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Effects of feedback-based balance and core resistance training vs. Pilates training on balance and muscle function in older women: A randomized-controlled trial

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ABSTRACT

Background: Aging is associated with decline in physical function that could result in the development of physical impairment and disability. Hence, interventions that simultaneously challenge balance ability, trunk (core) and extremity strength of older adults could be particularly effective in preserving and enhancing these physical functions.

Objective: The purpose of this study was to compare the effects of feedback-based balance and core resistance training utilizing the a special computer-controlled device (Huber®) with the conventional Pilates training on balance ability, neuromuscular function and body composition of healthy older women.

Methods: Thirty-four older women (age: 70 ± 4 years) were randomly assigned to a Huber group ($n = 17$) or Pilates group ($n = 17$). Both groups trained for 8 weeks, 3 times a week. Maximal isometric strength of the trunk flexors, extensors, and lateral flexors, leg power, upper-body strength, single- and dual-task static balance, and body composition were measured before and after the intervention programs.

Results: Significant group × time interactions and main effects of time ($p < 0.05$) were found for body composition, balance ability in standard and dual-task conditions, all trunk muscle strength variables, and leg power in favor of the Huber group. The observed improvements in balance ability under both standard and dual-task conditions in the Huber group were mainly the result of enhanced postural control in medial-lateral direction ($p < 0.05$).

Conclusion: Feedback-based balance and core resistance training proved to be more effective in improving single- and dual-task balance ability, trunk muscle strength, leg power, and body composition of healthy older women than the traditional Pilates training.

1. Introduction

Aging is associated with decline in physical function that could result in the development of physical impairment and disability both of which increase the risk of falls and fall-related injury. With respect to risk of falling and functional performance, aging-related deteriorations in postural control (balance) and muscle strength and power are of particular importance (for review, see Refs. (Granacher, Zahner, & Gollhofer, 2008; Granacher, Gollhofer, Hortobágyi, Kressig, & Muehlbauer; Pijnappels, van der Burg, Reeves, & van Dieën, 2008)). Given that falls represent the leading cause of injury deaths for adults over age 65 and the most common cause of nonfatal injuries and hospital admissions for traumatic injuries (Sleet, Moffett, & Stevens, 2008), interventions aimed at preserving and enhancing the above mentioned neuromuscular functions in older adults are of particular scientific and clinical interest.

So far, a number of exercise modalities have been recognized and evaluated regarding their effectiveness in fall prevention and preservation of functional performance (for review, see Refs. (Gillespie et al., 2012; Granacher, Muehlbauer, Zahner, Gollhofer, &

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Kressig, 2011)). Among them, most often studied have been balance training and resistance training, respectively. Recent literature reviews and meta-analyses support the use of balance perturbation training in functional performance enhancement and fall prevention in older individuals (Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011; Shubert, 2011). However, evidence that support the efficacy of lower extremity resistance training in balance or functional performance improvement is less compelling (Carter, Kannus, & Khan, 2001; Orr, Raymond, & Fiatarone, 2008). Notably, most resistance training studies in older adults included lower extremity exercises, which apparently do not transfer effectively strength gains to improvements in balance, functional tasks, or rate/risk of falling (Orr et al., 2008). On the other hand, training modalities focused on increasing core function (*e.g.* Pilates training) proved to be effective in improving balance, functional performance, and in reducing the risk of falling in healthy older adults (Granacher et al., 2013; Barker, Bird, & Talevski, 2015). By definition, the anatomical core represents axial skeleton and all soft tissues with a proximal attachment originating on the axial skeleton, regardless of whether the soft tissue terminates on the axial or appendicular skeleton (upper and lower extremities; (Behm, Drinkwater, Willardson, & Cowley, 2010)). In theory, a strong and functionally stable core may contribute to more efficient use of the extremities and improved balance/functional performance in older individuals (Granacher et al., 2013). Thus, balance perturbation training and core training appear to be effective exercise modalities for improving physical function (balance, core strength, and functional performance in particular) in older adults.

Recently, a combined balance and core resistance training device named Huber® (LPG Systems, Valence, France) has been introduced and promoted (Couillandre, Duque Ribeiro, Thoumie, & Portero, 2008; Fabre, Martin, Borelli, Fritsch, & Theurel, 2014; Guiraud et al., 2015). The Huber device consists of an oval motorized platform, which performs rotating, oscillatory movements of controlled amplitude and speed, and two large handles with force sensors, mounted on a movable column (see also Section 2). The platform interferes with the balance of the subject who must continually adjust his/her posture by exerting isometric pushing and pulling efforts with the arms (Couillandre et al., 2008). As a result, the device provides postural and muscle adaptation with visual force feedback. This type of training lasting only 20–30 min per session proved to be effective in improving static balance, leg and trunk extensors strength (Couillandre et al., 2008), as well as in improving body composition and reducing the energy cost of walking in young adults (Fabre et al., 2014). Also, recent clinical study demonstrated that Huber training can safely and

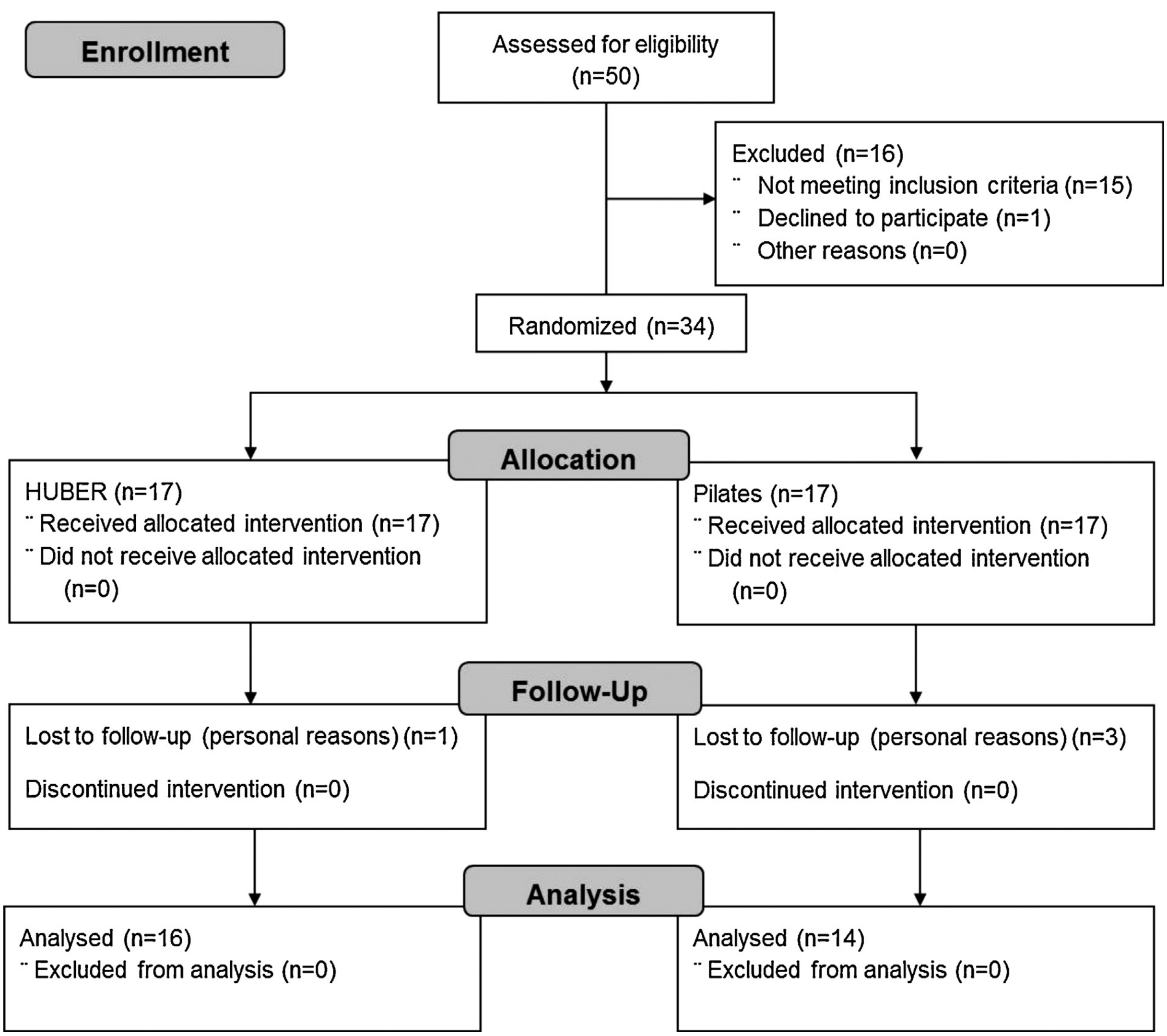

Fig. 1. Flow diagram of the progress through the phases of a parallel randomized trial.

effectively be applied in rehabilitation of coronary heart disease patients (Guiraud et al., 2015).

To which extent this type of training improves physical function of older adults is unknown. Given that Huber training characterizes simultaneous controllable balance perturbations and targeted core strength efforts while standing, and exercise session lasts considerably less than other typical exercise modalities in older adults, it could represent an effective alternative for improving or preserving physical function in this population. Hence, the purpose of this study was to compare the effects of feedback-based balance and core resistance training utilizing the Huber device with the conventional Pilates training on balance ability, neuromuscular function and body composition of healthy older women.

2. Methods

2.1. Study design and subjects

A parallel group, randomized control design was used to test whether a combined core and balance training, performed on Huber device, would be superior to a standard Pilates program.

In response to a local newspaper advertisement, 50 older women between the ages of 66 and 79 years volunteered to participate in this study. Each participant went through a medical examination and completed medical history questionnaire. Volunteers were not allowed to participate if they were taking medications or if they had signs/symptoms of, or diagnosed, disease. Also, volunteers should not participate in any other structured exercise program. Altogether 34 subjects met our inclusion criteria and were randomly divided into a Pilates and a Huber group. The group allocation schedule was developed by a statistician using computer generated random numbers and the list was held off site by an independent person. Group assignment was made by telephone contact after baseline medical screening was completed. The investigator that performed pre- and post-treatment outcome measurements remained blind to group allocation.

Four of 34 participants (one in Huber group and 3 in Pilates group) did not finish the experiment due to personal reasons. Thus, the final sample included 30 women (age: 70 ± 4 years; mass: 70.4 ± 9.0 kg; height: 160.4 ± 4.8 cm), 16 in Huber group, and 14 in Pilates group. Fig. 1 presents the flow diagram of the progress through the phases of this parallel randomized trial. Each volunteer signed an informed consent statement, in accordance with the ethics approval granted by the Human Experimentation Committee of the University of Zagreb.

2.2. Outcome measure testing

Pre- and post-training measurements were performed in a single laboratory testing session at the same time of day, which started with a warm-up consisting of cycling 3 min at 40 W, light dynamic stretching, and two static core exercises in supine and prone position. Body mass and height were measured using a digital scale and stadiometer (Seca 769; SECA, Chino, USA). Percent body fat was measured using a validated multi-frequency bioelectrical impedance analysis scale (InBody R20, Biospace, USA).

2.2.1. Static balance

Balance ability was measured in a quiet room using recently described protocol (Guiraud et al., 2015). In brief, each subject performed two quiet stance balance tasks (simple and dual-task) with feet in a "semi-tandem" position so the toes of one foot were level with the inside arch of the other foot. The dominant foot was placed forward. The dual-task included counting from 300 backward by 3 (*i.e.* 297, 294 . . .), thereby placing additional cognitive effort to the subject. In both balance tasks, the subjects were instructed to focus their vision on a reference point marked eyes high on the wall 1.5 m in front of them and to stand as still as possible throughout the balance tasks. The tasks were repeated three times for 30 s with 3-min breaks between repetitions. Throughout both tasks, the knees had to be extended; however, they had to be active and not in a position of locking the joint. Each subject performed two 20-s practice trials before the test started. The data were acquired using a force plate (AMTI, Watertown, USA; sampling frequency 1000 Hz) and signals were stored on a personal computer for further analysis. The center-of-pressure (CoP) time-series was quantified with custom-written software (LabView, 8.1; NI, Texas, USA). After removal of the potential noise from the signal (2nd order Butterworth, 0.1–20 Hz band-pass, bidirectional filter) the following traditional parameters of the body sway were calculated: mean CoP velocity, mean CoP velocity in medial-lateral direction, and mean CoP velocity in anterior-posterior direction. These parameters proved to be highly reliable in older individuals (Markovic et al., 2014).

2.2.2. Muscle strength and power

Strength and power testing consisted of (a) isometric strength testing of trunk extensors, flexors, and lateral flexors, (b) dynamic strength testing of upper-body muscles, and (c) power testing of leg muscles.

Maximal strength of trunk extensors, flexors and lateral flexors was measured under static conditions using a dynamometer (TNC, S2P Ltd., Ljubljana, Slovenia) with an embedded force sensor (PW10AC3-200 kg, HBM, Darmstadt, Germany) (Kocjan and Sarabon, 2014). The subject was standing upright with feet at shoulder width and arms across the chest. The pelvis was tightly fixed against the rigid support with a strap. The upper support containing the sensor was set to the shoulders height. To acquire maximal voluntary contraction force (MVC) the subject was asked to press against the upper support as strongly as possible for 3 s. Three MVC trials (20-s pause) were acquired for pushing forward, backward and aside (*i.e.* trunk flexion, extension and lateral flexion). One practice trial was given to all subjects. The strongest among the 3 MVC trials (mean force on 1-s time interval) was used for further analysis.

Upper-body strength (*i.e.* one repetition maximum load; 1RM) was measured using a pneumatic bilateral chest press system (Keiser Air 250; Fresno, USA). Briefly, subjects were seated with their back supported and their hands placed on handles at the mid-chest level. The proper testing position was marked for each subject. Subjects were instructed to push the handles away from the body (*i.e.* forward) until full extension in the elbows. One warm-up set (8 repetitions with 5 kg load) preceded 1RM testing. The process of assessment of upper-body 1RM generally required no more than 4–5 repetitions in order to complete.

Leg power was estimated via vertical jump height using a countermovement jump test (CMJ). It has been shown that vertical jump height represents a body size independent index of leg muscle power (Markovic and Jaric, 2007). Each subject performed 2 practice CMJ, followed by 3 maximal CMJ. During jumping, subject's hands were placed on the hips. The height of CMJ was measured using a Optojump photocell system (Microgate, Bolzano, Italy). The Optojump is a dual beam optical device that measures contact and flight times during a series of jumps (or single jump). Flight time (t_{air}) was used to calculate height of the rise of the body's center of gravity ($\text{heigh} = (g \times t_{air}^2)/8$). The validity and reproducibility of VJ testing using Optojump device proved to be excellent (Glatthorn et al., 2011).

2.3. Training procedure

Both groups trained for 8 weeks, 3 times a week on alternate days, giving a total of 24 sessions per group. Each training session was led by a trained specialist and supervised by the researchers. The compliance with training in both groups were >91%.

2.3.1. Huber training

The Huber training was performed on Huber® device (Fig. 2) under direct supervision of the trained specialist. Each training session started with a warm-up phase that included 3-min mobility/calisthenics exercises. This warm-up phase was followed by combined core and balance exercises on the computer-controlled Huber device lasting ~25–30 min. In particular, the program included push and pull exercises on the handles in different postures (feet parallel, apart at waist wide, right or left forward lunge), with different hand positions, (chest level, shoulder level, waist level), and in different directions (forward/backward, upward/downward, and left/right). The intensity of effort was carefully monitored during each training session using special 3-axial force sensors imbedded in the handles of the Huber device. An interactive interface, materialized as a target (bar graph), informed the subjects about their ability to maintain the required force level. Also, subjects were required to hit the target area by careful modulation of force applied on the handles, which placed an additional cognitive load to the motor task. The force level ranged from 50% of maximum voluntary contraction (MVC) during the first 2 weeks, over 65% MVC during the next 3 weeks, to 75% of MVC during the last 3 weeks. The duration of isometric actions ranged from 5 to 7 s, and participants performed between 30 and 60 contractions per session. These isometric actions required the strong synergistic activation of trunk muscles in all three planes of motion, as well as lower limbs. During the first 2 training weeks, no balance or core perturbations were used. During the 3rd week, core perturbations were introduced by raising and lowering the movable column during isometric exercises. During the 4th training week, we introduced balance perturbations via low-velocity rotation of the movable platform. From the 5th week till the end of the exercise program, both core and balance perturbations were included during each exercise. Particular attention was focused on keeping a neutral posture and stable core during all exercises.

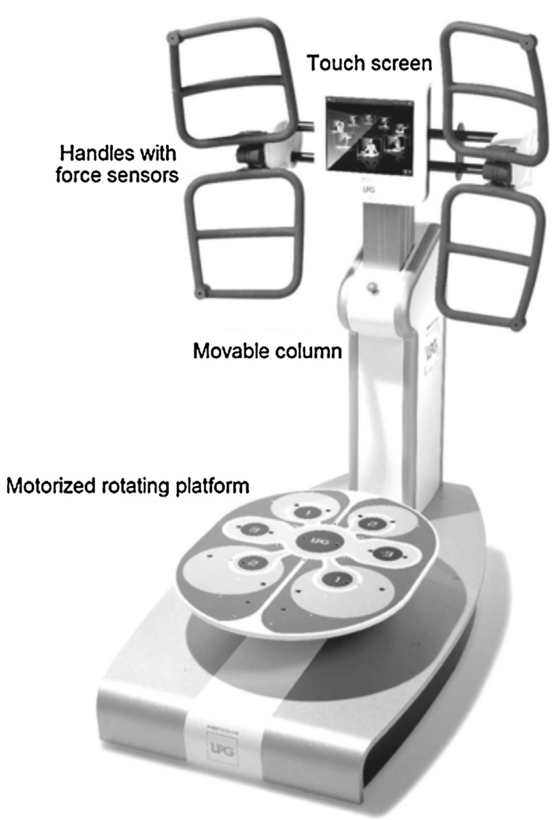

Fig. 2. The Huber® device.

2.3.2. Pilates training

The Pilates intervention involved three 1-h, supervised Pilates sessions per week taken by the same qualified Pilates instructor. Pilates classes were held in small groups of no more than 6 people. As a result, each participant performed the exercises using the best technique possible and was progressed in terms of repetitions and load of exercises at the earliest opportunity. In these classes, core stability was addressed by the use of abdominal bracing and pelvic tilt exercises. A typical session included supine, side-lying, sitting and quadruped exercises, thereby challenging core stability in all three planes of motion. The difficulty of these exercises was gradually increased and the focus was maintained on keeping a neutral posture and stable core in different gravity orientations. Kneeling and standing exercises were gradually introduced. Each session ended with lower- and upper-limb exercises using elastic bands. Each exercise was performed for 2–4 sets with 15–20 s contraction time (isometric exercise) or 15–20 repetitions (dynamic exercise).

2.4. Statistical analysis

Means and standard deviations (SD) were calculated for each primary dependent variable. Normality of distribution of all outcome variables was verified using a Kolmogorov–Smirnov test. A two-way ("group" × "time") analysis of variance with repeated measures on "time" factor was used for analyzing the effects of training programs on each dependent variable. Post hoc testing using Bonferroni method was used to identify within-group changes over time. An a priori power analysis was performed for the balance dependent variable (mean CoP velocity) based on previous research (Markovic, Mikulic, Kern, & Sarabon, 2014), indicating that a sample size of 15 participants per group would be required to provide 80% power at an alpha level of 0.05. We anticipated a 10% dropout rate and aimed for a starting population of 34. Clinically meaningful change was assessed by calculating Cohen *d* for effect size. All analyses were performed using Statistical Package for Social Sciences (SPSS) version 17.0. The significance level was set at $p < 0.05$.

3. Results

3.1. Morphological characteristics

Table 1 depicts pre- and post-training data for body mass and percent body fat in both training groups. Significant interaction (all $p < 0.015$), but not main effects (all $p > 0.05$) were observed for body mass and percent body fat, respectively. *Post-hoc* analyses revealed significant decrease in percent body fat in Huber group ($p < 0.01$; Cohen's $d = 0.75$).

3.2. Balance performance

Pre- and post-training data for balance performance in both groups are shown in Table 1. The ANOVA analyses revealed significant interaction (all $p \leq 0.05$), and main effects for time (all $p < 0.05$) for mean total CoP velocity in both standard and dual-task conditions. *Post-hoc* analyses found that participants in the

Table 1
Pre- and post-training data (mean ± SD) for all outcome measures with main analyses of variance results.

Measure	Huber group			PILATES group			F (*p*) values		
	Before	After	Cohen's d	Before	After	Cohen's d	Time	Group	Interaction
Morphological characteristics									
Body mass, kg	71.2 ± 8.1	70.4 ± 9.1	0.14	69.4 ± 8.6	70.0 ± 9.2	−0.10	0.13 (0.73)	0.12 (0.73)	7.4 (0.011)
Percent body fat, %	39.7 ± 8.8	35.4 ± 8.6	0.75	39.1 ± 8.4	39.5 ± 7.2	−0.08	3.65 (0.07)	0.39 (0.54)	6.9 (0.014)
Static balance									
Mean CoP velocity, mm/s[a]	37.7 ± 4.6	35.3 ± 5.4	0.48	37.5 ± 8.0	37.7 ± 8.4	−0.02	4.62 (0.04)	0.21 (0.65)	7.0 (0.013)
Mean CoP velocity in AP direction, mm/s[a]	21.7 ± 2.6	21.1 ± 2.9	0.20	22.6 ± 4.6	22.4 ± 3.8	0.04	3.2 (0.084)	0.75 (0.39)	0.79 (0.38)
Mean CoP velocity in ML direction, mm/s[a]	26.1 ± 4.0	23.8 ± 4.3	0.51	25.0 ± 6.0	25.4 ± 7.1	−0.06	3.1 (0.088)	0.02 (0.89)	6.3 (0.019)
Static balance with additional cognitive task									
Mean CoP velocity, mm/s[a]	43.7 ± 8.6	39.1 ± 7.6	0.52	46.3 ± 10.8	46.2 ± 12.3	0.01	4.25 (0.049)	1.73 (0.20)	4.23 (0.05)
Mean CoP velocity in AP direction, mm/s[a]	23.8 ± 3.5	22.4 ± 4.5	0.32	27.0 ± 6.6	27.4 ± 8.0	−0.05	0.57 (0.46)	3.97 (0.06)	1.64 (0.21)
Mean CoP velocity in ML direction, mm/s[a]	31.5 ± 7.6	26.9 ± 5.8	0.63	31.8 ± 9.1	31.1 ± 11.0	0.06	8.03 (0.008)	0.60 (0.45)	4.28 (0.048)
Trunk muscle strength									
Isometric trunk extension, N	302 ± 84	397 ± 108	−0.90	337 ± 94	349 ± 102	−0.08	16.6 (0.000)	0.06 (0.80)	12.2 (0.001)
Isometric trunk flexion, N	340 ± 64	441 ± 102	−1.11	360 ± 107	376 ± 125	−0.13	20.8 (0.000)	0.44 (0.51)	11.1 (0.002)
Isometric trunk right lateral flexion, N	251 ± 45	313 ± 64	−1.04	252 ± 91	256 ± 87	−0.04	16.3 (0.000)	1.20 (0.28)	13.0 (0.001)
Isometric trunk left lateral flexion, N	260 ± 42	328 ± 70	−1.11	272 ± 93	277 ± 88	−0.02	11.6 (0.002)	0.68 (0.42)	10.7 (0.003)
Upper body muscle strength									
Chest press, kg	23.0 ± 4.0	24.8 ± 4.4	−0.36	22.9 ± 6.7	24.4 ± 6.8	−0.25	45.2 (0.000)	0.01 (0.94)	1.03 (0.32)
Lower body power									
Vertical jump height, cm	9.1 ± 2.6	10.3 ± 2.5	−0.43	8.2 ± 3.4	8.0 ± 3.1	0.06	4.1 (0.05)	2.35 (0.14)	7.9 (0.01)

[a] Inversely scaled variable (lower score means better performance).

Huber group significantly increased mean total CoP velocity in both testing conditions (all $p < 0.05$; Cohen's $d = 0.48–0.52$). No significant main or interaction effects were found for mean CoP velocity in A–P direction (all $p > 0.05$). Finally, for mean CoP velocity in M–L direction, significant interaction effect ($p < 0.05$) and main effect for time ($p < 0.01$) were found in both the standard and dual task condition. *Post-hoc* analyses revealed significant improvement in these balance performance variables in the Huber group ($p < 0.05$; Cohen's $d = 0.51–0.63$).

3.3. Muscle strength and power

Table 1 also depicts pre- and post-training data for muscle strength and power measures in both training groups. The ANOVA analyses revealed significant interaction (all $p < 0.01$) and main effects for time (all $p < 0.01$) for all trunk muscle strength variables and for vertical jump height. *Post-hoc* analyses found that participants in the Huber group significantly increased trunk muscle strength in all directions (all $p < 0.01$; Cohen's $d = 0.90–1.11$), and leg power ($p < 0.05$; Cohen's $d = 0.43$). For upper-body strength, only significant main effect for time effect was observed ($p < 0.01$). *Post-hoc* analyses found that both groups significantly improved upper-body strength (all $p < 0.05$; Cohen' $d = 0.25–0.36$).

4. Discussion

The main finding of this study was that a novel feedback-based balance and core resistance training was more efficacious in improving balance ability, trunk strength, leg power, and body composition of healthy older women when compared to traditional Pilates training. Given that the applied novel training was simultaneously focused on balance, core stability and strength, and total body strength, these results are not unexpected.

In this study there were significant improvements in singe-task (6.4%) and dual-task (10.5%) balance ability in Huber group. The fact that the gains in postural control were more pronounced in dual-task conditions is particularly interesting, since dual balance task are ecologically more valid, and may have an added value over the single balance task for fall prediction (Bergland & Wyller, 2004; Verghese et al., 2002). Also, recent research synthesis indicates that dual-task training appears to be necessary to improve dual-task performance (Agmon, Belza, Nguyen, Logsdon, & Kelly, 2014). The applied Huber intervention was a dual-task since the subjects were required to precisely modulate force applied on the handles via hitting the target area on the screen (see Section 2). It should be also noted that the observed balance improvements were mainly related to the enhanced postural control in m-l direction (Table 1). This could be of importance in fall prevention in seniors since aging-induced balance deterioration appears to be more pronounced in a bilateral asymmetric stance in which m-l body sway is particularly evident (Amiridis, Hatzitaki, & Arabatzi, 2003; Onambele, Narici, & Maganaris, 2006). Several studies also reported gains in single-task balance ability in older individuals following core strengthening (Kahle & Tevald, 2014) and core instability training programs (Granacher, Lacroix, Muehlbauer, Roettger, & Gollhofer, 2012). The fact that the Pilates group did not significantly improve postural control in the single-task was somewhat surprising, considering the results of previous Pilates training studies in older women (Barker et al., 2015; Bullo et al., 2015; Newell, Shead, & Sloane, 2012; Pata, Lord, & Lamb, 2014; Siqueira Rodrigues, Ali Cader, Bento Torres, Oliveira, & Martin Dantas, 2010). This contradictory finding could be related to differences in balance assessment (dynamic balance testing in previous studies vs. static balance testing in the current study). Indeed, systematic reviews of the effects of Pilates method exercise showed that this type of training is more suitable for enhancing dynamic balance (Bullo et al., 2015; Siqueira Rodrigues et al., 2010). Also, inter-study differences in the exercise protocol applied (*e.g.* use of wobble boards and specific machines vs. mat exercise) could be partly responsible for the above mentioned contrasting findings.

Recent systematic review of literature accentuated the importance of trunk muscle strength for balance and fall prevention in seniors (Granacher et al., 2013). In that regard, the observed significant and quantitatively large (~25–30%) improvements in trunk muscle strength following Huber training intervention are of particular importance. These improvements in trunk muscle function are not surprising, given that Huber training required constant trunk muscle activation during isometric pushing/pulling efforts (50–75% of MVC) in various directions. Our results are in concordance to those reported by other authors that examined the effects of core strength or core stability training on trunk muscle function in older adults (Granacher et al., 2012; Cruz-Ferreira, Fernandes, Laranjo, Bernardo, & Silva, 2011; Petrofsky, Cuneo, Dial, Pawley, & Hill, 2005). Granacher et al. (2012) reported 21–53% increase in trunk muscle strength following 9-week core training under unstable conditions in older individuals. Petrofsky et al. (2005) showed that 4-week core strength training program increased strength of trunk flexors and extensors of seniors by 33–36%. Kahle and Tevald (2014) recently reported 44% increase in abdominal muscle endurance following core strengthening program in healthy older men and women. The authors also reported that changes in abdominal muscle endurance correlated significantly with the changes in the field balance tests ($r = 0.44$–0.61). In contrast to Huber training, Pilates training had only minor positive effects on strength of trunk flexors and extensors (4–5%). Donahoe-Fillmore, Hanahan, Mescher, Clapp, Addison, & Weston, 2007 studied the effects of 10-week home Pilates program in women and reported no significant effect on abdominal strength but both flexor and extensor endurance appeared to improve. On the other hand, Irez, Ozdemir, Evin, Irez, & Korkusuz, 2011 reported significant (~40%) increase in hip muscle strength of older women following a 12-week Pilates training. Similarly, Sekendiz, Altun, Korkusuz, & AkÝn, 2007 studied the effects of 5-week Pilates exercise on abdominal and lower back muscle strength and endurance in sedentary women. They observed significant improvements in all studied trunk muscle function tests. The contrasting findings related to the effects of Pilates training on trunk muscle function suggest that the type, intensity, and duration of exercise (which differed among cited studies) could be responsible for specific changes in motor function following Pilates training. Future studies are needed verify this conjecture.

In addition to enhanced balance and trunk muscle strength, Huber training also improved upper-body strength and leg power of seniors. These changes in physical function were also accompanied by a significant decrease in body fat percentage. It should be noted that total-body pushing and pulling isometric efforts between 50% and 75% of MVC in various standing postures were the main exercises in the Huber group. Hence, gains in upper-body strength in pushing motion were expected. However, the magnitude of this change was considerably smaller compared with the changes in trunk strength (8% vs. 25–30%), suggesting that core strength is likely to be the major limiting factor in total-body strength efforts in standing, at least in older women. Also, the applied core resistance training was of sufficient volume and intensity to elicit favorable changes in body composition and power, in line with previous research on the effects of resistance training in older adults (for review, see Ref. (Hunter, McCarthy, & Bamman, 2004)). In a similar study performed on sedentary women, Fabre, Martin, Borelli, Fritsch, & Theurel, 2014 also reported significant decrease in body fat percentage following 8-week Huber training program. The Pilates group also significantly improved upper-body strength by 6%, while percent body fat and leg power remained unchanged. These findings are in line with the results of recent systematic reviews of the effects of Pilates training that showed limited evidence of this type of exercise for improving vertical jump performance (Cruz-Ferreira et al., 2011) or body composition (Aladro-Gonzalvo, Machado-Díaz, Moncada-Jiménez, Hernández-Elizondo, & Araya-Vargas, 2012) in healthy adults.

5. Conclusions

To conclude, we have demonstrated that feedback-based balance and core resistance training was more efficacious in improving single- and dual-task balance ability, trunk muscle strength, leg power, and body composition of healthy older women when compared to traditional Pilates training. Given that aging-induced deterioration of these physical qualities is related to risk of falling in older people, this type of exercise could be effective in reducing rate of falls and fall-related injuries in seniors. Obviously, our findings could only be generalized to healthy older women. This represents the limitation of the current study. Hence, future studies are needed to verify the external validity of our findings in other populations like older men and patients with low back pain.

Conflict of interest

The authors declare that they have no competing financial interests or relationships with other people or organizations that could inappropriately influence this work.

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