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PREVENTION & REHABILITATION: RANDOMIZED CONTROLLED TRIAL

Pilates Reformer exercises for fall risk reduction in older adults: A randomized controlled trial

Margaret Roller [a, *], Aimie Kachingwe [a], Janna Beling [a], Dawn-Marie Ickes [b], Allyson Cabot [c], Gabrielle Shrier [c]

[a] Department of Physical Therapy, California State University, Northridge, Northridge, CA, United States
[b] Department of Physical Therapy, Mount Saint Mary's University, Los Angeles, CA, United States
[c] Core Conditioning, Studio City, CA, United States

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ABSTRACT

Objective: To investigate the effects of Pilates exercises using a Reformer on measures of fall risk, balance and mobility, self-efficacy, and active range of motion in adults age 65 and over at risk for falls compared to a control group.
Design: Randomized Controlled Trial.
Methods: Fifty-five subjects (27 Pilates intervention, 28 control; 38 females, 17 males; mean age 77.6 years, range 65–95) were randomly assigned to either a Pilates Reformer intervention group or a control group (no intervention). Subjects in the intervention group attended a Pilates Reformer exercise program in a group format once a week over a 10-week period. The primary outcome measures were the Sensory Organization Test (SOT) composite scores on the NeuroCom® system, Timed Up-and-Go (TUG), and Activities-specific Balance Confidence (ABC) scale. The secondary outcome measures were the Adaptation Test (ADT), straight leg raise (SLR), hip extension, and ankle dorsiflexion active range of motion (AROM), Berg Balance Scale (BBS), and 10 Meter Walk Test (10MWT).
Results: There was a significant interaction between group and time on the TUG, BBS, 10MWT, and SLR, hip extension, and ankle dorsiflexion AROM measurements. Over time, subjects in the Pilates intervention group improved their scores significantly on all mentioned measures, whereas subjects in the control group did not ($P \le 0.05$). Significantly improved AROM was found between groups following the Pilates intervention for hip extension, left SLR, and right ankle dorsiflexion.
Conclusion: Pilates Reformer exercises performed once per week for 10 weeks resulted in reduced fall risk and significant improvements in static and dynamic balance, functional mobility, balance self-efficacy, and lower extremity AROM in adults age 65 and older at risk for falling, whereas the control group did not significantly improve in any measures. Pilates Reformer exercises are more effective compared to no exercise intervention at improving hip and ankle AROM.

1. Introduction

Falls are among the most common and serious problems facing aging adults. Shumway-Cook and Woollacott (2007) define a fall as “an unplanned, unexpected contact with a supporting surface such as the floor, a chair, or a wall.” An estimated one third of adults 65 years and older fall annually, resulting in injuries, significant healthcare costs, and restricted activity (Carroll et al., 2005; Gillespie et al., 2010; Hausdorff et al., 2001; Hornbrook et al., 1994; National Center for Injury Prevention and Control, 2008; Peel et al., 2002; Shumway-Cook et al., 2009; Soriano et al., 2007; Stevens et al., 2006; Tinetti et al., 1994b). In addition, post-fall anxiety and fear of falling can have a powerful psychological effect that can further increase fall risk and have a devastating impact on quality of life (Tinetti et al., 1994a). Thus, it is important to screen and identify individuals at risk for falling through utilization of activity/function-based instruments and impairment-based measurement tools (Muir et al., 2010b).

The etiology of falls in the elderly is multifaceted, involving both extrinsic factors such as poor lighting and improper footwear, and

* Corresponding author. California State University, Northridge, Department of Physical Therapy, 18111 Nordhoff Street, Northridge, CA 91330-8411, United States.
E-mail address: peggy.roller@csun.edu (M. Roller).

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intrinsic factors such as use of medication, cognitive decline, and visual impairment (Almeida et al., 2012; Bourque et al., 2007; Braun, 1998; Close et al., 2005; da Silva et al., 2010; Horak, 2006; Jennifer et al., 1993; Muir et al., 2010a; Pijnappels et al., 2008; Sinaki et al., 2005; Sirola et al., 2004). In addition, musculoskeletal impairments, including decreased hip and ankle AROM, can increase fall risk (Chiacchiero et al., 2010; Nelson and Amin, 1990; Tinetti et al., 1988). Chiacchiero et al. (2010) found a statistically significant ROM decrease in hip extension, internal rotation, abduction, and ankle dorsiflexion in a group of elderly fallers compared to non-fallers. Finally, a diminution in fall self-efficacy, or one's belief or fear regarding his/her risk of falls when attempting a task, has been found to be linked to increased fall risk (Hadjistavropoulos et al., 2011; Hadjistavropoulos et al., 2012).

The use of exercise to reduce fall risk in community-dwelling older individuals has been studied widely. Tai Chi (Arnold et al., 2008; Li et al., 2005; Sattin et al., 2005; Wolf et al., 2003; Wu et al., 2010), customized balance training programs (Beling and Roller, 2009; Davison et al., 2005; Gitlin et al., 2006; Nitz and Choy, 2004; Shumway-Cook et al., 1997a, 1997b; Wolf et al., 2001; Yates and Dunnagan, 2001), progressive resistance strengthening programs (Hess and Woollacott, 2005; Sousa and Sampaio, 2005), fall education programs (Brouwer et al., 2003; Hakim et al., 2007; Huang and Acton, 2004), and multitask training and walking activities (Trombetti et al., 2011; Yamada et al., 2010) have been found to be highly effective interventions for reducing fall risk and improving balance self-efficacy.

Another form of exercise that may improve impairments related to fall risk is Pilates-based exercise. Pilates is a mind-body exercise regimen named after its founder Joseph Pilates (Friedman and Eisen, 2005; Latey, 2001; Latey, 2002), and can be performed on a mat or on specialized apparatuses including the Reformer, Trapeze Table/Cadillac, Ladder Barrel, and Step/Wunda Chair (Anderson and Spector, 2000; Latey, 2002). The Reformer consists of a sliding platform inside a wooden or metal frame connected to a system of springs, pulleys and ropes. It allows users to vary the resistance when working the extremities while concurrently focusing on postural alignment and lumbopelvic stability (Shedden and Kravitz, 2006; Wilson, 2007). The Reformer is an ideal apparatus for the elderly population as it provides a low-impact form of exercise that assists the joints, and the resistance can be modified by changing the springs and pulleys, changing the direction of the body with respect to gravity, and/or modifying the base of support (transitioning from lying to sitting to kneeling to standing). In addition, Reformer exercises focus on maintaining a neutral posture and correct body alignment, all of which challenge and reeducate balance and functional movements (Anderson, 2001; Kaesler et al., 2007; Mallery et al., 2003; Wilson, 2007).

Clinical studies document that Pilates-based exercise is effective in improving flexibility (Cruz-Ferreira et al., 2011; Kao et al., 2015; Segal et al., 2004), transversus abdominis contraction (Herrington and Davies, 2005), balance (Cruz-Ferreira et al., 2011; Johnson et al., 2007), trunk extensor strength (Kolynaik et al., 2004), lower extremity muscular co-contraction and strength (Bernardo, 2007; Cruz-Ferreira et al., 2011; Kao et al., 2015; Petrofsky et al., 2005), and is an effective intervention for the treatment of low back pain in the general adult population (da Fonseca et al., 2009; da Luz et al., 2014; Donzelli et al., 2006; Gladwell et al., 2006; La Touche et al., 2008; Lim et al., 2011; Pajek and Pajek, 2009; Posadzki et al., 2011; Rajpal et al., 2008; Rydeard et al., 2006; Vad et al., 2007; Wells et al., 2012; Wells et al., 2014). In the elderly, Pilates-based mat exercises have been found to have positive effects on bone formation in women with osteopenia (Betz, 2005; Kim et al., 2014; Sinaki and Mikkelsen, 1984), improve static and dynamic balance (Barker et al., 2015; de Siqueira Rodrigues et al., 2010; Gildenhuys et al., 2013; Hyun et al., 2014; Kovach et al., 2013; Mokhtari et al., 2013), improve functioning (de Siqueira Rodrigues et al., 2010), and improve social and emotional well-being (Mokhtari et al., 2013; Roh, 2016).

To date, there are few published studies evaluating whether Pilates-based exercises that include the Reformer can improve static and dynamic balance in older adults. In a pilot study of 7 older adults (aged 66–71), Kaesler et al. (2007) evaluated the effects of four Pilates-based exercises (Reformer leg press, Trapeze table trunk lateral flexion and hip adduction, Wunda chair single leg press) and four non-Pilates exercises performed two times per week over 8 weeks and found statistically significant improvements in static stability and dynamic balance. A randomized control study of the effect of non-specified "Pilates exercises" on elderly nursing home dwelling women over age 72 by Irez et al. (2011) reported a statistically significant reduction in the number of falls and improvements in static balance, hip strength, and flexibility compared to a control group. A randomized control study by de Siqueira Rodrigues et al. (2010) of 52 community dwelling women, average age 66, engaged in supervised Pilates exercises on 4 apparatuses (Trapeze, wall-unit, Reformer, combo chair) found statistically significant improvements in static balance and measures of personal autonomy and quality of life compared to a control group. A randomized crossover design Pilates intervention study by Bird et al. (2012) including standing exercises, mat exercises, and 3 Reformer exercises: Footwork, Scooter and Standing Series, found no significant difference in static or dynamic balance between the Pilates and control groups. The authors did report that balance on foam, TUG, and Four Square Step Test scores significantly improved in the Pilates group without significant changes in the control group. Also, none of the parameters that improved in the Pilates group returned to baseline after a washout period, suggesting Pilates exercise may produce a resilient neuromuscular adaption that remained after 6 weeks. Thus, the lack of between-condition differences may be attributed, in part, to the cross-over study design (Bird et al., 2012). To date, no studies have been published on the effects of performing Pilates exercises utilizing only the Reformer with older adults at risk for falling.

The purpose of this study was to investigate whether Pilates Reformer exercises would improve balance, reduce fall risk, improve functional mobility, and improve balance confidence in adults age 65 and older at risk for falls. It was hypothesized that participating in Pilates Reformer exercises would lead to improvements in fall risk, balance and postural control, gait velocity, functional mobility, balance confidence, and lower extremity active range of motion.

2. Methods

2.1. Participants

Subjects were recruited via advertisements in newspapers and at senior centers, and by word of mouth, and were screened via a telephone interview to determine if inclusion and exclusion criteria were met. Inclusion criteria included aged 65 years or older, self-reported history of two or more falls or one injurious fall in the past year, TUG test score of $\geq$13.5 s suggesting risk for falling (Shumway-Cook et al., 1997a), and physician approval to participate in the study. Exclusion criteria included a failed NeuroCom® Motor Control Test (MCT) (Natus Medical, Inc., San Carlos, CA), a failed Mini-Mental State Examination (MMSE) (score <24/30), history of fracture within the previous year, neurological impairment with severe motor deficit, history of severe orthopedic impairment of the lower extremities, and requiring an assistive device for static or dynamic balance. The MMSE has been found to have construct validity, concurrent validity, and good interrater reliability (Folstein et al., 1975). The MCT is used to determine the integrity of long-loop postural reflexes (Shepard and Janky, 2010), however no reliability/validity studies on the MCT have yet been published.

Fifty-five subjects (17 males, 38 females) with a mean age of 77.6 years participated in the study. Subjects were randomly assigned via a random number generator to either the intervention group (Pilates Reformer exercise) (N = 27) or the control group (no intervention) (N = 28). The randomization and distribution of subjects into each group was carried out by one of the investigators who was also involved with measuring AROM and administering the TUG test. The second investigator, who was blinded to group assignment, performed all other pre- and post-test measures. Control group subjects were instructed to continue their usual activities, not to start a new exercise program or perform Pilates exercises, and were scheduled to return for post-testing in 11 weeks. Subjects could identify their group allocation and therefore were not blinded to the intervention.

2.2. Outcome measures

Subjects who met the above-mentioned criteria were invited to participate in the study, and all baseline testing was performed in a balance and vestibular laboratory at a large university campus within one month of the telephone screening. Subjects completed a screening questionnaire, developed for the purpose of this study, to determine the nature, frequency, and number of falls in the past year and to assess the nature of their balance problem.

Primary outcome measures were the SOT (Cohen et al., 1996; Ford-Smith et al., 1995; Whitney et al., 2006; Wrisley et al., 2007), TUG (Podsiadlo and Richardson, 1991; Shumway-Cook et al., 2000; Steffen et al., 2002; Whitney et al., 2004), and ABC scale (Lajoie and Gallagher, 2004; Powell and Myers, 1995). These outcome measures were selected based on inclusion of all primary measurement categories (body structure/function, activity limitation, and participation restriction) of the International Classification of Functioning, Disability and Health (ICF) (World Health Organization, 2013). The secondary outcome measures were the ADT (Camicioli et al., 1997), AROM (Clapper and Wolf, 1988; Norkin and White, 2009), BBS (Berg et al., 1992b), and 10MWT (Bohannon, 1997; Perera et al., 2006).

The SOT and ADT were used to assess balance and postural control on the NeuroCom® Smart Equitest® utilizing standard operating procedures. (see Fig. 1). The SOT has previously been shown to have predictive validity for falls (Whitney et al., 2006), reliability (Cohen et al., 1996; Ford-Smith et al., 1995), and a minimally detectable clinical difference has been established (Wrisley et al., 2007). The ADT has been used to assess the ability to adapt to repeated platform rotations, however no reliability or validity studies have yet been published. The TUG test has been found to be a reliable measure of functional balance status in community-dwelling older adults (Hughes et al., 1998; Lin et al., 2004; Lusardi et al., 2003; Steffen et al., 2002), has good sensitivity and specificity of 87%, and has a fall-risk cut-off level of 13.5 s (Lin et al., 2004; Perell et al., 2001; Podsiadlo and Richardson, 1991; Steffen et al., 2002; Shumway-Cook et al., 2000; Whitney et al., 2004). The ABC scale, a 16-item Likert scale asking a person to rate his/her confidence in balance during the performance of various activities of daily living, has been found to have high sensitivity/specificity and reliability (Lajoie and Gallagher, 2004; Powell and Myers, 1995; Talley et al., 2008; Wrisley and Kumar 2010). Scores less than 67% on the ABC scale indicate risk for falls in the elderly (Lajoie and Gallagher, 2004). Lower extremity AROM was measured using a goniometer which has been found to be reliable (Clapper and Wolf, 1988). Ankle dorsiflexion was measured in a seated position with knees flexed over an elevated clinic table. (see Fig. 2). Hip extension was measured prone on a treatment table keeping the knee straight and pelvis neutral on the table. SLR (hamstring muscle length) was measured by actively lifting one leg straight up to the perceived level of subjects' comfort from a supine position while keeping the pelvis neutral and contralateral leg on the table. The 14-item BBS assesses functional balance, and has been shown to have concurrent, discriminant, and predictive validity and high interrater and intrarater reliability in older adults (Berg et al., 1992a, 1992b; Berg et al., 1995; Perell et al., 2001) and a minimally detectable clinical difference of 6.5 points has been established in older adults at risk for falling (Romero et al., 2011). Gait velocity measured using a timed 10MWT, where subjects walk an unobstructed 14-m pathway, has been shown to be reliable and responsive (Bohannon, 1997; Perera et al., 2006).

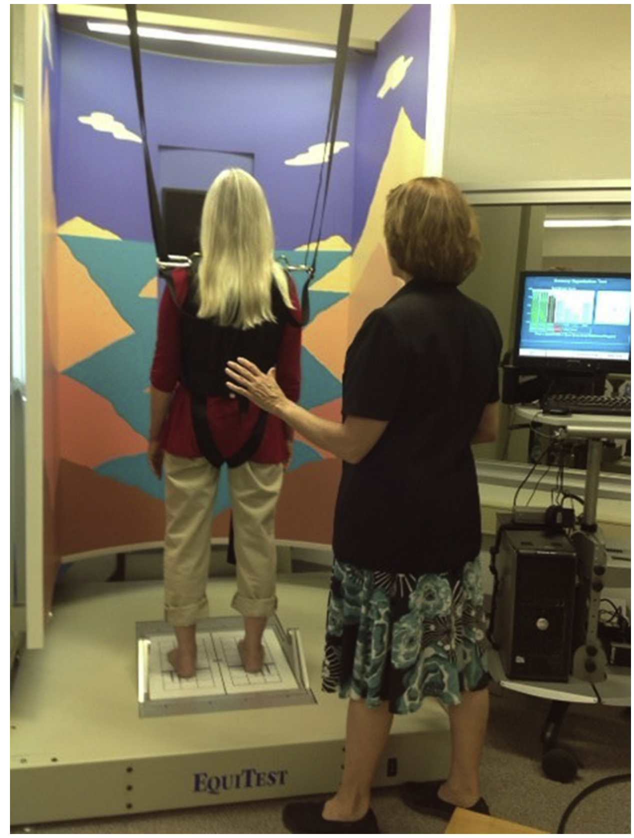

Fig. 1. Testing balance and postural control on the NeuroCom® Smart Equitest®.

Fig. 2. Measuring ankle dorsiflexion active range of motion with a goniometer.

Subjects were given adequate rest time between test trials to avoid fatigue and allow for optimal performance of the testing procedures. The above measures were repeated at the post-test session within one week following the 10-week intervention period. Subjects were asked to recall the number, nature, and frequency of any falls experienced since the pre-test session, plus asked to comment on their overall experience with participating in the study.

2.3. Intervention

Participation in the Pilates intervention began within 1 week after the pre-test session. Subjects in the Pilates group attended 8–10 sessions of a 45-min Pilates exercise program using a Reformer once a week over a 10-week period at Core Conditioning in Studio City, CA. Subjects were instructed that they must attend at least 8 of the 10 sessions to remain in the study. Pilates exercises utilized the Balanced Body® Pilates Studio Reformer® under the supervision of a Gold Certified Pilates Method Alliance instructor. Participant to instructor ratio was 4–5:1 with all subjects working on Reformers concurrently in a group class format. (see Fig. 3). Each subject performed 10 specific exercises (See Appendix), 10 repetitions each, using progressive resistance of 2–4 springs according to each participant's ability as judged by the instructor.

2.4. Data analysis

All data analyses were performed using SPSS 22.0 (IBM Corporation, 2013). Simple baseline descriptive statistics were calculated on all subjects. (see Table 1), and means and standard deviations were determined. Chi-square tests for cross-tabulation tables and t-tests for independent samples were used to compare the prevalence of gender distribution and the means of age, height, scores on the MMSE, and number of falls of the intervention and control at initial assessment. Scores on the SOT composite equilibrium score, BBS, TUG, 10MWT, ABC and AROM measurements were compared with a 2 (intervention) X 2 (time) Analysis of Variance (ANOVA) with repeated measures on the last factor (baseline and post-intervention) for both the intervention and control groups. In cases where no significant interaction occurred, the main effects were interpreted. In cases where a significant interaction occurred, simple main effects for group were tested with a univariate ANOVA and simple main effects for time were tested with a repeated measures ANOVA. The Wilcoxon signed rank test was used to make comparisons within each of the two groups and the Mann-Whitney *U* test was used to analyze the difference in number between the intervention and control groups for performance on the ADT category. All statistical tests were conducted at the $P \leq 0.05$ level.

No outlying values were identified using Tukey's rule, which defines an extreme outlier as being more than 3.0 interquartile ranges away from the 25th or 75th percentile (Tukey, 1977). Data were normally distributed as assessed by the Shapiro-Wilk test, ($P > 0.05$). The assumption of homogeneity of variance was not violated as assessed by Levine's Test of Homogeneity of Variance ($P > 0.05$).

Fig. 3. Participants performing Pilates Reformer exercises.

Table 1
Baseline characteristics of subjects according to group: Intervention and control.

Baseline Characteristic	Intervention n = 27	Control n = 28	Total Subjects n = 55
Age (years)	78.52 ± (7.57)	76.68 ± (6.79)	77.58 ± (7.18)
Female Gender N (%)	19 (70.4%)	19 (67.9%)	38 (69%)
Height (inches)	64.30 ± (4.19)	65.32 ± (3.63)	64.82 ± (3.92)
MMSE (score/30)	29.04 ± (1.53)	29.29 ± (1.21)	29.16 ± (1.37)
Number of falls reported in past year	2.00 ± (2.30)	3.21 ± (5.57)	2.62 ± (4.30)

NOTE. Values are mean ± standard deviation or n (%). No significant differences were noted between groups at baseline, $P > 0.05$.
Abbreviations: MMSE, Mini-Mental State Examination.

3. Results

3.1. Descriptive statistics

The number of participants in this study was a sample of convenience, and based on the results of the TUG and the sample size, the power was calculated at 0.56. Seventy-five subjects who responded by the study's deadline and met the telephone screening criteria were enrolled in the study. In total, twenty subjects were excluded from the study. Sixteen subjects were excluded at the pre-test session due to not meeting inclusion criteria (10 subjects had a TUG < 13.5 s and/or no falls, 5 subjects had neurological/orthopaedic medical conditions preventing study participation, 1 subject failed the MCT). After group allocation but before starting the Pilates intervention, three subjects in the intervention group voluntarily withdrew due to illness or personal reasons, and one participant in the Pilates intervention group voluntarily withdrew during the post-test session (see Fig. 4). Fifty-five subjects, mean age 77.6 years, range 65–95 years of age, 69% (38/55) women, completed the study. Intervention and control groups did not differ at baseline for age, gender, height, cognitive status, or number of falls in the year prior to baseline data collection, $P > 0.05$. (see Table 1).

All participants in the Pilates group finished the intervention. One subject missed 2 appointments and 2 subjects missed 1 appointment due to personal reasons. The investigators did not examine differences in outcomes between the individuals who only attended 8 or 9 sessions versus all 10.

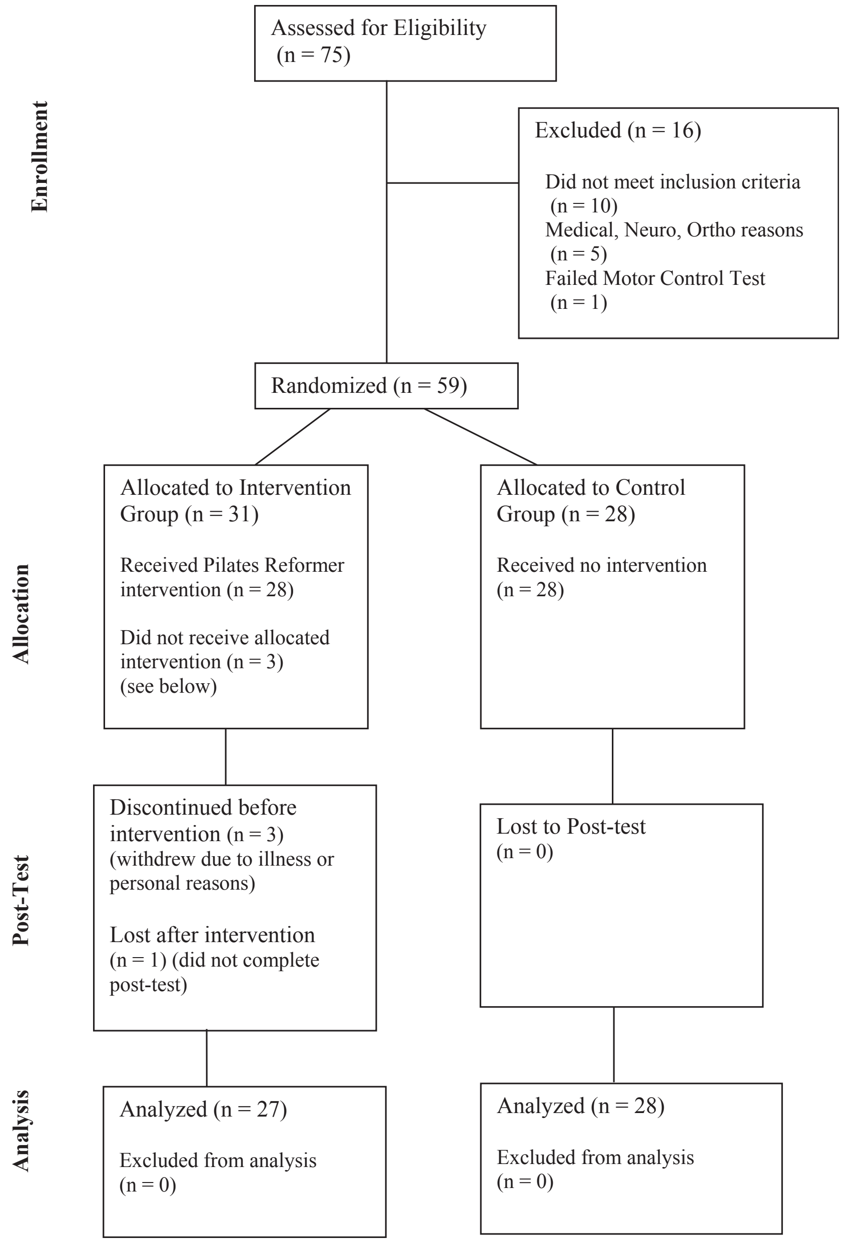

Fig. 4. CONSORT diagram showing the flow of participants through each stage of the randomized trial.

3.2. Balance

3.2.1. Sensory Organization Test and Adaptation Test

No significant interaction occurred between group and time on SOT composite scores, $F(1,52) = 45.370$, $P > 0.05$, partial eta squared = 0.026. The two groups did not respond differently across the pre-test and post-test repeated measures. There were two significant main effects. There was a significant difference in SOT scores between groups $F(1,52) = 4.683$, $P \leq 0.05$, partial eta squared = 0.083 such that the mean SOT composite score was significantly lower in the intervention group by 6.74 points. The main effect of time showed that there was a significant difference in SOT composite scores at the different time points, $F(1,52) = 37.420$, $P \leq 0.05$, partial eta squared = 0.418 such that SOT composite scores improved over time from 59.57 to 66.31 points, $P \leq 0.05$. A Wilcoxon signed ranks test revealed that subjects in neither group improved significantly over time on the ADT in the toes up condition, toes down condition, or the number of subjects who scored in the normal range on the SOT composite. (see Table 2). A Mann-Whitney test revealed no significant between group differences in subjects who scored within the normal and abnormal ranges of the SOT composite or in performance on the ADT at either of the two time periods. (see Table 2).

3.2.2. The Timed Up-and-Go test, Berg Balance Scale, and ten meter walk test

There was a statistically significant interaction between the intervention and time on TUG scores, $F(1,53) = 8.06$, $P \leq 0.05$, partial eta squared = 0.132. Subjects in the Pilates group significantly decreased their TUG scores over time $F(1,26) = 22.22$, $P < 0.05$, partial eta squared = 0.461, from 12.84 to 10.98 s, whereas there was no significant change in TUG scores within the control group over time, $P > 0.05$. There were no significant between group differences on TUG scores at either of the two time points (pre-

Table 2
Sensory organization, adaption, balance, fall risk, gait speed, and balance self-efficacy mean and standard deviation measurements.

Outcome Measure	Intervention Group (n = 27)		Control Group (n = 28)	
	Pretest	Posttest	Pretest	Posttest
SOT Composite Score (n/100)	55.7 ± (11.77)	63.74 ± (11.77)	63.44 ± (12.20)	68.89 ± (10.89)
SOT Composite Score N in Normal Range (%)	16 (59.3%)	19 (70.4%)	16 (57.1%)	14 (50%)
ADT ability to adapt Toes Up	15 (55.6%)	19 (70.4%)	14 (50%)	18 (64.3%)
ADT ability to adapt Toes Down	15 (55.6%)	18 (66.7%)	17 (60.7%)	17 (60.7%)
BBS (score/56)[a]	50.63 ± (5.48)	53.22 ± (2.59)[b]	52.11 ± (3.59)	52.70 ± (3.11)
TUG (seconds)[a]	12.84 ± (4.56)	10.98 ± (4.67)[b]	11.99 ± (2.49)	11.54 ± (2.62)
10MWT (seconds)[a]	9.54 ± (3.93)	8.49 ± (3.78)[b]	8.51 ± (1.80)	8.28 ± (1.81)
10MWT (m/sec)	1.05 m/sec	1.18 m/sec	1.18 m/sec	1.21 m/sec
ABC (score/100%)	68.28 ± (16.67)	74.19 ± (18.58)	66.17 ± (20.84)	72.13 ± (17.58)

NOTE. Values are mean ± standard deviation or n (%). Normal SOT Composite Score Range = Green color and Abnormal SOT Composite Score Range = Red color (as compared to older adult normative values by height and age up to 79 years old - NeuroCom® International, Inc., Santa Clara, CA). ADT Able to Adapt = ≤ 2 out of 5 trials are abnormal; Maladaptive = ≥3 out of 5 trials are abnormal; Unable to Adapt = any fall during the five trials.
[a] Significant interaction between group and time, P ≤ .05.
[b] Significant improvement compared to baseline (within group change), P ≤ .05.; Abbreviations: SOT, Sensory Organization Test; ADT, Adaptation Test; BBS, Berg Balance Scale; TUG; Timed Up-and-Go test; 10MTW, 10 Meter Walk Test; ABC, Activities-specific Balance Confidence scale.

intervention or post-intervention), P > 0.05. (see Table 2).

There was a statistically significant interaction between the intervention and time on the BBS, F(1,52) = 6.281, P ≤ 0.05, partial eta squared = 0.108. Subjects in the Pilates group significantly improved their scores over time from 50.63 to 53.22/56, P ≤ 0.05, and subjects in the control group did not (52.11–52.70/56), P > 0.05. There were no significant between group differences on BBS measurements pre- or post-intervention, P > 0.05. (see Table 2).

There was a statistically significant interaction between the intervention and time on the 10MWT scores F(1,53) = 6.802, P ≤ 0.05, partial eta squared = 0.114. Subjects in the Pilates group significantly improved over time from 9.54 to 8.49 s (P ≤ 0.05) and the control group did not (8.51–8.28 s), P ≤ 0.05. There were no significant between group differences on 10MWT scores at either time measurement (pre-intervention or post-intervention), P > 0.05. (see Table 2).

3.2.3. Activities-specific Balance Confidence Scale

There was no statistically significant interaction between the intervention and time on the ABC scale scores F(1,53) = 0.000, P > 0.05, partial eta squared = 0.000. There was one significant main effect for the repeated measure of time F(1,53) = 8.726, P ≤ 0.05, partial eta squared = 0.141. Scores on the ABC improved over time from 67.20% ± (18.76) to 73.14% ± (17.94), P ≤ 0.05. (see Table 2).

3.3. Active range of motion

There was a statistically significant interaction between group and time on the SLR AROM for both the right and left legs, F(1,53) = 332.577, partial eta squared = 0.104 and F(1,53) = 347.022, partial eta squared = 0.111, respectively, P ≤ 0.05. The Pilates group had significantly greater left SLR AROM (76.37°) compared to the control group (68.61°), F(1,54) = 4.297, P ≤ 0.05, partial eta squared = 0.075, but not in the right leg, P > 0.05. A repeated measures ANOVA revealed that the Pilates group had a statistically significant AROM increase in the right SLR of 7.78° and the left SLR of 6.96° from pre-to post-test, F(1,26) = 11.801, P ≤ 0.05, partial eta squared = 0.312 and F(1,26) = 15.506, P ≤ 0.05, partial eta squared = 0.374, whereas the control group only improved 0.82° on the right and 0.14° on the left, P > 0.05, which was not a significant improvement. (see Table 3).

There was a statistically significant interaction between group and time on hip extension AROM for both the right and left legs, F=(1,53) = 5.498, partial eta squared = 0.094, P ≤ 0.05, respectively. The Pilates group had significantly greater hip extension AROM in both the right (10.85°) and left legs (10.63°) compared to the control group (7.14 and 6.93°), F(1,54) = 15.074, partial eta squared = 0.221 and F(1,54) = 16.143, partial eta squared = 0.233, P ≤ 0.05, respectively. A simple main effect for time revealed that subjects in the Pilates group significantly increased hip extension AROM in the right by 3.29° and in the left by 3.22° F(1,26) = 11.801, partial eta squared = 0.312 and F(1,26) = 19.664, partial eta squared = 0.431, P ≤ 0.05, respectively, whereas the control group only increased 0.71° on the right and 0.64 on the left, P > 0.05 which was not a significant improvement. (see Table 3).

There was a statistically significant interaction between group and time on ankle dorsiflexion AROM for both the right and left legs, F=(1,53) = 15.749, P ≤ 0.05, partial eta squared = 0.229. A simple main effect for group revealed that the Pilates group had significantly greater right ankle dorsiflexion AROM (10.33°) compared to the control group (4.75°), F(1,55) = 23.626, partial eta squared = 0.308, P ≤ 0.05. However, there was no significant

Table 3
Lower extremity active range of motion mean and standard deviation measurements.

Outcome Measure	Intervention Group		Control Group	
Active Range of Motion of Lower Extremities in Degrees (SD)	Pretest	Posttest	Pretest	Posttest
Straight Leg Raise Right[a]	66.78 ± (14.02)	74.56 ± (12.45)[b]	69.11 ± (15.57)	69.93 ± (16.45)
Straight Leg Raise Left[a]	69.41 ± (12.71)	76.37 ± (11.26)[b, c]	68.75 ± (16.83)	68.61 ± (16.01)
Hip Extension Right[a]	7.56 ± (3.91)	10.85 ± (3.68)[b, c]	6.43 ± (2.77)	7.14 ± (3.41)
Hip Extension Left[a]	7.41 ± (3.13)	10.63 ± (4.02)[b, c]	6.29 ± (2.42)	6.93 ± (2.71)
Ankle Dorsiflexion Right[a]	6.26 ± (4.01)	10.33 ± (3.21)[b, c]	4.57 ± (5.89)	4.75 ± (5.07)
Ankle Dorsiflexion Left[a]	3.30 ± (6.02)	7.26 ± (4.60)[b]	4.00 ± (5.48)	5.14 ± (4.71)

Abbreviations: SD, Standard Deviation.
[a] Significant interaction between group and time, P ≤ .05.
[b] Significantly greater than baseline (within group change), P ≤ .05.
[c] Intervention group significantly greater than control group in post-test (between group change), P ≤ .05.

difference in left ankle dorsiflexion AROM between the two groups $P \leq 0.05$. A simple main effect for time revealed that subjects in the Pilates group significantly increased ankle dorsiflexion AROM in the right by 4.07° and in the left by 3.96°, $F(1,26) = 36.203$, partial eta squared = 0.582 and $F(1,26) = 27.773$, partial eta squared = 0.516, respectively, $P \leq 0.05$, whereas the control group only increased 0.18° on the right and 1.14° on the left. (see Table 3).

4. Discussion

4.1. Lower extremity active range of motion

Subjects who participated in Pilates Reformer exercises had significantly improved hip and ankle AROM from the pre-to post-test, whereas the control group did not. Post-intervention, hip extension AROM improved approximately 3° bilaterally in the Pilates group, but remained the same in the control group. Boone et al. (1978) reported that a 3–4° improvement in goniometric measurement of an upper or lower extremity joint demonstrates improvement when conducted by the same tester. The degree of clinical error during goniometric AROM testing has been reported to be approximately 5° (Gajdosik and Bohannon, 1987). Therefore, these improvements in AROM can be interpreted as change due to the Pilates intervention and not experimenter error or test variability. Also important to note is that the intervention group post-test active hip extension values approached the normal active hip extension range of 10°, while the control subjects averaged 7 degrees of hip extension at both pre-and post-testing. It is probable that several of the Reformer exercises could have contributed to this increase in active hip extension ROM including Pelvic Lifts, Long Box Pulling Straps, Scooter, and Eve's Lunge.

Subjects who participated in Pilates Reformer exercises had significantly improved straight leg raise (SLR) AROM of grossly 7–8° on both lower extremities whereas the control subjects' SLR remained the same. In addition to being a measure of hamstring muscle length and stiffness, the active SLR test is a common lower quadrant neurodynamic mobility test (Boyd et al., 2009; Butler, 2000). Thus, any improvements in SLR range may also be attributed to improved mechanosensitivity of the lower extremity peripheral nerves to limb movement (Nee and Butler, 2006). It is probable that the Pilates Reformer exercises including the Reverse Scooter, Hundreds, and Footwork could have contributed to this increase in active SLR.

Subjects who participated in Pilates Reformer exercises also demonstrated improved bilateral ankle dorsiflexion AROM by grossly 4°. This proved to be significantly greater than control subjects on the right, close to significance on the left, and closer to the functional range of 10° (10.33° right and 7.26° left) (Root et al., 1977), whereas control subjects averaged approximately 5 degrees of dorsiflexion in both ankles at post-test. The biomechanical improvement in ankle DF AROM found in the Pilates group could be functionally significant as rising from a chair, going up and down stairs, and normal gait mechanics requires a minimum of 10 degrees of ankle DF ROM (Root et al., 1977). It is probable that Pilates Reformer Footwork, Pelvic Lift, Scooter, and Eve's Lunge exercises contributed to the increase in ankle dorsiflexion AROM. Since all Reformer exercises are performed bilaterally and symmetrically, there is no side dominance that would explain right-left AROM differences, except perhaps if the exercises are always started with the right lower extremity.

4.2. Balance, mobility, and fall risk

Pilates Reformer training had a positive effect on improving static and dynamic balance (SOT, ADT, BBS) and functional mobility (TUG, 10MWT). Changes of greater than 8 points on the SOT composite equilibrium scores indicate change due to rehabilitation and not simply a learning effect or performance adaptation as seen in a young adult population (Wrisley et al., 2007), however no studies were found evaluating this effect on older adults. Since the Pilates group's overall improvement on the SOT was 8 points, this may suggest the change was due to the Pilates Reformer intervention (Wrisley et al., 2007). Subjects in both groups demonstrated improved ability to adapt to both the toes up and toes down force plate perturbations on the ADT, which could be due to a learning effect and simply getting used to the test itself. Practicing the SOT and ADT at least one time prior to baseline testing could have diminished the learning effect seen in these subjects.

The Pilates Reformer exercises did not include any exercises standing on the moving carriage. Many of the Reformer exercises moderately challenged balance such as standing on one leg to perform the Scooter and Reverse Scooter exercises. Many of the moving carriage exercises, including the Hundreds Prep Arm Circles, Long Box Pulling Straps, and Long Box Seated Arms challenged balance as participants did not hold on to a fixed bar but held on to suspended cables while exercising (Barker et al., 2015). Future studies may consider incorporating standing exercises on the moving Reformer carriage using an overhead harness for safety, which may have a greater impact on SOT and ADT performance since both tests require the subject to react to a moving surface.

Scores on the BBS improved significantly (2.5 points) in the Pilates group while the control group showed no appreciable improvement (0.6 points), and a minimally detectable clinical difference of 6.5 points has been established in older adults at risk for falling (Romero et al., 2011). Typically, BBS scores less than 45/56 indicate a risk for falling in older adults, and combining BBS scores of ≤51/56 and a prior history of falls increases the sensitivity of fall risk prediction on this test (Shumway-Cook et al., 1997a). Although this study included participants who were at risk of falling or had a history of falls, the pre-test mean BBS scores in both the Pilates and control groups were above 50/56, well above the commonly accepted 45/56 cut-off for community-dwelling older adults at risk for falling (Berg et al., 1992b), yet near the ≤51/56 cut-off for older fallers (Shumway-Cook et al., 1997a). The Pilates group improved significantly over time, suggesting that even people who are higher functioning can improve static and dynamic balance ability and decrease fall risk on the BBS with Pilates Reformer training.

Subjects who participated in Pilates Reformer exercises had significantly greater improvements in the amount of time to perform the TUG and the 10MWT compared to control subjects, indicating faster speed of walking, turning, and transferring from a chair. The mean time for older adult non-fallers (age 60–87) to perform the TUG is 8.4 s ± 1.63 s (Hofheinz and Schusterschitz, 2010), with scores > 13.5 s indicating fall risk (Hofheinz and Schusterschitz, 2010; Shumway-Cook et al., 2000). The 2 s mean improvement in the Pilates group on the TUG indicates a decrease in fall risk, with resulting scores closer to the norm for non-fallers. Future studies should consider recording split time TUG measurements to determine the actual improvement in gait speed versus chair stand/sit transfer speed (Brown et al., 1995). Reformer exercises that could contribute to improved leg strength and therefore faster chair stand times in the TUG include Footwork, Pelvic Lift, Scooter, Reverse Scooter, and Eve's Lunge, as these activities require concentric and eccentric muscle activity of the hip and knee extensors and ankle plantarflexors.

Subjects in the Pilates group improved gait speed by 0.13 m/second on the 10MWT, while the control group only improved 0.03 m/sec. According to Perera et al. (2006), an improvement in gait velocity of 0.10 m/sec in the 10MWT is considered a substantial meaningful change, and an improvement of 0.05 m/sec is considered a small meaningful change. The Pilates group had a greater than substantial improvement in gait speed and the control group had no significant functional improvement in gait speed. Normal gait velocity for older adults 60–80 years of age is 1.20 m/sec for women and 1.28 m/sec for men (Waters et al., 1988). The Pilates group was ambulating at a mean of 1.05 m/sec at the pre-test, suggesting that the intervention may have contributed to near-normal gait speed at the post-test (1.18 m/sec). It should be noted that the control group was ambulating near normal speed at the pre-test (1.18 m/sec) and at the post-test (1.21 m/sec), which may explain why their gait speed did not significantly improve. Since usual gait speed decreases up to 16% per decade starting at age 60 (Abellan van Kan et al., 2009; Bassey et al., 1982; Bendall et al., 1989), maintaining and increasing walking speed as one ages is clinically important since this activity predicts a person's functional status (Beijersbergen et al., 2013).

Walking velocity and step/stride length are related (Beijersbergen et al., 2013). The increases in active hip extension, SLR/hamstring length and ankle ROM seen in the Pilates group may have contributed to the improvements in TUG and 10MWT times by increasing step and stride length, resulting in meaningful improvements in functionality in the elderly (Fritz and Lusardi, 2009). Pilates Reformer exercises may also improve walking velocity due to increases in strength. A recent study by Uematsu et al. (2014) discusses the biomechanical plasticity of aging gait, noting that hip extensor and ankle plantarflexor strength improvements relate to gait speed in older adults. Brown et al. (1995) also found that moderate resistive exercises for the lower extremities improves gait. Although lower extremity strength was not measured, it is probable that Pilates Reformer exercises also improved leg strength enough to improve gait mechanics and therefore functional speed on the 10MWT and TUG (Irez et al., 2011; Kolynaik et al., 2004; Queiroz et al., 2010; Uematsu et al., 2014).

Postural stability comes from the rapid integration of information from the vestibular, somatosensory, visual and musculoskeletal systems. These body systems activate balance strategies that rely on activation of hip and ankle musculature to counteract the direction of a perturbation or loss of balance. Since a lack of necessary ROM and/or strength would decrease the effectiveness of hip and ankle strategies and impair their ability to maintain or regain balance (Chiacchiero et al., 2010; Nolan et al., 1996; Shumway-Cook and Woollacott, 2007), the improvements noted in the Pilates group may have contributed to the improvements in balance and fall risk.

Pilates Reformer exercises may also improve gait speed due to improvements in lumbar segmental motor control. Some have theorized that Pilates exercise activates the internal and external obliques, transversus abdominis, and multifidi muscles, important for segmental control of spinal motion (Costa et al., 2009; Endleman and Critchley, 2008; Ferriera et al., 2007; Hodges and Richardson, 1999; Queiroz et al., 2010) that thus stabilizes the lumbar spine and pelvis (Costa et al., 2009; Ferriera et al., 2007; Granata and Wilson, 2001; Urquhart et al., 2005). This isolated, segmental movement of the spine coordinated with limb movement involves muscle or motor control (Costa et al., 2009; Ferriera et al., 2007). It has been theorized that the Reformer springs that are individually adjusted can provide greater proprioceptive feedback during exercise (Latey, 2002) and thus improved motor control of the spine. Many of the improvements in outcome measures observed in this study (TUG, BBS, 10MWT) could be explained in part by improved motor control of the musculature involved in lumbar segmental control.

4.3. Balance self-efficacy

Balance confidence scores on the ABC scale improved approximately 6% in both groups over time indicating some increase in self-reported balance confidence that was probably not influenced by the intervention. Mean pre-test ABC scores were 68% for the Pilates group and 66% for the control group, both near the established fall risk cut off score for older adults of 67% (Lajoie and Gallagher, 2004). ABC scores between 50 and 80% are considered to indicate a "moderate level of functioning" characteristic of older adults in retirement homes and persons with chronic health conditions (Myers et al., 1998). All participants in this study scored themselves within the moderate level of functioning by the end of the study (intervention 74%, control 72%), indicating decreased fall risk and improved balance confidence over time. It can be speculated that all participants felt reassured knowing that their balance concerns were being addressed by experts, leading both groups to have more confidence at post-test.

Limitations. There were various limitations with this study. There was no long-term follow up, and thus it cannot be determined if the positive outcomes seen in the Pilates group at the post-test were still evident 6 months or a year later. Secondly, the participants were not asked to document their falls in a daily log, but rather at the post-test were asked to recall the number of falls they had experienced since the pre-test, and thus there may have been recall error. Thirdly, the investigator who allocated the participants to their respective groups was not blinded to group assignment. Since this investigator also performed the TUG test and AROM measurements, these results may have been biased.

5. Conclusion

Pilates Reformer exercises performed once per week for 10 sessions resulted in reduced fall risk, significant improvements in static and dynamic balance, functional mobility, balance self-efficacy, and improved hip and ankle active range of motion in adults over age 65 who were at risk for falling whereas similar-aged subjects who did not receive the Pilates intervention did not improve in these measures. The cost effectiveness of performing Pilates exercises on a Reformer must be examined. Although Pilates Reformer group classes can be pricey, in this study the Pilates intervention was only performed once per week for 10 weeks primarily due to access of equipment and qualified trainers. Despite the fact that Pilates Reformer exercises were only performed once per week, significant improvements in outcome measures were documented after training. At the post-test, subjects stated they felt their improvements would have been even more substantial if the Pilates intervention was twice a week. Thus, it would be interesting to compare Pilates Reformer exercises performed once a week to twice a week in future studies.

Future studies examining the effect of Pilates Reformer exercises on balance, gait, and fall risk in older adults may also want to consider performing exercises that work specifically on balance in upright postures such as standing on a moving carriage. Although theoretically such exercises may lead to greater improvements in impairments related to increased fall risk, these exercises would have to be performed with one-on-one supervision or using an overhead harness system, adding to patient cost and decreasing study design feasibility. Long-term follow-up studies should also be performed to document lasting improvements in fall-risk measures.

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The authors affirm that they have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript or any other conflict of interest (i.e., personal associations or involvement as a director, officer, or expert witness).

The study protocol was approved by the Institutional Review Board at California State University Northridge. Informed consent was obtained for experimentation with human subjects and the privacy rights of human subjects was observed.

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The Institutional Review Board at California State University Northridge reviewed and approved the study protocol. The rights of all participants were protected, including confidentiality of data, and all participants provided informed consent. The study was supported by a Research, Scholarship and Creative Activity Award from the Office of Research and Sponsored Projects at California State University, Northridge. The funder played no role in the design of the study, interpretation of the data, or decision to publish this work.

Appendix of Pilates Reformer exercises and descriptions

(1) *Pilates Footwork: Six Stance Positions*
(2) *Pelvic Lift*
(3) *Hundreds Prep Arm Circles: Drawing Down, Circles Flexion*
(4) *Hundreds*
(5) *Long Box Pulling Straps*
(6) *Long Box Seated Arms: Chest Expansion Seated, Biceps Curls, Serving Bread*
(7) *Scooter*
(8) *Reverse Scooter*
(9) *Eve's Lunge*
(10) *Repeat Pilates Footwork*

1. Pilates Footwork

Preparation: Supine on Reformer with headrest ½ elevated, knees flexed, neutral spine position maintained throughout, feet on footbar in 6 stance positions described below.

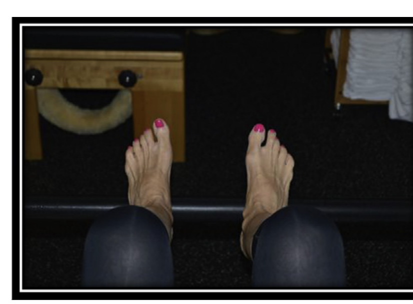
Sequence: In each stance position (a-f) below, inhale to prepare, exhale while pushing the carriage out until the knees are fully extended, maintaining a neutral spine position. Inhale as the carriage slowly moves back to the start position and the knees flex.

Repetitions: Repeat each footwork stance position (a-f) 8x, then repeat each stance position with one leg only 8x.

a. First Position: Balls of feet on footbar with legs and feet turned out in 1st position.

b. Toes Demi-Point: Balls of feet on footbar with feet in demi-point and legs parallel.

c. Arches: Arches of feet on footbar with legs parallel.



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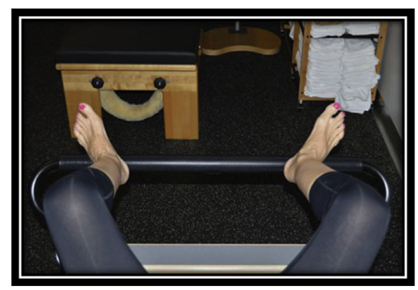
d. Heels: Heels of feet on footbar with legs parallel.

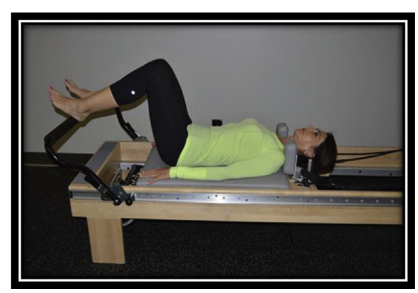
e. Tendon Stretch/Running in Place: Balls of feet on footbar with feet in plantarflexion (heels lifted). Push out on bar and extend knees while feet move into dorsiflexion and heels go under the bar. Move carriage back in as feet plantarflex and knees bend. Repeat 8x bilaterally (tendon stretch). Then perform 8x alternating (running in place).

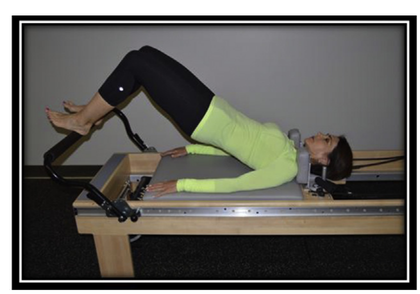
f. Second Position: Heels of feet on footbar slightly wider than shoulder width with legs and feet turned out from the hips.



2. Pelvic Lift

Preparation: Supine with proximal end of longitudinal arch of feet on footbar, headrest lowered.
Sequence: Inhale to prepare. Exhale and engage abdominals. Tilt pelvis posteriorly and lift body to level of thoracic spine. Inhale and hold. Exhale and roll down the spine segmentally from top to bottom.
Repetitions: Repeat 8x.





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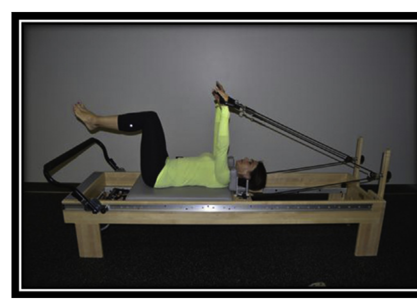
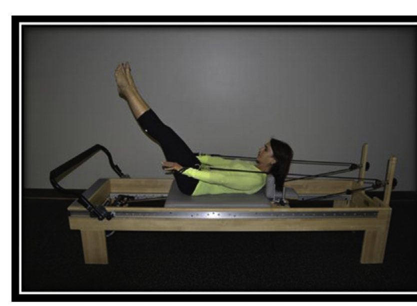
3. Hundreds Prep Arm Circles
Preparation: Supine on carriage with trunk neutral, legs in tabletop position with hips and knees flexed 90° off of carriage, hands in straps, arms at 90° shoulder flexion.

a. Drawing Down Sequence: Inhale to prepare. Exhale while drawing arms down toward the carriage, flexing the upper body off of the carriage. Inhale while returning the arms to the start position.
Repetitions: Repeat 8x.

b. Circles Flexion Sequence: Inhale to prepare. Exhale while drawing arms down towards the torso. Inhale while moving arms into abduction. Exhale while returning arms to the start position from 90 degrees of shoulder abduction to 90 degrees of shoulder flexion.
Repetitions: Repeat 4x, then reverse direction of circles 4x.

4. Hundreds
Preparation: Supine on carriage with trunk neutral, legs in tabletop position with hips and knees flexed 90° off of carriage, hands in straps, arms at 90° shoulder flexion.
Sequence: Inhale to prepare. Exhale while flexing the upper body off carriage, reaching arms towards the hips. Inhale for 5 counts as arms pump up and down. Exhale for 5 counts as arms pump up and down.
Option: Knees extended as pictured. However, the legs were maintained in tabletop in this study.
Repetitions: Continue until 100 counts are completed.





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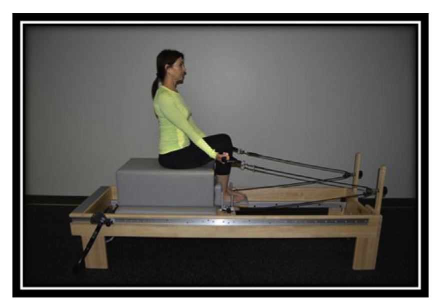
5. Long Box Pulling Straps
Preparation: Place Long Box on Reformer carriage. Lie prone on box facing pulley end of Reformer with mid-chest at edge of box. Hold ropes above straps with shoulders flexed to about 90°, forearms neutral with palms facing inward toward carriage.
Sequence: Inhale to prepare. Exhale while engaging abdominals and scapular depressors, extending arms to level of torso. Inhale while slowly returning arms against resistance to starting position.
Contraindications: Persons with spinal disc injuries should maintain neutral spine position throughout this exercise.
Persons with shoulder injuries should avoid shoulder flexion above 90°.

6. Long Box Seated Arms
Preparation: Seated on the Long Box with feet on carriage or headrest.
a. Chest Expansion Seated Preparation: Sit facing the pulley end of Reformer, hold straps with hands at sides, palms down as if reaching towards the floor.
Sequence: Inhale to prepare. Exhale while engaging abdominals and scapular depressors, extending arms past midline of body. Hold the position, then inhale while slowly returning arms against resistance to starting position.
Repetitions: Repeat 8x

b. Bicep Curls Preparation: Seated on the Long Box facing the ropes, holding straps with palms facing up.
Sequence: Inhale to prepare. Exhale while flexing elbows. Bring palms towards the shoulders while keeping elbows at the waistline and engaging abdominals and scapular depressors. Hold the position, then inhale while slowly returning arms against resistance to starting position.
Repetitions: Repeat 8x.



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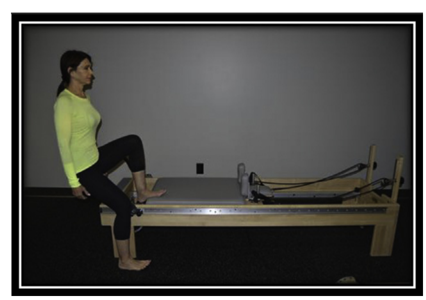
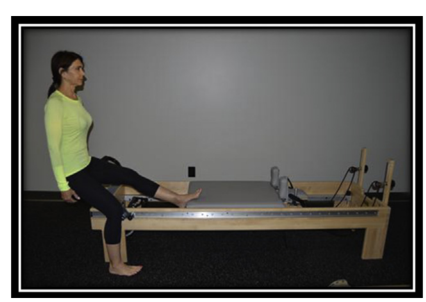
c. Serving Bread Preparation: Sit on Long Box facing the footbar with straps in hands, elbows bent 90° with arms at waist level and palms facing up. Shoulders are drawn down in to scapular depression. Alternate position: Sit with back against shoulder rests and legs crossed or extended on carriage.
Sequence: Inhale while reaching forward until the elbows are straight and the shoulders are flexed to 90°. Exhale while slowly bending the elbows, returning the arms to the start position.
Repetitions: Repeat 8x.

7. Scooter
Preparation: Stand next to the Reformer facing footbar with chest open and lifted. Place both hands on footbar shoulder width apart. Place inside knee on carriage with ball of foot against shoulder rest.
Sequence: Inhale to prepare. Exhale while pushing leg on Reformer backward, extending hip and knee. Inhale while slowly allowing leg to return to starting position by flexing hip and knee.
Repetitions: Repeat 8x.

8. Reverse Scooter
Preparation: Stand next to Reformer. Sit on the footbar with chest open and lifted. Place heel of inside leg on edge of carriage and allow toes to relax onto surface of carriage. Place outside leg on floor with the knee bent.
Sequence: Inhale to prepare. Exhale while pushing carriage forward until knee is fully extended. Inhale while slowly allowing leg to return to starting position by flexing hip and knee.
Repetitions: Repeat 8x on each leg.





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9. Eve's Lunge

Preparation: Stand next to Reformer facing footbar. Place hands on footbar, rest inside knee on carriage and foot on the shoulder rest. Keep other leg bent with knee pointed toward end of Reformer.
Sequence: Inhale while pushing carriage backward, extending knee and hip into a hip flexor stretch. Allow stance leg to flex at hip (about 30°) without increasing lumbar extension while depressing scapulae and lifting chest.
Repetitions: Repeat 3 x, holding each repetition 20 s.

10. Repeat Pilates Footwork as in #1 (a–f) above.

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