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Original Research

Effect of an 8-Week Eccentric Training Program on Strength and Balance in Older Adults

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ABSTRACT

International Journal of Exercise Science 11(3): 468-478, 2018. The purpose of the current study was to determine changes in balance and strength following an eccentric resistance training program in community-dwelling older adults who reported no history of falling. Participants (N = 14, 8 female, 6 male; age = 63.5 ± 2.0 years) completed an 8-week eccentric exercise training intervention on a commercially available eccentric step machine. Training included 2 training sessions per week, with a duration of 5 to 10 minutes and an intensity of 30 to 50% maximal eccentric strength. Single leg stance, 30-second repeated chair stand, timed up-and-go, and maximal eccentric strength were assessed at baseline, mid-point, and within one week of the final training session. In addition, total negative work and rating of perceived exertion were recorded for each exercise session. Negative work completed in training increased approximately three times, while rating of perceived exertion plateaued at the mid-point of training. The results indicated that significant improvements were observed in the 30-second repeated chair stand ($p < .001$), the timed up-and-go ($p < .001$), and maximal eccentric strength ($p < .001$), while there was no significant change in single leg stance time based on post-hoc analyses. The eccentric training was sufficient to yield improved performance on balance and strength tasks. These improvements, in community-dwelling individuals reporting no previous falls, indicate eccentric training may be a viable modality for older individuals aiming to minimize future fall-risk and prolong physical independence.

KEY WORDS: Negative work, resistance training, physical independence

INTRODUCTION

Training modalities to reduce fall-risk in older adults are vital to overcoming the social, economic, and functional burdens associated with falls (10, 30). Although no single variable can independently predict fall-risk, balance deficits and muscle weakness have been established as significant, modifiable risk factors (3, 27, 33). An emerging training method for concurrently eliciting improvements in balance and lower extremity strength is eccentric training. Relative to concentric-based training, eccentric training is characterized by lower physiological demand at a given workload (5, 11, 24, 34), higher work output (15, 20), and lower attrition with age (13).

Combined, these characteristics present a particularly tenable training modality for an older population with potentially diminished exercise tolerance. Previous research has shown that various modalities of eccentric training yield improvements in balance and muscular strength in older adults (9, 17, 19, 22, 25, 31).

One specific modality of eccentric training utilizes a machine designed to target only the eccentric component of a movement (ECC), which include cycle ergometry and step machines. Research of ECC using a cycle ergometer has indicated improvements in strength and balance in older adults (17, 22). When comparing 12 weeks of ECC to traditional resistance training in older men and women (mean age = 80.6 years), Mueller et al. (22) identified significant improvements in isometric leg extension strength and eccentric coordination in the ECC group only.

LaStayo et al. (17) also found greater improvements following 11 weeks of ECC when compared to traditional resistance training in older men and women identified as high fall-risk (mean age = 80.2 years). However, their outcome variables were focused primarily on functional assessments associated with fall-risk (17). Performance on the Berg balance scale and isometric strength significantly improved only in the ECC group (17). Moreover, while the timed up-and-go (TUG) assessment improved for both training groups, only ECC yielded improvements in the fall-risk classification for this test (17). While LaStayo et al. (17) found that ECC positively affected many assessments known to reflect fall-risk, the sample included only those classified as high fall-risk.

There is a paucity of information on the effect of ECC on balance and muscular strength in average, community-dwelling older adults. Furthermore, to the knowledge of the authors this is the first investigation of ECC on a step machine with older adults. Defining the influence of ECC in this population would allow for the implementation of strategies earlier in the fall-risk continuum, with a goal of prolonging independence and maintaining quality of life. As such, the current study aimed to identify the impact of an 8-week ECC program on static balance, dynamic balance, and muscular strength in community-dwelling older adults who have not yet fallen.

METHODS

Participants

An a priori power analysis was conducted using G*Power (Version 3.0.5), which indicated that a sample of 14 participants was required to have 80% power for detecting a medium effect size. Thus, the sample included 14 community-dwelling volunteers between 61 and 67 years old (see Table 1 for descriptive statistics). Participants were recruited from a local senior center and within the community. All participants completed a Physical Activity Readiness – Questionnaire (PAR-Q; 1) and AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire (2) prior to participation. Medical clearance was obtained, when necessary, in accordance with the American College of Sports Medicine standards (2). In order to be eligible to participate, participants were required to report community-dwelling status and no history of falling. The definition used for falling was "inadvertently coming to rest on the ground or other lower level with or without loss of consciousness and other than as the consequence of sudden onset of paralysis, epileptic seizure, excess alcohol intake or overwhelming external force" (8). Exclusion criteria included having undergone hip surgery within the past year. If surgical intervention of the hip, back, or knee was undergone 2 to 3 years prior, medical clearance was required for participation. All participants signed an informed consent and the study was approved by the university Institutional Review Board.

Table 1. Descriptive Statistics of Participants

Sample	Body Mass (kg)	Height (m)	Age (years)
All (*N* = 14)	85.1 ± 14.3	1.71 ± 0.10	63.5 ± 2.0
Female (*n* = 8)	80.2 ± 16.0	1.64 ± 0.05	63.0 ± 2.0
Male (*n* = 6)	91.7 ± 9.0	1.80 ± 0.06	64.2 ± 1.8

Protocol

The training protocol was completed on an eccentric exercise machine, which consists of a recumbent seat with step-like pedals (Eccentron, BTE Technologies Inc., Hanover, MD; Figure 1). Prior research has documented safe and effective use of similar equipment with older adults (17, 18, 22). Total negative work output was determined for each week, which was a product of the step frequency and force production.

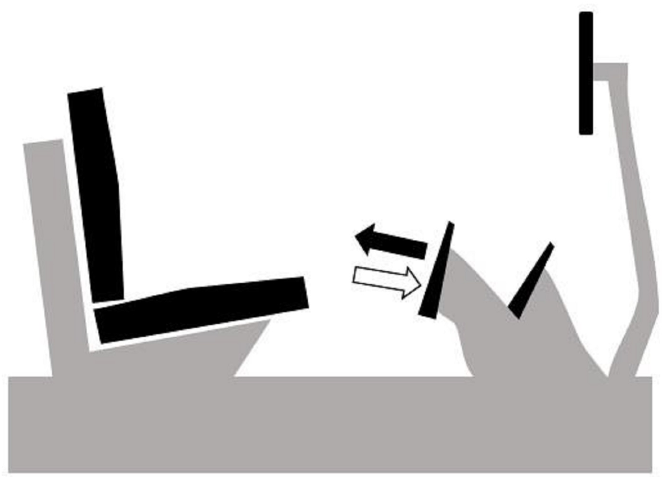

Figure 1. Pedals are driven in opposing directions by a 3-horsepower motor, producing a stepping pattern of motion. As each pedal drives toward the participant (knee and hip flexion; represented by black arrow), the movement is resisted (represented by outlined arrow). Since the power of the motor exceeds that exerted by the participant, the result is an eccentric contraction, or negative work. Unilateral force is measured by dynamometers within the pedals during this motion. As pedals are driven away (knee and hip extension), the participant is to provide no force against the pedal.

Participants were asked to come to the laboratory 2 times per week for a total of 9 weeks. This included 1 week of familiarization and 8 weeks of training. All training sessions included approximately 1 minute of warm-up and cool-down in addition to the training duration. The week of familiarization was intended to provide a gradual introduction to eccentric exercise. Participants completed 3 minutes of self-mediated exercise intensity on Day 1. The second day was used to familiarize participants with the use of visual feedback, with 3 minutes of exercise at 20% of maximal eccentric strength (MES). The training program is displayed in Table 2. A minimum accuracy of 70%, determined by falling within 10% of the prescribed force output, was required for progression in training. In addition, if participants reported a Visual Analogue Scale (VAS) above "5," the intensity and duration from the prior week were maintained. Based on these parameters, the training protocol for some participants diverged from that displayed in Table 2.

As mentioned above, a 10-cm VAS, which has been validated for use with older adults, was used to monitor lower extremity soreness (32). Prior to each session participants were asked to mark their level of lower extremity soreness along a line anchored by "no soreness" and "worst soreness possible," with a midway marker of "moderate soreness." In addition, participants were asked to provide a rating of perceived exertion (RPE) using the 6-20 Berg Scale (6) following each training session. This information was collected in order to have data regarding the participants' perception of training program difficulty, as this was the first study to the authors' knowledge to set intensity based on a percentage of maximal strength.

Table 2. Eccentric Training Protocol

Week	Intensity (% MES)	Duration (min)
Familiarization	20	3
1	30	5
2	30	7
3	30	10
4	35	10
5	40	10
6	45	10
7	50	10
8	50	10

Note. MES = Maximal eccentric strength. Warm-up and cool-down ranged from 1.0 to 1.5 minutes each per session.

Upon arrival for the first day of familiarization, participants provided written consent and competed the PAR-Q and health history questionnaire. Next shoeless height and body mass were measured using a wall-mounted stadiometer (SECA model 222, SECA Corporation, Hamburg, Germany) and Tanita BF-522 electronic scale (Tanita Corporation, Tokyo, Japan), respectively.

Next, participants completed baseline assessments. The mid-training assessments were completed before training on Day 1 of Week 5 and the post-training assessments were completed within 1 week of the final training session. Assessments were completed in the following order: single leg stance with eyes open (SLS), 30-second repeated chair stand (RCS), TUG, and MES. Aside from baseline, midway, and post-training assessments, MES was measured prior to training on Day 1 of each odd week to determine the exercise resistance.

The SLS was used to assess static balance, which has been identified as a predictor of fall-risk in older adults (23, 33). Participants were asked to stand for as long as possible on their self-selected dominant leg with eyes open and hands on their hips. The assessment was completed shod, as Briggs et al. (7) identified no difference in performance between shoes-on and shoes-off. Time began when the foot was lifted from the ground and stopped when the hands left the hips or the lifted foot touched the ground or standing leg. To avoid a ceiling effect, no maximal performance time was applied. Participants were given 2 practice and 3 timed trials, with the best performance utilized for data analysis.

The RCS was used to assess lower body strength, which is a valid and safe measure of lower extremity strength with older adults (14). The test was completed on a chair with a seat height of 44 cm. The assessment began in a seated position, with instructions to stand up and sit down as many times as possible in 30 seconds. Participants were instructed to exhibit control during the whole movement and fully extend, but not lock, the hip and knee joints upon standing. The assessment began on the command "Go" and repetitions were counted using a clicker. The number of full movements completed in 30 seconds was recorded.

Dynamic balance was assessed using the TUG, which is a sensitive measure of fall-risk (28). The participants began in a seated position, rose from the chair upon the command "Go," walked 3 meters at a fast but safe pace, turned 180 degrees around a cone, and walked back to the chair. Participants then turned around and returned to a seated position. Time was started when the test administrator said "Go" and stopped when the participant was again seated. The fastest of 3 trials was used for data analysis.

The training equipment (Eccentron, BTE Technologies Inc., Hanover, MD; see Figure 1) was utilized to assess MES. Prior to testing, participants completed a 2-minute warm-up at a self-mediated intensity. The MES assessment involved 6 maximal eccentric contractions on each leg (23 steps/min). To avoid inducing excessive strain, participants were instructed to maintain normal breathing and posture. Force was measured by dynamometers within the pedals. The strength assessment was completed 3 times, with 3-5 minutes of rest between each attempt. The best MES performance of the 3 attempts was used to set the training intensity. Per manufacturer recommendations, the exercise intensity was based off of the second highest force of the weaker leg.

Statistical Analysis

Data are presented as mean ± standard deviation. An a priori alpha of .05 was utilized to determine statistical significance. One-way, repeated measures analyses of variance (ANOVAs) were used to assess changes in SLS, RCS, TUG, and MES at baseline, midway through training, and post-training. One-way, repeated measures ANOVAs were also utilized to assess differences in RPE and negative work output among Week 1, Week 4, and Week 8. Greenhouse-Geiser adjusted p values were used. The Sidak procedure was used to assess pairwise comparisons for all one-way, repeated-measures ANOVAs. All data were analyzed using SPSS (Version 23).

RESULTS

All participants completed 1 week of familiarization and 8 weeks of training with a 99% compliance rate. Performance on the SLS significantly improved across time, F (1.82, 33.60) =

4.87, *MSE* = 476.72, *p* = .02, Partial η^2 = .27. There was a significant improvement in RCS performance across time, *F* (1.71, 22.25) = 13.74, *MSE* = 4.94, *p* < .001, Partial η^2 = .51, performance on the TUG was significantly faster across time, *F* (1.69, 21.96) = 28.53, *MSE* = 0.08, *p* < .001, Partial η^2 = .69, and MES significantly increased across time, *F* (1.35, 17.60) = 22.56, *MSE* = 8298.74, *p* < .001, Partial η^2 = .63. Pairwise comparisons for SLS, RCS, TUG, and MES are displayed in Figure 2.

There was a significant increase across time for RPE, *F* (1.4, 18.8) = 10.61, *MSE* = 3.84, *p* = .002, Partial η^2 = .45 and total negative work output, *F* (1.2, 15.6) = 24.73, *MSE* = 717.02, *p* < .001, Partial η^2 = .66. Mean weekly RPE and negative work output are presented in Table 3, along with pairwise comparisons for Weeks 1, 4, and 8.

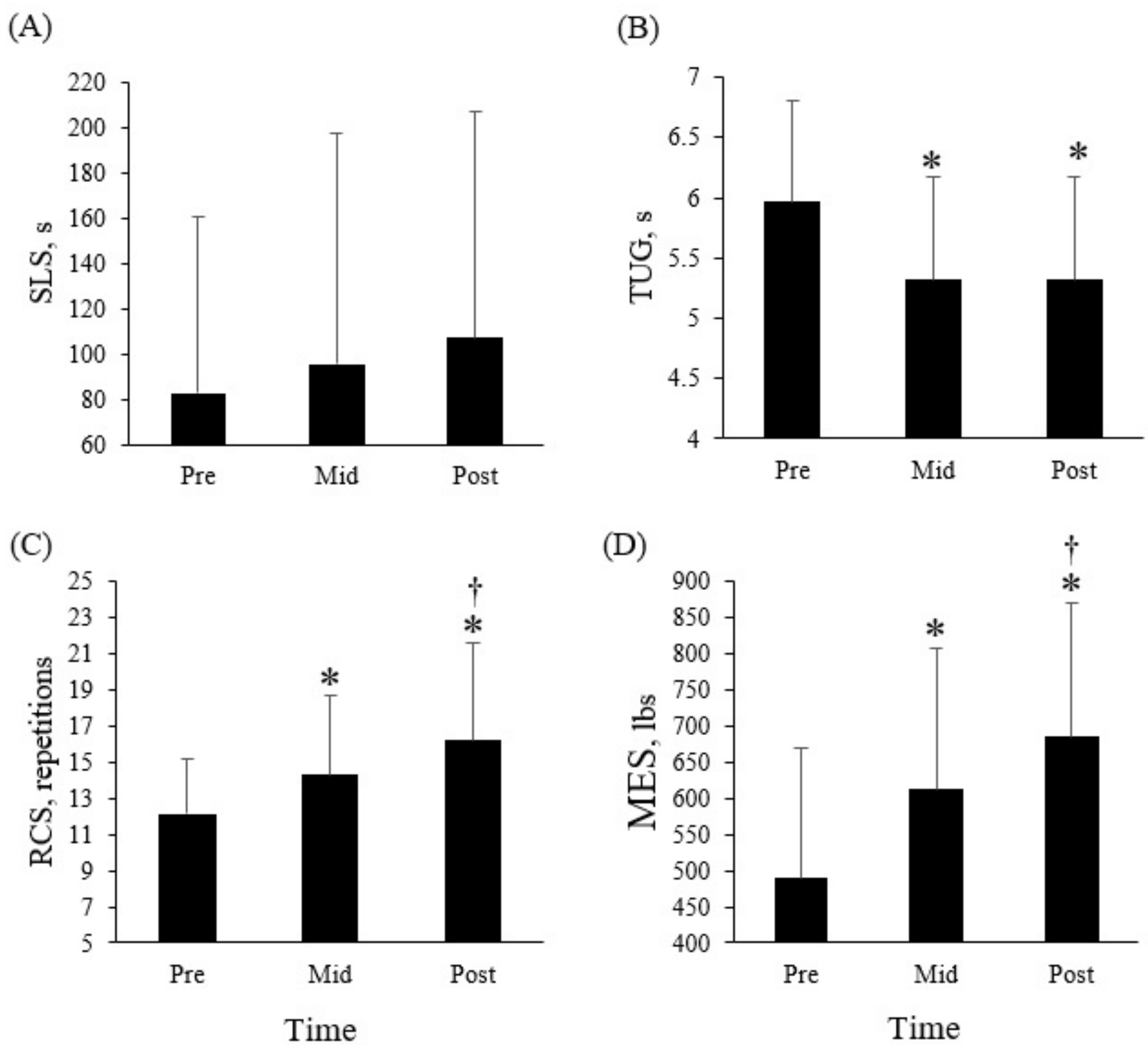

Figure 2. Columns represent mean performance. Errors bars represent standard deviation. SLS = Single leg stance. TUG = timed up-and-go. RCS = 30-second repeated chair stand. MES = combined (right and left leg) maximal eccentric strength. Pre-, mid-, and post-training mean and standard deviation for (A) SLS, (B) TUG, (C) RCS, and (D) MES. * = significantly different form pre; † = significantly different from mid.

Table 3. Weekly Work Output and Rating of Perceived Exertion

Week	Negative Work (kJ)	RPE
Familiarization	8.1 ± 3.4	--
1	20.0 ± 7.7	10.2 ± 1.6
2	28.9 ± 12.1	10.7 ± 1.4
3	40.9 ± 20.3	10.5 ± 1.7
4	52.9 ± 25.0*	11.9 ± 1.1*
5	61.1 ± 29.0	11.9 ± 1.6
6	68.9 ± 32.1	12.3 ± 1.4
7	75.4 ± 34.2	12.5 ± 2.1
8	74.8 ± 43.0**	13.1 ± 2.0

Note. RPE = Rating of perceived exertion. Week 1 (pre), Week 4 (mid) and Week 8 (post) negative work and RPE were compared. * = significantly different from Week 1. ** = significantly different from Week 4.

DISCUSSION

High potential force output (15, 20), low physiological demand (5, 11, 24, 34), and limited attrition (13) make ECC a sensible and viable training modality for older adults. The key findings of the current study were that 8 weeks of ECC yielded significant improvements in performance on balance and strength assessments for community-dwelling older adults with no history of falling. While similar outcomes have been previously documented following eccentric training (9, 17-19, 21, 22, 25, 31), participants in the current study completed ECC on a step machine, initiated training with notably higher performance on the assessments, and completed a training program with lower total volume and duration. The observed improvements were coupled with a consistent progression of negative work output, while the average RPE plateaued at "somewhat hard" (see Table 3).

In accordance with prior studies of ECC (17, 18), an increase in RPE does not appear to be a prerequisite for increasing negative work output. Average RPE in the current sample increased significantly from Week 1 to Week 4 and exhibited a plateau from Week 4 to Week 8, with a final average RPE of 13 or "somewhat hard." In contrast, negative work output increased significantly from Week 1 to Week 4 and again from Week 4 to Week 8, with an average total increase of 3.7 times (see Table 3). To the knowledge of the authors, this is the first study to prescribe intensity as a percentage of maximal strength instead of using RPE. As such, both methods of intensity mediation yielded similar increases in work output with a plateau in RPE at "somewhat hard" (17, 18). Beyond the importance of increasing work output without concurrently increasing perceived difficulty, it is important that training results in improved balance and strength.

The training volume and duration of the current study were sufficient to elicit improvement on the TUG, RCS, and MES assessments. Similar changes have been documented following eccentric step and ergometer training over 11 and 12 weeks, with 2 to 3 sessions per week lasting up to 20-30 minutes (17, 18, 21, 22). In the current study, improvements occurred following 8 weeks of training, with just 2 days of training per week, and progression to a maximal training duration of 10 minutes. In consideration of the greater potential force production and lesser attrition of eccentric strength with older adults (13), it is plausible that the mediation of intensity based on MES provided sufficient mechanical stress to stimulate adaptations, even with comparatively short session and training program durations**.** Based on the training duration, it is anticipated that the observed improvements primarily resulted from neuromuscular adaptations. Hortobágyi and DeVita (11) identified significant neuromuscular changes in older adults paired with increased muscular strength following only 1 week of ECC. Further research is warranted with assessment of neuromuscular changes throughout an ECC program.

The TUG has been identified as a predictor of fall-risk, with times exceeding 14 seconds being classified as high risk (28). Further, the TUG is a meaningful outcome measure due to its significant correlation with balance (4, 16), reaction time (16), and lower limb strength (16). The current participants initiated training with an average TUG of 6.0 seconds, classifying the sample at low risk of falling and in the average category for moderately active older adults (26). In comparison, individuals in other research with more advanced age (14, 18) or who had undergone knee replacement in the last 1 to 4 years (18) exhibited slower baseline TUG performance, with a range of means from 7.4 to 16.7 seconds (17, 18, 22). Although our participants did not exhibit an immediate need to improve performance based on fall-risk classification and reported averages, this training may be beneficial as a preventive tool used to circumvent age-related decline in performance, as significantly improvements were observed. This is further demonstrated when comparing the current results to criterion-referenced standards, which were developed to indicate the level of performance needed at a given age to maintain independence later in life, accounting for the average rate of age-related decline in TUG performance (26). After only 16 training sessions, 43% of participants (4 females, 2 males) met the standard for sustained physical independence while only 2 females began training at the standard.

It is also noteworthy that the observed improvement in TUG performance in the current participants occurred within the first 4 weeks of training and did not improve significantly more between mid- and post-training. Because this is the first study to assess TUG performance after 4 weeks of training, it cannot be discerned if this is a common trend for older adults or a unique response to the participants of this study. Future studies should complete assessments throughout training to document improvement trends across time and further compare improvements in performance to criterion-referenced standards for prolonged physical independence (26).

In accordance with the reported correlation between the TUG and muscular strength (16), participants demonstrated improved performance on both assessments. Changes in lower extremity strength following ECC are well documented (17, 18, 21, 22). However, the use of the RCS as a lower body assessment in the current sample was unique. Aside from the contribution of lower extremity strength to minimizing fall-risk (28), Rikli and Jones (26) also identified age-specific, normative and criterion-referenced standards for performance on the RCS. As discussed with the TUG, the criterion-referenced standards were developed to predict the performance needed on the RCS to maintain physical function later in life (26). Although normative comparisons of participants in the current study closely resemble average performance for moderately active older adults on the RCS (26), only 1 male participant completed enough repetitions at pre-test to meet the standard indicative of independence later in life. However, 43% of participants (5 females, 2 males) completed enough repetitions following the 8 weeks of ECC to meet the standard for independence. Thus, a training program of only 8 weeks (16 total sessions) was able to yield changes in RCS performance that are indicative of prolonged physical independence. With the importance of maintaining independent living in the older population, future studies should assess the impact of a longer training program duration on RCS performance with reference to the criterion-referenced standards (26).

Improvement in MES on the training apparatus has not been previously documented following this form of ECC in older adults. However, prior investigations of ECC using a cycle ergometer or step machine for training have documented improvement on alternate assessments of eccentric strength, including timed stair descent (17, 18) and isokinetic eccentric strength (21). It is also noteworthy that older adults exhibit reduced control of submaximal eccentric contractions (12). As such, one limitation of this study is that control of submaximal eccentric contractions was not specifically assessed. Following a 12-week eccentric ergometer training program, eccentric coordination was improved (22). Similar improvements would be expected from the current training, particularly since training progression required accuracy of submaximal eccentric contractions. Further research is warranted regarding changes in -submaximal eccentric control following ECC. In accordance with previous suggestions (22), researchers should also consider assessing the relationship between eccentric coordination and balance or other measures of physical function.

When post-hoc analyses were completed for the SLS, there were no significant differences. This test may have demonstrated a ceiling effect, as the means pre- and post- training were 82.9 ± 78.3 seconds and 107.4 ± 99.9 seconds, respectively. In comparison, the established normative value for SLS performance for individuals between 60 and 69 years old is 32.1 ± 16.2 seconds (29). Future studies should focus on utilizing an adequately sensitive static balance assessment to optimize detection of changes in performance. A similar lack of improvement in balance performance was found by Mueller et al. (22) with high functioning older adults with the Berg Balance Scale, which the authors identified as a test lacking sufficient sensitivity for their sample.

In summation, the results of the current study further advocate the safety and efficacy of ECC with older adults. Participants were able to significantly increase negative work output while the perceived difficulty of the exercise plateaued at "somewhat hard." The 8 weeks of progressive ECC, with only 2 sessions per week, provided sufficient mechanical stimulation for improved balance and strength in community-dwelling older adults who reported no previous falls. The assessments were specifically selected to detect changes in outcomes known to contribute to fall-risk. As such, further consideration for the impact of the observed improvements in minimizing fall-risk and maximizing independence is warranted.

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