endorsement of the product by the authors or the NSCA.

REFERENCES

1. Briggs, AM, Cross, MJ, Hoy, DG, Sànchez-Riera, L, Blyth, FM, Woolf, AD, and March, L. Musculoskeletal Health Conditions Represent a Global Threat to Healthy Aging: A Report for the 2015 World Health Organization World Report on Ageing and Health. *Gerontologist* 56 Suppl 2:S243-255, 2016.
2. Bruseghini, P, Calabria, E, Tam, E, et al. Effects of eight weeks of aerobic interval training and of isoinertial resistance training on risk factors of cardiometabolic diseases and exercise capacity in healthy elderly subjects. *Oncotarget* 6:16998-17015, 2015.
3. Bryanton, M and Bilodeau, M. The role of thigh muscular efforts in limiting sit-to-stand capacity in healthy young and older adults. *Aging Clin Exp Res* 29:1211-1219, 2017.
4. Cadore, EL, Pinto, RS, and Kruel, LFM. Neuromuscular adaptations to strength and concurrent training in elderly men. *Braz J Kin Hum Perform* 14:483–495, 2012.
5. Cadore, EL, Rodríguez-Mañas, L, Sinclair, A, and Izquierdo, M. Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: a systematic review. *Rejuvenation Res* 16(2):105-114, 2013.
6. Cugini, K, Ayers, L, Keys, C. Changes in Weight Distribution and Subsequent Biomechanical Characteristics Across Starting, Transitional, and End Phases of the Back Squat in Healthy Adults. *Angelo State University*, 2015.

7. Dias, CP, Toscan, R, de Camargo, M, Pereira, EP, Griebler, N, Baroni, BM, and Tiggemann, CL. Effects of eccentric-focused and conventional resistance training on strength and functional capacity of older adults. *Age (Dordr)* 37(5):99, 2015.
8. Escamilla, RF, Fleisig, GS, Zheng, N, Barrentine, SW, Wilk, KE, and Andrews, JR. Biomechanics of the knee during closed kinetic chain and open kinetic chain exercises. *Med Sci Sports Exerc* 30(4):556-569, 1998.
9. Fernandez-Gonzalo, R, Fernandez-Gonzalo, S, Turon, M, Prieto, C, Tesch, PA, and García-Carreira, M del C. Muscle, functional and cognitive adaptations after flywheel resistance training in stroke patients: a pilot randomized controlled trial. *J Neuroeng Rehabil* 13:37, 2016.
10. Fernandez-Gonzalo, R, Lundberg, TR, Alvarez-Alvarez, L, and de Paz, JA. Muscle damage responses and adaptations to eccentric-overload resistance exercise in men and women. *Eur J Appl Physiol* 114: 1075-1084, 2014.
11. Gault, ML, Clements, RE, Willems, ME. Functional mobility of older adults after concentric and eccentric endurance exercise. *Eur J Appl Physiol* 112(11):3699-3707, 2012.
12. Gluchowski, A, Harris, N, Dulson, D, Cronin, J. Chronic Eccentric Exercise and the Older Adult. *Sports Med* 45(10):1413-1430, 2015.
13. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41:3-13, 2009.
14. Isner-Horobeti, ME, Dufour, SP, Vautravers, P, Geny, B, Coudeyre, E, and Richard, R. Eccentric exercise training: Modalities, applications and perspectives. *Sports Med* 43(6):483-512, 2013.

15. Kim, HK, Susuki, T, Saito, K, et al. Effects of exercise and amino acid supplementation on body composition and physical function in community-dwelling elderly japanese sarcopenic women: a randomized controlled trial. *J Am Geriatr Soc* 60:16–23, 2012.
16. LaStayo, PC, Ewy, GA, Pierotti, DD, Johns, RK, and Lindstedt, S. The positive effects of negative work: increased muscle strength and decreased fall risk in a frail elderly population. *J Gerontol A Biol Sci Med Sci* 58(5):M419–424, 2003.
17. Leszczak, TJ, Olson, JM, Stafford, J, and Brezzo, RD. Early Adaptations to eccentric and high-velocity training on strength and functional performance in community-swelling older adults. *J Strength Cond Res* 27(2):442–448, 2013.
18. Lindstedt, SL. Skeletal muscle tissue in movement and health: positives and negatives. *J Exp Biol* 219(Pt 2):183-188, 2016.
19. Maroto-Izquierdo, S, García-López, D, Fernandez-Gonzalo, R, Moreira OC, González-Gallego, J, and de Paz, JA. Skeletal muscle functional and structural adaptations after eccentric overload flywheel resistance training: a systematic review and meta-analysis. *J Sci Med Sport* 20(10):943-951, 2017.
20. Melo, RC, Takahashi, ACM, Quitério, RJ, Salvini, TF, and Catai, AM. Eccentric torque-producing capacity is influenced by muscle length in older healthy adults. *J Strength Cond Res* 30(1): 259–266, 2016.
21. Morie, M, Reid, KF, Miciek, R, et al. Habitual physical activity levels are associated with performance in measures of physical function and mobility in older men. *J Am Geriatr Soc* 58:1727–1733, 2010.
22. Mueller, M, Breil, FA, Vogt, M, et al. Different response to eccentric and concentric training in older men and women. *Eur J Appl Physiol* 107:145–153, 2009.

23. Norrbrand, L, Fluckey, JD, Pozzo M, and Tesch, PA. Resistance training using eccentric overload induces early adaptations in skeletal muscle size. *Eur J Appl Physiol* 102:271–281, 2008.
24. Norrbrand, L, Pozzo, M, and Tesch, PA. Flywheel resistance training calls for greater eccentric muscle activation than weight training. *Eur J Appl Physiol* 110:997–1005, 2010.
25. Ochala, J, Lambertz, D, Pousson, M, Goubel, F, and Hoecke, JV. Changes in mechanical properties of human plantar flexor muscles in ageing. *Exp Gerontol* 39:349–358, 2004.
26. Onambele, GL, Maganaris, CN, Mian, OS, Tam, E, Rejc, E, McEwan, IM, and Narici, MV. Neuromuscular and balance responses to flywheel inertial versus weight training in older persons. *J Biomech* 41:3133-3138, 2008.
27. Orr, R. Contribution of muscle weakness to postural instability in the elderly. A systematic review. *Eur J Phys Rehabil Med* 46(2):183-220, 2010.
28. Raj, IS, Bird, SR, Westfold, BA, and Shield, AJ. Effects of eccentrically biased versus conventional weight training in older adults. *Med Sci Sports Exerc* 44(6):1167–1176, 2012.
29. Reeves, ND, Maganaris, CN, Longo, S, and Narici, MV. Differential adaptations to eccentric versus conventional resistance training in older humans. *Exp Physiol* 94(7):825–833, 2009.
30. Reid, KF, and Fielding, RA. Skeletal muscle power and functioning in older adults. *Exerc Sport Sci Rev* 40:1e12, 2012.
31. Rikli, RE, and Jones, CJ. Development and validation of a functional fitness test for community-residing older adults. *J Aging Phys Act* 7: 129–161, 1999.

32. Roig, M, Macintyre, DL, Eng, JJ, Narici, MV, Maganaris, CN, and Reid, WD. Preservation of eccentric strength in older adults: Evidence, mechanisms and implications for training and rehabilitation. *Exp Gerontol* 45(6):400-409, 2010.
33. Roig, M, Shadgan, B, and Reid, WD. Eccentric exercise in patients with chronic health conditions: a systematic review. *Physiother Can* 60(2):146-160, 2008.
34. Semmler, JG, Kornatz, KW, Dinenno, DV, Zhou, S, and Enoka, RM. Motor unit synchronisation is enhanced during slow lengthening contractions of a hand muscle. *J Physiol* 545(Pt 2):681–695, 2002.
35. Startzell, JK, Owens, DA, and Mulfinger, LM, Cavanagh PR. Stair negotiation in older people: A review. *J Am Geriatr Soc* 48:567–580, 2001.
36. Studenski, S, Perera, S, Patel, K, et al. Gait speed and survival in older adults. *JAMA* 305(1):50-58, 2011.
37. Symons, TB, Vandervoort, AA, Rice, CL, Overend, TJ and Marsh, GD. Effects of maximal isometric and isokinetic resistance training on strength and functional mobility in older adults. *J Gerontol A Biol Sci Med Sci* 60(6):777-781, 2005.
38. Valenzuela, PL, Morales, JS, Pareja-Galeano, H, Izquierdo, M, Emanuele, E, de la Villa, P, and Lucia, A. Physical strategies to prevent disuse-induced functional decline in the elderly. *Ageing Res Rev* 47:80-88, 2018.

Figure Legends

Fig 1. Consolidated Standards of Reporting Trials flow diagram of participants through the study.