Clinical Biomechanics 40 (2016) 14–19

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Lecture

Efficacy of a progressive resistance exercise program to increase toe flexor strength in older people

Karen J. Mickle [a,*,1], Peter Caputi [b], Jan M. Potter [c], Julie R. Steele [a]

[a] Biomechanics Research Laboratory, University of Wollongong, Northfields Ave, Wollongong, NSW 2522, Australia
[b] School of Psychology, University of Wollongong, Northfields Ave, Wollongong, NSW 2522, Australia
[c] Division of Aged Care, Illawarra Shoalhaven Local Health District, Wollongong Hospital, Wollongong, NSW 2500, Australia

ARTICLE INFO

Article history:
Received 18 April 2016
Accepted 5 October 2016

Keywords:
Falls
Resistance exercise
Toe strength
Elderly

ABSTRACT

Background: Reduced toe flexor strength is an independent predictor of falls in older people. However it is unknown whether strengthening programs can restore toe flexor strength in older individuals. The aim of this study was to investigate whether a progressive resistance training program, focused specifically on the foot muscles, could improve toe flexor strength in community-dwelling older people.
Methods: After baseline testing, 85 men and women (age range 60–90 years) were randomized to either a supervised, progressive resistance training ($n = 43$) or a home-based exercise ($n = 42$) group for 12 weeks. A further 32 participants were recruited for a control group. The primary outcome measures were hallux and lesser toe flexor strength pre- and post-intervention. Secondary outcome measures were exercise compliance, components of the Foot Health Status Questionnaire and single-leg balance time.
Findings: Average class attendance was 89% with 68 participants from the two intervention groups (80%) completing the follow-up assessments. Participants in the supervised, progressive resistance training group significantly increased their toe strength (up to 36%; $P < 0.02$), whereas there was no change in toe strength in either the home-based or control groups. This increased toe strength was accompanied by a significant improvement in perceived general foot health and single-leg balance time compared to the other groups ($P < 0.05$).
Interpretation: Progressive resistance exercises are a viable intervention to increase toe flexor strength in older adults. A clinical trial is now required to determine whether this intervention can reduce the number of falls suffered by older adults.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

A decline in muscle strength is typically regarded as an inevitable consequence of ageing, and age-related loss of muscle mass is one of the main determinants of frailty. Muscle atrophy in older adults has been associated with an annual decline in lower leg strength of approximately 3% (Goodpaster et al., 2006). This muscle atrophy and strength loss can arise from muscle disuse and are inversely associated with changes in physical activity (Kent-Braun et al., 2000). Although under researched compared to other lower limb muscles, it appears that muscles within the feet also suffer from atrophy and an associated loss of strength with ageing. For example, older adults have 27–36% less toe flexor muscle strength than their younger counterparts (Endo et al., 2002; Menz et al., 2006). This reduction in toe flexor strength is likely to have a profound effect on the ability of older adults to walk safely. An individual's toes are in contact with the ground for 75% of the stance phase when walking(Hughes et al., 1990) and the long toe flexor muscles help control forward progression of the leg over the foot (Hamel et al., 2001). This could be critical when attempting to take corrective steps to maintain balance in a near-fall situation. Of concern, a prospective study of over 300 older people found that fallers had a reduction of >20% in their hallux and lesser toe strength compared to non-fallers (Mickle et al., 2009). Hallux strength was also found to be a stronger predictor of falls than other more commonly measured falls risk factors, such as age, gender, falls risk score and quadriceps strength. In fact, each unit (% body weight) increase in hallux strength decreased the odds of sustaining a fall by 7% (Mickle et al., 2009).

Strengthening the toe flexor muscles should improve the ability of the toes to perform their specific roles in balance and walking. Supporting this theory, Kokkonen et al. (1988) monitored athletes while they completed toe resistance training for 12 weeks. Compared to an age- and gender-matched control group, toe flexor strength increased by approximately 46% and resulted in a significant improvement in vertical jump performance. Similarly, Unger & Wooden

* Corresponding author at: Institute of Sport Exercise and Active Living, Victoria University, PO Box 14428, Melbourne, VIC 8001, Australia.
E-mail address: Karen.mickle@vu.edu.au (K.J. Mickle).
1 Permanent address: Institute of Sport Exercise and Active Living, Victoria University, Melbourne, VIC 8001, Australia.

http://dx.doi.org/10.1016/j.clinbiomech.2016.10.005
0268-0033/© 2016 Elsevier Ltd. All rights reserved.

(2000) employed a within-subject design whereby 15 men and women (aged 21–62 years) completed toe strengthening exercises (Archxerciser™) on one foot over 6 weeks. Compared to the "untrained" (control) foot, toe flexor strength improved almost four-fold after 6 weeks. Importantly, these unilateral strength gains were accompanied by significant improvements in single limb horizontal and vertical jump performance. The most impressive toe strength gains have been reported in 14 males who performed high resistance toe training, which resulted in a 60–70% increase in toe flexor strength (Goldmann et al., 2013). These results suggest that increasing toe strength can lead to improved motor task performance in young adults.

There is emerging evidence that toe-strengthening exercises may be effective for older adults or people with foot pathologies. For example, individuals with pes planus (flat feet) exhibited significant increases in hallux flexor strength following a 2-month intervention program that incorporated the Short Foot strengthening exercise (Jung et al., 2011). Other research has associated toe exercises with improved motor task performance in older adults. Nine nursing home residents undertook training three times a week using their toes to gather a weighted towel and pass beanbags from one place to another (Kobayashi et al., 1999). After 8 weeks the toe-grasp training was found to significantly improve the participants' spontaneous sway performance with both their eyes open and closed by 16% and 26%, respectively. In contrast, no change, or poorer balance was displayed by an age-matched control group, who participated in a group exercise program. Unfortunately, although balance performance improved after toe-grasp training, toe strength was not measured in this study. Therefore, it is unknown whether the training lead to toe strength gains or whether improvements in balance were associated with some other mechanism. Toe strengthening exercises were also included in a multifaceted podiatry intervention study involving older adults with foot pain and who were identified as being at an increased risk of falling (Spink et al., 2011). This intervention (foot orthoses, advice on footwear, footwear subsidy, a home-based program of foot and ankle exercises, a falls prevention education and routine podiatry care) resulted in a 36% reduction in falls incidence compared to the control group who received routine podiatry care for 12 months. The toe-strengthening portion of the program consisted of participants completing exercises on an Archxerciser™ and picking up stones with their toes, three times a week for 6 months. At the 12 month conclusion of the intervention, a non-significant 9% increase in toe flexion strength was reported. This program, however, was non-progressive (resistance did not increase as strength improved) and did not target the intrinsic foot muscles (Spink et al., 2011). Consequently, the objective of the current study was to address the limitations in previous studies, by investigating whether a progressive resistance training program, focused specifically on the foot muscles, could improve toe flexor strength in community-dwelling older people. We hypothesized that older people who participated in the structured 12-week progressive resistance training program would increase their toe flexor strength more than older people who performed home-based general foot exercises and controls.

2. Methods

2.1. Design overview

This study was a longitudinal study with parallel and randomized allocation of two exercise interventions to determine the effectiveness and adherence of each program. A control group, who were unavailable to participate in the exercise program due to other commitments, was assessed to allow comparison of the outcome variables to the exercise groups. *Due to logistics associated with implementing the interventions (i.e. the intervention needed to be completed before a summer holiday break), the control group was recruited after the other groups. As there was no further follow-up or clinical outcomes measured (e.g. number of falls), the study was not deemed to be a full RCT.*

2.2. Setting and participants

Volunteers were recruited from the Illawarra region of New South Wales, Australia between September 2013 and June 2014. Potential participants responded to either an advertisement placed on the university staff email list or in the local newspaper, and were screened according to the participant selection criteria. Male and female participants were included in the study if they were aged over 60 years, living independently in the community, able to ambulate for at least 10 m without an aid, free from known neurological disorders, and were willing and able to attend 12 weeks of group-based exercise classes. Eighty-five individuals were eligible to participate in the exercise intervention (19 men and 66 women; mean age 69.7 (SD 5.8) years, range = 60–90 years). A further 32 participants were recruited for the control group, the majority from the initial recruitment call whom were unable to commit to the exercise program (7 men and 25 women; mean age 68.3 (SD 5.3) years, range = 60–79 years). Each participant gave written informed consent after reading the participant information package before any testing procedures began. The University of Wollongong Human Research Ethics Committee (HE13/282) approved all recruiting and testing procedures. All data were collected in the Biomechanics Research Laboratory, University of Wollongong, Australia.

2.3. Randomization and interventions

Baseline testing for the intervention groups was performed over 3 weeks, with up to 30 participants enrolled each week (week 1 = 30, week 2 = 29, week 3 = 26). After the participants completed the baseline assessment and questionnaires, they self-selected a sealed envelope that revealed their group allocation, with 15 supervised, group training and 15 home-exercise places available each week. To ensure allocation concealment, a research assistant who was not involved with the recruitment or follow-up assessments performed the group randomization.

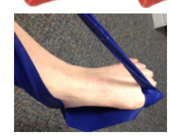
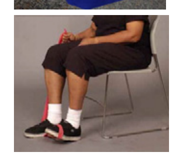
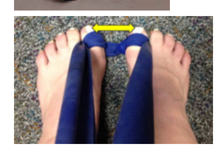
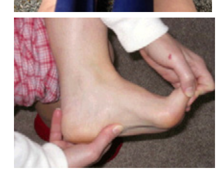
Participants in the supervised, progressive resistance training group (Toe Training group) attended three 45-minute group-exercise classes each week, for 12 weeks, with class sizes typically ranging from 5 to 10 participants. During each class, an Accredited Exercise Physiologist (not associated with the study), led the participants through a warm-up, followed by a series of eight exercises that were developed by the Chief Investigator [K.J.M] to strengthen the foot muscles (see Table 1). Most exercises were performed using exercise bands (66fit latex, Physio Supplies, Spalding, UK), with the resistance level starting from light (yellow) and progressing through to x-heavy (blue). The level of exercise difficulty progressively increased throughout the 12-week program, by increasing either the strength of the resistance bands or the number of repetitions (1–3 sets; 10–15 reps) (Balady et al., 2000).

The home-exercise group (Home group) received a booklet containing a series of eight general foot exercises that had little or no resistance and did not progress in amount of resistance. The warm-up consisted of ankle rotations, calf raises and toe raises, and the cool down consisted of rolling a golf ball underneath each foot for 2 min. They then performed a prescribed number of repetitions of toe squeezes, toe pulls, marble pickups and towel pulls as suggested by Frey (2000) and the Short Foot exercise (Jung et al., 2011) three times per week.

The instructor recorded class attendance at the group strength-training sessions; whereas participants in the home-based exercise group were asked to record the exercise sessions they performed in a training diary. Participants were asked to report any adverse effects of the exercise program and reasons for program dropouts were recorded.

Participants recruited for the Control group completed the assessments at baseline and again after 12 weeks, but were not given any exercises. They were asked to maintain their normal activities. It was not possible to blind participants to their group assignment because they actively participated in their randomly assigned training program.

Table 1
The progressive Toe Training exercise program.

Exercise instructions	Week 1	Maximal progression	Illustration
Warm-up exercises (5 min): Example exercises included walking, toe walking, ankle rotations and drawing the alphabet with the foot.			
Short foot exercise (Jung et al., 2011): Raise the arch of your foot by sliding your big toe towards your heel without curling your toes or lifting your heel.	3 × 5 reps on each foot, holding position for 5 s	5 × 5 reps on each foot, single leg, hold for 10 s	
Heel raises: Stand and rise up onto your toes by lifting your heels off the ground. Hold the position for 3–5 s.	1 × 10	1 × 10, single leg	
Invertors: Wrap the band around your forefoot and cross the opposite foot across your shin to add resistance to the band. Abduct your foot against the resistance.	1 × 10 (yellow band)	2 × 12 (blue band)	
Evertors: Wrap the band around your forefoot while the opposite foot adds resistance to the band. Place the opposite foot around the band, so the band is now around one foot and behind the other (legs are parallel). Adduct & evert your forefoot against the resistance.	1 × 10 (yellow band)	3 × 10 (blue band)	
Toe flexion: Place band over the sole of your foot with one end under the heel and the other over the toes and take up the slack. Keeping your ankle still, crunch your toes downward into the band (like a monkey, grabbing a branch with its feet). Hold and slowly return.	2 × 10 (yellow band)	2 × 10 (blue band)	
Hallux flexion: Same as above, but wrap the band solely around your big toe.	2 × 10 (yellow band)	2 × 10 (blue band)	
Ankle dorsiflexion: Wrap the middle of the band around the foot you are exercising. Place the ends of the band under the opposite foot to stabilize the band. Grasp the ends of the band at your opposite knee. Lift your foot upward against the band. Hold and slowly return.	1 × 10 (yellow band)	1 × 10 (blue band)	
Big toe pulls: Place the band around your big toes and hold the end of the bands in opposite hands. Leaving your heels on the ground, pull your big toes away from each other and towards your little toes. Hold for 5 s.	1 × 10 (yellow band)	2 × 10 (blue band)	
Cool down (3–5 min): Combination of straight and bent knee calf stretches; plantar fascia stretch/massage - sitting down, cross your leg over your knee. With one hand, pull your toes back. With the other hand, massage the area on the bottom of your foot just in front of your heel. Do this for 1 min per foot.			

However, no information was provided to the participants about which program was hypothesized to be more beneficial.

2.4. Outcomes and follow-up

All measurements were collected before and after the intervention period, 12 weeks later, by study personnel who were unaware of the randomization assignments. Toe flexor strength was the primary outcome, and was quantified using our previously developed, reliable (ICC > 0.92) protocol (Mickle et al., 2009; Mickle et al., 2006). Each participant stood with their feet placed hip-width apart, with the test foot centred on an emed AT-4 pressure platform (Novel GmbH; Munich, Germany), and were instructed to push down on the platform as hard as possible under two conditions: (i) using their hallux and lesser toes, or (ii) using only their hallux. Three trials were completed on both the left and right feet for each condition, with the centre of pressure inspected to exclude trials in which participants displayed excessive body sway. The data were then analysed using Novel Projects software, whereby the hallux and lesser toes were masked on the peak pressure picture. Peak force (N) was then determined for the mask of interest under each condition and normalised to body weight to represent maximum hallux flexor strength and lesser toe flexor strength (% BW) for each foot.

Health-related quality of life with respect to foot health, was a secondary outcome measure of the trial and was assessed using the Foot Health Status Questionnaire (FHSQ) (Bennett et al., 1998). The FHSQ uses 19 items to assess the domains of foot pain, foot function, footwear, general foot health, general health, physical activity, social capacity and vigour. Each domain was scored from 0 to 100 whereby a higher score indicates better function.

Single-leg balance time was used as a reliable (ICC > 0.75) (Sherrington & Lord, 2005) clinical measure of balance to characterise the functional capacity of the participants in the trial. The participants stood with their weight evenly distributed across both feet, with their eyes open and focused on a point on the wall/floor. Keeping their arms by their sides, each participant was asked to lift the non-test foot off the floor and try to maintain their balance as long as possible. The test (and timer) was stopped after 60 s or when the lifted foot was placed on the floor (Rooks et al., 1997). Participants were given two attempts on each leg unless they were able to complete 60 s on their first attempt. If a participant was able to complete at least 10 s on the eyes-open component, the task was progressed to performing the test with their eyes closed. The single-limb balance task is a challenging balance task and the eyes-closed component was used to discriminate small improvements, particularly if the cohorts displayed few functional impairments.

2.5. Statistical analysis

Participant characteristics including age, BMI and balance were compared between the three groups at baseline using a one-way ANOVA. The purpose of this analysis was to ensure the three groups were appropriately matched on factors that could influence their performance of the exercise programs. For variables where both feet were tested (one-leg balance, toe strength), only data from the left foot were used to satisfy the statistical assumption of data independence. A two-way repeated measures analysis of variance design, with one between factor (group: Toe-Training class, home-exercises and control) and one within factor (test session: pre and post), was then conducted to test whether the foot strengthening exercises affected toe strength and balance over time. For variables that differed between groups at baseline (lesser toe strength), an analysis of covariance was conducted to test differences between the three groups at post-intervention, using baseline strength as a covariate. Scores from the Foot Health Status Questionnaire were not normally distributed, so the between-group difference was determined by comparing the change in score between baseline and follow-up using a Kruskal-Wallis test. An alpha of $P < 0.05$ was established for all statistical analyses, which were conducted using SPSS software (IBM SPSS Statistics 22).

3. Results

Fig. 1 shows the flow of participants through the study. Participants in the three groups had very similar characteristics at baseline (see Table 2).

Table 2
Descriptive characteristics and single-leg balance time of the Control (n = 32), Home (n = 42) and Toe Training (n = 43) groups at baseline. Values given are mean (SD), unless indicated.

	Control	Home	Toe Training	*P*-value
Age (y)	68.3 (5.3)	69.5 (6.0)	70.6 (5.6)	0.18
BMI (kg/m^2)	26.5 (5.7)	28.1 (6.7)	28.8 (5.9)	0.40
Men:women (n)	8:24	11:31	8:35	0.68
Balance – EO (s)	32.9 (22.6)	26.0 (22.2)	23.9 (20.0)	0.19
Balance – EC (s)	6.7 (11.0)	4.9 (9.5)	3.2 (3.6)	0.21

EO = eyes open; EC = eyes closed.

3.1. Toe strength

Significant time x group interaction effects were found for hallux strength ($F_{[2,93]} = 3.57$; $P = 0.03$; $\eta^2_p = 0.07$) and lesser toe strength ($F_{[2,93]} = 10.57$, $P < 0.001$; $\eta^2_p = 0.18$ see Fig. 2). For hallux strength, although there was no change across time for either the Control group ($M_{diff} = 0.33\%BW$, $P = 0.50$), or Home groups ($M_{diff} = 0.05\%BW$, $P = 0.92$), there was a significant increase in hallux strength from pre- to post-intervention testing for the Toe Training group ($M_{diff} = 1.7\%BW$, $P < 0.001$). In addition to the significant time x group interaction for lesser toe strength, when using baseline strength as a covariate, we found a significant increase in the adjusted means (95% CI) of the Toe Training (7.7 (7.1–8.4) % BW) compared to the Control (5.9 (5.2–6.6) % BW) and Home (6.3 (5.6–6.9) % BW) groups after the intervention ($F_{[2,95]} = 8.3$, $P < 0.001$).

3.2. Foot health

Scores obtained for the Home, Toe Training and Control participants at baseline and post-intervention for each domain of the Foot Health Status Questionnaire are displayed in Table 3. A significant improvement for the General Foot Health domain was found in the Toe Training group (mean change (95% CI) = 12.6 (6.0–19.1) points) compared to the Home and Control groups ($P \leq 0.05$). None of the other domains showed any significant change following the 12 week follow-up period for any participant group.

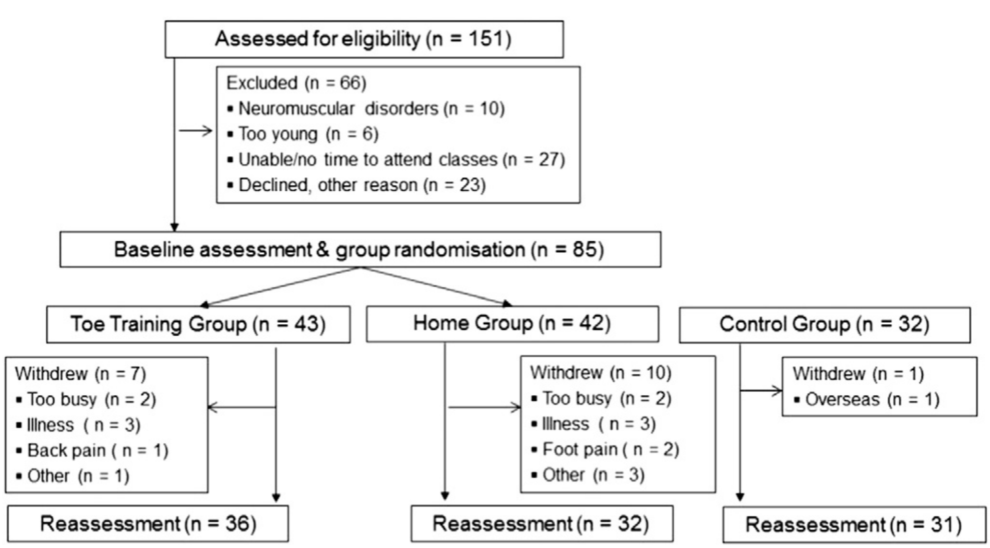


Fig. 1. The flow of participants through the trial.

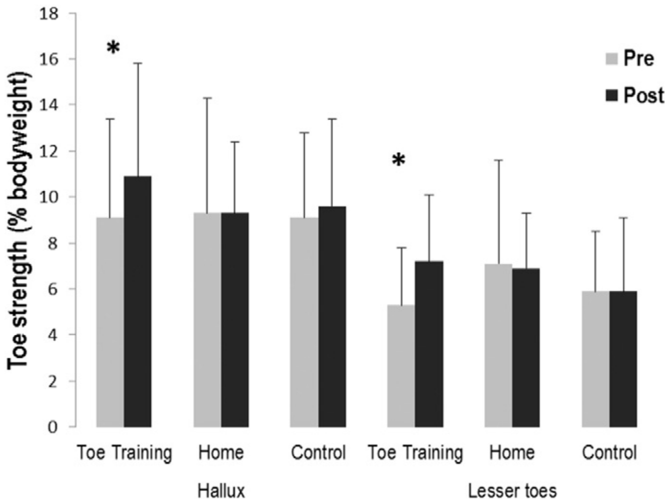


Fig. 2. Change in hallux and lesser toe strength for participants in the Toe Training, Home and Control groups. * indicates a significant difference between pre- and post-intervention ($P < 0.05$).

3.3. Balance

Significant time x group interaction effects were found for single leg balance with eyes open ($F_{[2,96]} = 4.49$; $P = 0.01$; $\eta_p^2 = 0.09$) whereby there was no change across time for either the Control group ($M_{diff} = -5.1$ s, $P = 0.06$), or Home groups ($M_{diff} = 4.2$ s, $P = 0.12$), but there was a significant increase in time from pre- to post-intervention testing for the Toe Training group ($M_{diff} = 5.1$ s, $P = 0.04$). A significant effect of time was found for single-leg balance with eyes closed ($F_{[2,96]} = 10.7$; $P \leq 0.001$; $\eta_p^2 = 0.1$) whereby pairwise comparisons revealed no change across time for the Control group ($M_{diff} = 0.9$ s, $P = 0.43$), but there was a significant increase in time from pre- to post-intervention testing for the Home ($M_{diff} = 2.7$ s, $P = 0.03$) and the Toe Training groups ($M_{diff} = 3.0$ s, $P = 0.01$).

3.4. Compliance

Thirty-six of the 43 participants (84%) completed the supervised Toe Training exercise program. Average class attendance was 89% (range 37–100%). Thirty participants (81%) attended at least 75% of their scheduled classes with eight participants (22%) attending all 36 classes. Thirty-two of the 42 participants (76%) in the Home group returned for the follow-up assessment. Average compliance to the home-based exercise program was 83% (range 0–100%). Twenty-four participants (80%) completed at least 75% of their programmed exercises with 13 participants (43%) completing 100% of the exercise program. The reasons for participant dropouts are included in Fig. 1. No serious adverse events were reported during the classes; although one participant experienced an exacerbation of existing lower back pain during the first week of the program and withdrew from the study.

4. Discussion

The aim of this study was to determine whether a progressive resistance training program, focused specifically on the foot muscles, could strengthen the toe flexor muscles in community-dwelling older people in comparison to home-based general foot exercises and controls. The findings indicate that older people can significantly increase both their hallux and lesser toe flexor strength by participating in a structured, progressive group exercise class within a 12-week program. The implications of these findings are discussed below.

Similar to previous research (Spink et al., 2011), the non-progressive general foot exercises completed by the home-based exercise group, failed to elicit a significant change in toe strength. In fact, despite performing foot exercises such as picking up marbles with their toes, the home-based exercise group displayed a 1% reduction in lesser toe strength. The programs performed by the home-based exercise group and participants in previous research (Spink et al., 2011), were ineffective as they were non-progressive, that is, the resistance did not increase as the strength of the participants improved over time. Conversely, the supervised training group in this study performed foot exercises using exercise bands, which gradually progressed in resistance, as the participants became stronger. This program resulted in an increase in lesser toe strength of 1.9% BW, representing a 36% increase in strength from baseline. Both foot exercise groups appeared to have small improvements in their balance after completing their respective programs. Only the Toe Training group showed a significant improvement in the balance time with their eyes open, but both groups improved the length of time they could balance on one-leg with their eyes closed. The only exercises that were replicated in both exercise programs were the short foot exercise and heel raises. These were also the only exercises that were weight bearing and progressed to being performed on a single leg, which may explain why both groups improved their single-leg balance time. Further research is required to determine the contribution of toe strength to balance, however, it worth noting that the Toe Training resulted in improved balance.

The significant increase in toe strength displayed by the supervised training group was accompanied by a significant improvement in perceived general foot health. Anecdotally, many of the participants in the supervised training intervention reported positive feedback about the exercise program. One female participant noted that a forefoot callus that had been present for 19 years had "disappeared" during the program. Other participants made positive statements such as: "I walk out of the class and feel like I'm walking on clouds", "I have the bounce back

Table 3
Foot related quality of life scores (out of 100), obtained for each domain of the Foot Health Status Questionnaire for the three groups, at baseline and completion of the intervention period.

Variable	Control		Home		Toe Training	
	Baseline	Post-intervention	Baseline	Post-intervention	Baseline	Post-intervention
Foot health	mean (95% CI)	mean (95% CI)	mean (95% CI)	mean (95% CI)	mean (95% CI)	mean (95% CI
Foot pain	78.9 (71.6–86.2)	82.2 (74.8–89.6)	79.3 (70.7–87.9)	81.2 (75.0–87.5)	82.9 (75.0–90.8)	85.3 (78.0–92.6)
Foot function	85.9 (78.9–92.9)	88.5 (80.6–96.4)	85.5 (77.1–93.8)	87.3 (81.4–93.2)	91.8 (85.7–97.9)	92.9 (87.6–98.2)
Shoes	53.2 (41.7–64.8)	54.3 (41.4–67.2)	44.9 (32.8–57.0)	46.8 (36.1–57.4)	48.1 (37.2–59.0)	48.1 (37.3–59.0)
General foot health	56.3 (45.1–67.5)	58.9 (47.8–70.0)	64.4 (53.6–75.1)	68.2 (58.3–78.0)	54.0 (44.2–63.8)	66.6 (58.3–74.9)[a]
General health	77.4 (69.1–85.7)	77.1 (69.2–85.0)	81.9 (75.1–88.7)	78.7 (70.1–87.3)	70.9 (62.7–79.0)	73.1 (66.0–80.3)
Physical activity	76.2 (68.2–84.2)	76.3 (67.3–85.4)	73.8 (66.8–80.9)	72.4 (64.5–80.3)	76.8 (70.7–83.0)	76.7 (70.0–83.4)
Social capacity	87.1 (79.5–94.7)	87.1 (80.3–94.0)	86.3 (79.4–93.2)	84.3 (75.5–93.1)	85.7 (78.7–92.7)	90.7 (85.7–95.8)
Vigour	61.9 (55.0–68.8)	62.7 (56.3–69.1)	59.7 (54.1–65.2)	63.1 (55.5–70.7)	55.5 (48.6–62.5)	59.8 (52.7–66.9)

[a] Significant change in score for the Toe Training group from baseline to post-intervention compared to the Control and Home groups.

in my steps", and "I can see muscles and joints in my feet that I've never seen before".

Adherence to the supervised, progressive resistance training intervention was very high, with >80% of the participants attending at least 75% of the exercise classes over the 12 weeks. Compliance to the home-based exercises was also high (80% completing >75% of the exercise sessions), although trial dropout was greater in the home-based exercise group compared to the supervised group (24% *vs* 16%). Adherence to this home-based program was higher than that reported by Spink et al. (2011), who had 66% self-reported completed exercise sessions, with 52% of the participants completing 75% or more of the requested three exercise sessions per week. However, their exercise program lasted for 24 weeks, twice as long as the current intervention. Participants in the supervised training were offered 16 class times per week, with the small classes supervised by the same instructor. This led to the participants developing a strong rapport with the instructor and fellow trial participants, which is likely to have contributed to the high exercise class compliance.

The strengths of this study are the high compliance rates in both progressive training and home exercise groups, small losses to follow-up and the inclusion of an active home-based exercise group who still did a form of simple foot exercises. This will allow us to make a more accurate sample size calculation to adequately power a clinical trial. However, the findings of the current study need to be interpreted in the context of the following limitations. Firstly, owing to the nature of the intervention, it was not possible to blind participants to their group allocation. Secondly, the sample may have been biased towards volunteers with a heightened interest in and commitment to the intervention. Twenty-seven people who initially expressed interest declined participation, primarily due to reluctance to commit to the study for a 3-month period. Finally, care needs to be taken in generalising these findings, as all participants were living independently in the community and there was an over representation of female participants. Whether the intervention is effective in residential care settings or in older people who have specific foot problems associated with muscle weakness, such as hallux valgus, lesser toe deformities and pes planus, requires investigation. The foot exercises, however, have the advantage of being performed in a seated position, allowing individuals with stability problems or poor cardiovascular health to participate in the program.

We have previously identified that reduced strength of the muscles that flex the toes is one of the strongest independent contributors to falls in older people (Mickle et al., 2009). In fact, each unit (% body weight) increase in hallux strength decreased the odds of sustaining a fall by 7%. Results of this study provide evidence that a 12-week progressive resistance training intervention can significantly increase strength of the toe flexor muscles in community-dwelling older people. Based on the current study, the 1.7%BW average increase in hallux flexor muscle strength associated with the progressive resistance training program has the potential to result in a 12% reduction in falls incidence. A prospective clinical trial, following participants after they have completed a Toe Training intervention and monitoring their future falls is required to confirm or refute this notion.

As falls are the leading cause of injury, disability, hospitalisation and death for older adults, effective evidence-based interventions are urgently required to reduce the risk of falling in older adults. This innovative study has been designed to fulfil a gap in our current knowledge by establishing that a progressive resistance training intervention can increase the strength of the toe flexor muscles in older people. As minimal negative effects of the intervention can be foreseen and the intervention can be readily translated into community practice, the potential benefits associated with this toe strengthening training program for older adults are substantial. A clinical trial that determines whether this intervention can reduce the risk of falling is now recommended.

Funding

This work was supported by the Illawarra Health and Medical Research Institute and completed while Dr. Mickle held an Australian National Health and Medical Research Council Post-doctoral Fellowship (Overseas Clinical Training Fellowship, ID 1016521). The funding agencies did not have a role in the design, conduct, or reporting of the study or in the decision to submit the article for publication.

Acknowledgements

The authors wish to acknowledge all of the participants in the trial. The authors would like to thank the Clinical Trials Unit staff at the Illawarra Health and Medical Research Institute for assistance with the group exercise classes.

References

Balady, G.J., et al., 2000. In: Franklin, B.A. (Ed.), ACSM's Guidelines for Exercise Testing and Prescription, Sixth ed. Lippincott Williams & Wilkins, USA.

Bennett, P.J., et al., 1998. Development and validation of a questionnaire designed to measure foot-health status. J. Am. Podiatr. Med. Assoc. 88 (9), 419–428.

Endo, M., Ashton-Miller, J., Alexander, N., 2002. Effects of age and gender on toe flexor muscle strength. J. Gerontol. A Biol. Sci. Med. Sci. 57A (6), M392–M397.

Frey, C., 2000. Foot health and shoewear for women. Clin. Orthop. Relat. Res. 372, 32–44.

Goldmann, J.-P., et al., 2013. The potential of toe flexor muscles to enhance performance. J. Sports Sci. 31 (4), 424–433.

Goodpaster, B.H., et al., 2006. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. J. Gerontol. Ser. A Biol. Med. Sci. 61 (10), 1059–1064.

Hamel, A.J., Donahue, S.W., Sharkey, N.A., 2001. Contributions of active and passive toe flexion to forefoot loading. Clin. Orthop. Relat. Res. 393, 326–334.

Hughes, J., Clark, P., Klenerman, L., 1990. The importance of the toes in walking. J. Bone Joint Surg. (Br.) 72-B (2), 245–251.

Jung, D.-Y., Koh, E.-K., Kwon, O.-Y., 2011. Effect of foot orthoses and short-foot exercise on the cross-sectional area of the abductor hallucis muscle in subjects with pes planus: a randomized controlled trial. J. Back Musculoskelet. Rehabil. 24 (4), 225–231.

Kent-Braun, J.A., Ng, A.V., Young, K., 2000. Skeletal muscle contractile and noncontractile components in young and older women and men. J. Appl. Physiol. 88 (2), 662–668.

Kobayashi, R., et al., 1999. Effects of toe grasp training for the aged on spontaneous postural sway. J. Phys. Ther. Sci. 11 (1), 31–34.

Kokkonen, J., et al., 1988. Improved performance though digit strength gains. Res. Q. Exerc. Sport 59 (1), 57–63.

Menz, H.B., et al., 2006. Plantarflexion strength of the toes: age and gender differences and evaluation of a clinical screening test. Foot Ankle Int. 27 (12), 1103–1108.

Mickle, K.J., et al., 2006. A novel and reliable method to measure toe flexor strength. Proceedings of the 10th Emed Scientific Meeting. Spitzingsee, Germany.

Mickle, K.J., et al., 2009. ISB clinical biomechanics award 2009: toe weakness and deformity increase the risk of falls in older people. Clin. Biomech. 24, 787–791.

Rooks, D.S., et al., 1997. Self-paced resistance training and walking exercise in community-dwelling older adults: effects on neuromotor performance. J. Gerontol. 52A (3), M161–M168.

Sherrington, C., Lord, S.R., 2005. Reliability of simple portable tests of physical performance in older people after hip fracture. Clin. Rehabil. 19 (5), 496–504.

Spink, M.J., et al., 2011. Effectiveness of a multifaceted podiatry intervention to prevent falls in community dwelling older people with disabling foot pain: randomised controlled trial. BMJ 342, d3411.

Unger, C.L., Wooden, M.J., 2000. Effect of foot intrinsic muscle strength training on jump performance. J. Strength Cond. Res. 14 (4), 373–378.