Clinical Section / Original Paper

Gerontology

Gerontology
DOI: 10.1159/000442087

Received: June 12, 2015
Accepted: November 2, 2015

Effects of a Supervised versus an Unsupervised Combined Balance and Strength Training Program on Balance and Muscle Power in Healthy Older Adults: A Randomized Controlled Trial

André Lacroix[a] Reto W. Kressig[b] Thomas Muehlbauer[a] Yves J. Gschwind[b]
Barbara Pfenninger[c] Othmar Bruegger[c] Urs Granacher[a]

[a]Division of Training and Movement Sciences, University of Potsdam, Potsdam, Germany; [b]University Center for Medicine of Aging, Felix Platter Hospital, Basel, and [c]Swiss Council for Accident Prevention, Bern, Switzerland

Key Words
Sensorimotor training · Resistance training · Gym-based/home-based training · Detraining · Seniors

Abstract

Background: Losses in lower extremity muscle strength/power, muscle mass and deficits in static and particularly dynamic balance due to aging are associated with impaired functional performance and an increased fall risk. It has been shown that the combination of balance and strength training (BST) mitigates these age-related deficits. However, it is unresolved whether supervised versus unsupervised BST is equally effective in improving muscle power and balance in older adults. ***Objective:*** This study examined the impact of a 12-week BST program followed by 12 weeks of detraining on measures of balance and muscle power in healthy older adults enrolled in supervised (SUP) or unsupervised (UNSUP) training. ***Methods:*** Sixty-six older adults (men: 25, women: 41; age 73 ± 4 years) were randomly assigned to a SUP group (2/week supervised training, 1/week unsupervised training; n = 22), an UNSUP group (3/week unsupervised training; n = 22) or a passive control group (CON; n = 22). Static (i.e., Romberg Test) and dynamic (i.e., 10-meter walk test) steady-state, proactive (i.e., Timed Up and Go Test, Functional Reach Test), and reactive balance (e.g., Push and Release Test), as well as lower extremity muscle power (i.e., Chair Stand Test; Stair Ascent and Descent Test) were tested before and after the active training phase as well as after detraining. ***Results:*** Adherence rates to training were 92% for SUP and 97% for UNSUP. BST resulted in significant group × time interactions. Post hoc analyses showed, among others, significant training-related improvements for the Romberg Test, stride velocity, Timed Up and Go Test, and Chair Stand Test in favor of the SUP group. Following detraining, significantly enhanced performances (compared to baseline) were still present in 13 variables for the SUP group and in 10 variables for the UNSUP group. ***Conclusion:*** Twelve weeks of BST proved to be safe (no training-related injuries) and feasible (high attendance rates of >90%). Deficits of balance and lower extremity muscle power can be mitigated by BST in healthy older adults. Additionally, supervised as compared to unsupervised BST was more effective. Thus, it is recommended to counteract intrinsic fall risk factors by applying supervised BST programs for older adults.

KARGER 125 YEARS

E-Mail karger@karger.com
www.karger.com/ger

0304–324X/15/0000–0000$39.50/0

Prof. Urs Granacher, PhD
Research Focus Cognition Sciences
Division of Training and Movement Sciences, University of Potsdam
Am Neuen Palais 10, Building 12, DE–14469 Potsdam (Germany)
E-Mail urs.granacher@uni-potsdam.de

Introduction

With increasing age, physical inactivity together with degenerative processes in the central nervous (e.g., loss of sensory and motor neurons) and muscular (e.g., loss of type II muscle fibers) systems results in impaired balance and muscle strength/power performance [1]. These declines have a major impact on the occurrence of falls. Falls are caused by intrinsic (e.g., muscle weakness, visual disorder, cognitive impairment) and extrinsic (e.g., medication, lighting conditions, stairs) factors, or a combination of both [2]. Deficits in balance, gait instability, and muscle weakness represent the most important intrinsic fall risk factors in older adults [3]. Recently, Rapp et al. [4] observed that in Germany, 29.7% of community-dwelling men and 38.7% of women aged 65–90 years fall at least once per year. The rate of falls rises from old to oldest old people, with institutionalized persons being at highest risk for falls and consequential complications (1.7 falls per year; community-living older persons: 0.7 falls per year) [3]. Falls cause serious injuries, contribute to immobility in terms of a decline in the ability to perform activities of daily living, and are responsible for premature nursing home admission [5]. Consequently, there is a need for a widespread implementation of cost-efficient and easy to administer fall prevention programs for people at risk.

Fall-preventive intervention programs should particularly include exercises that have the potential to mitigate intrinsic fall risk factors like muscle weakness, balance deficits, and gait instability [3]. In the past, a large number of studies investigated the effects of resistance and balance training in older adults [e.g., 1, 6, 7]. Liu and Latham [6] illustrated in a meta-analysis that progressive resistance training resulted in enhancements of muscle strength and physical ability (e.g., physical domain of the SF-36 questionnaire) in older adults. Additionally, it has been reported that balance training has the potential to improve balance performance, muscle strength, and fall rate in older adults [1]. More specifically, Gillespie et al. [7] showed in a meta-analysis that combined balance and resistance training has the potential to reduce the fall rate in older adults, whereas strength training alone had no significant effect.

In the past, fall-preventive exercise programs have been implemented as supervised gym-based (SUP) or unsupervised home-based (UNSUP) programs [6]. If the goal is to cost-effectively implement fall-preventive exercise programs for large populations, it has to be taken into consideration that a great amount of older people may not have the ability or motivation to participate in a gym-based program [8]. In fact, findings from a recent study [9] indicate that older adults with a history of falls prefer to participate in exercise programs that can be conducted at home or require no transport. However, the benefits of implementing cost-effective exercise programs (UNSUP) have to be evaluated with regard to their potential on mitigating intrinsic fall risk factors. Earlier studies that investigated the effects of UNSUP versus SUP after a combined balance and strength training (BST) in the older population provided only preliminary evidence [10–14]. Some of these studies indicate a slight superiority of SUP regarding improvements in balance and leg strength [11–13], while others do not [14]. Results of studies indicating a superiority of SUP are not consistent as they detected either a superiority regarding effects on static balance in SUP versus UNSUP [12, 13] or an additional improvement of leg strength in SUP [11]. Further, previous studies are limited inasmuch as they tested specific components of balance only (e.g., static but not dynamic, proactive, and reactive balance) [10], or conducted different and thus not comparable training protocols (e.g., varying volumes) in the intervention groups (IGs) [10, 14]. Other studies did not follow a randomized controlled trial (RCT) approach [e.g., 11], or implemented only a quasi-unsupervised IG in which participants received additional supervised exercise sessions [12]. Due to the heterogeneous and controversial results with tendencies indicating a superiority of SUP, there is a need for studies providing a clearer and more comprehensive view on the effects of supervision in older adults. To the authors' knowledge, no study has compared the effects of a supervised versus an unsupervised BST and inactivity [control (CON)] on static/dynamic steady-state, proactive, and reactive balance as well as lower extremity muscle power in healthy older adults.

Further, information on detraining effects is important to document the robustness of possible training-related adaptations. Especially older people may be prone to longer periods of training cessation because of their high susceptibility to diseases, injuries, or personal factors like family commitments or even extended travels. However, there are only a few studies available which examined detraining effects following BST and reported contradictory findings [e.g., 14–16].

Thus, the aims of this study were: (1) to examine the effects of a 12-week BST on measures of static/dynamic steady-state, proactive, and reactive balance, lower extremity muscle power (primary outcomes), falls efficacy, cognitive function, quality of life, and body composition

Table 1. Baseline characteristics by group

Measure	SUP (n = 22)	UNSUP (n = 22)	CON (n = 22)
Males/females	8/14	8/14	9/13
Age, years	72.7 (4.0)	73.1 (3.6)	72.7 (3.8)
Body height, cm	166.2 (7.7)	168.9 (12.2)	168.6 (9.0)
Body mass, kg	69.9 (10.7)	73.7 (12.1)	74.1 (15.8)
Body mass index	25.2 (3.1)	26.0 (5.0)	25.9 (3.9)
Total body water, l	35.6 (6.5)	36.8 (8.5)	37.5 (8.6)
Total skeletal muscle mass, kg	26.5 (5.3)	27.3 (6.8)	27.9 (6.8)
MMSE score	27.8 (1.7)	28.4 (1.6)	28.5 (1.3)
CDT performance	all participants were classified as nonpathological		
Physical activity, h/week	15.4 (11.4)	17.9 (13.2)	14.3 (10.7)
Handgrip strength, kg	29.7 (7.7)	27.0 (8.8)	28.5 (8.7)

Values are presented as mean (SD). No group baseline differences were detected (all $p > 0.05$).

(secondary outcomes) in healthy older adults; (2) to compare the effects of SUP versus UNSUP, and (3) to detect detraining effects. The authors hypothesized that: (1) BST results in significant improvements in primary and secondary outcomes as compared to the CON group; (2) the SUP group shows larger performance enhancements as compared to the UNSUP group, and (3) training-related improvements will remain above baseline values after 12 weeks of detraining in both training groups.

Methods

To test the hypotheses, an RCT design was used. Measurements were conducted before and after training and 12 weeks after training completion.

Participants

Sixty-six community-dwelling healthy adults (men: 25, women: 41) aged 65–80 years participated in this RCT (ClinicalTrials.gov ID: NCT01906034) [17]. Trial participants were recruited by posting flyers and by publishing articles in local newspapers. After the experimental procedure was explained, participants gave their written informed consent. All participants were able to walk independently and did not use any walking aids. Eligibility was examined with a standard protocol, which comprised the assessment of demographic and anthropometric data, relevant diseases, recent operations, acute injuries, and drug intake to detect contraindications to training. We deemed participants as generally healthy if no relevant diseases (e.g., neurophysiological, cardiovascular, vestibular/gait disorder) were reported. Participants were excluded if they did not reach cutoff scores for the Mini-Mental State Examination (MMSE; <24 points) [18] and the Clock Drawing Test (CDT; pathological test performance) [19]. Additionally, subjects were excluded if they participated in a regular strength and/or balance training program 6 months prior to the start of the study. All inclusion and exclusion criteria were specified prior to the beginning of the study. Participants were randomly assigned to two IGs (SUP, UNSUP) or a CON group (i.e., no training). The randomization process was conducted with Research Randomizer (www.randomizer.org). Figure 1 shows a flowchart of the study design. Participants' baseline characteristics are presented in table 1. The study was approved by the Ethics Committee of the University of Potsdam (reference No.: 34/2012) and conducted according to the ethical standards of the latest version of the Declaration of Helsinki.

Combined BST

Participants of the two IGs conducted a 12-week BST program with three training sessions per week. The exercise program was based on recommendations developed by an expert panel which is publicly accessible (http://www.stuerze.bfu.ch). Progressive exercise routines with different intensity stages were compiled from the given exercises. In general, exercises were performed using participants' own body weight or with the help of small, low-cost equipment (e.g., towels, bottles, balls). The intensity of the training was examined with the help of a perceived exertion rating scale (Borg scale; 6–20 points) [20]. Participants were asked to perform each exercise with a rate of perceived exertion of 12–16 ('somewhat hard' to 'hard'). A single training session comprised either static balance exercises, dynamic balance exercises or strength/power exercises for leg and trunk muscles. Before the beginning of the intervention, all subjects were extensively introduced to the exercise program, training principles, and potential risks. Table 2 illustrates the training protocol. For a detailed description, see Granacher et al. [21].

The SUP group exercised twice a week at a local gym, supervised by an instructor, and once a week unsupervised at home. For the home-based sessions, an illustrated exercise book was provided to all participants [22]. Participants also received a training log and were asked to document each completed training session and the respective stage of progression. The UNSUP group followed the same exercise routine as the SUP group, except that they trained unsupervised at home only (three times per week). Quality and quantity of the training were controlled by phone calls every fortnight. Participants of the CON group maintained their habitual physical activity level. They did not take up new sports-related ac-

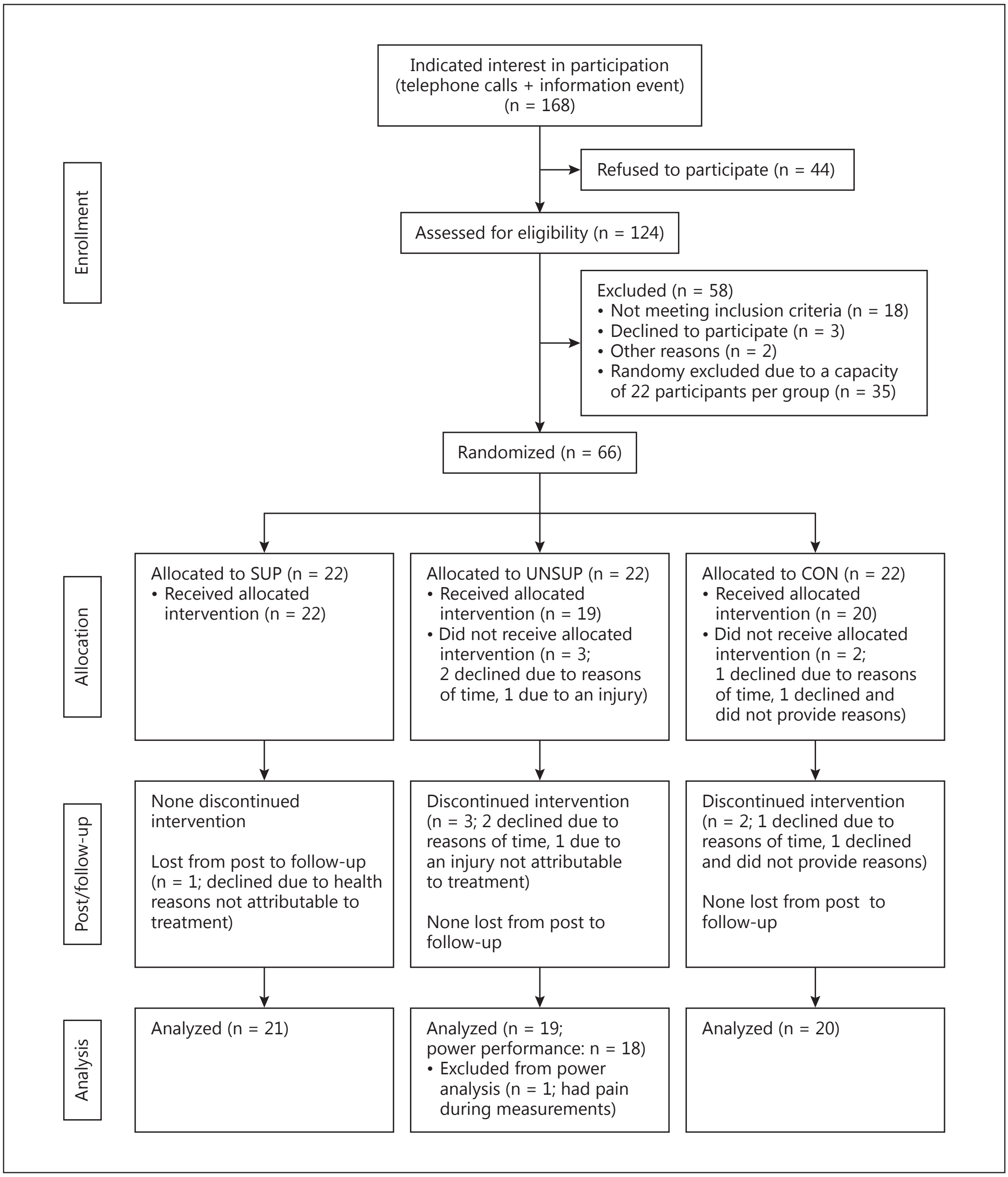

Fig. 1. Flowchart of the study design.

tivities during the experimental period and received a supervised 12-week program after the trial.

Testing Procedure

All tests were conducted at our biomechanics laboratory by the same assessor (graduated sport scientist). Participants received standardized verbal instructions regarding the test procedure. Subsequently, subjects were asked to answer the following questionnaires [i.e., pretest: MMSE, CDT, Freiburg Questionnaire of Physical Activity (FQoPA)]. Thereafter, the testing started. Pre-, post-, and follow-up (12 weeks after the intervention) tests included: (1) questionnaires [i.e., Falls Efficacy Scale International (FES-I), Digit Symbol Substitution Test (DSST), World Health Organization Quality of Life-BREF (QoL)], measurement of anthropo-

Table 2. Protocol of the training program

Training protocol	
Exercises	(1) Static balance exercises (basic exercise: upright, bipedal stance) (2) Dynamic balance exercises (basic exercise: normal gait) (3) Strength/power exercises for the lower extremities and trunk muscles (basic exercises: squats, plank, standing side leg lifts, calf raises/toe raises, standing trunk extensions)
Training volume	– 12-week training program with a total of 36 sessions – Each session lasted 45 min (inclusive 15 min warm-up and cooldown) – Static balance exercises – 4 series, each lasting 20 s – 30 s of rest between series – Dynamic balance exercises – 4 series, each lasting 20–60 s – 30 s of rest between series – Strength/power exercises – 3 series, each consisted of 8–15 repetitions – 60–120 s of rest between series – muscle groups: thigh, abdominal, gluteal, calf/shin, and upper/lower back
Training frequency	– Three training sessions per week (on nonconsecutive days)
Training intensity	– Progressive exercise routines for static/dynamic balance exercises – reduction of base of support (bipedal – semi-tandem – tandem – one-legged stance; normal – narrow – overlapping – tandem gait) – reduction of visual input – weight shifts – changes of gait rhythm/direction/velocity – additional motor/cognitive tasks – inclusion of unstable surfaces (e.g., foam cushions, towels) – combinations of these variations – Progressive exercise routines for strength/power exercises – from slow to fast movement velocity – increasing lever arms and involvement of multiple joints – from static to dynamic exercises – additional movements of arms and legs – inclusion of unstable surfaces (e.g., foam cushions, towels)

metric data (e.g., body height, body mass), and body composition (e.g., lean tissue mass of the legs, skeletal muscle mass); (2) a 5-min warm-up program on a bicycle ergometer at a rate of perceived exertion of 12 (‘somewhat hard’) on the Borg scale; (3) measurement of static/dynamic steady-state, proactive, and reactive balance, and (4) the analysis of lower extremity muscle power. Additionally, handgrip strength was assessed at baseline. Prior to testing, participants performed one to three practice trials for each test. Balance tests were performed before the power tests to prevent muscle fatigue. If several trials were conducted for one test, mean values were used for further data analysis.

Testing Material

Assessment of Balance

Static steady-state balance was assessed using the modified Romberg Test (ROM) [23] while standing on a three-dimensional force plate (Leonardo 105 Mechanograph®; Novotec Medical GmbH, Pforzheim, Germany). Participants stood in an upright position on a balance pad (Airex®) for 30 s without shoes, feet closed, and arms fully extended in front of the body with palms facing upwards, and eyes closed. The test was terminated if participants opened their eyes, moved their arms or feet in order to achieve stability or required operator intervention. Standing time (s) and the path velocity (mm/s) of the center of force (CoF) were assessed. If a subject failed, an additional trial was provided. For the modified ROM, a high test-retest and interrater reliability has been shown previously [21].

Dynamic steady-state balance was tested while walking on a 10-meter walkway using the OptoGait© System (Microgate, Bolzano, Italy). The OptoGait System is an optoelectric system with bars 1 m in length. Each bar contains 100 LEDs, which continuously transmit to receiving bars. Spatiotemporal gait data were registered at 1,000 Hz. Participants were asked to walk at their habitual walking speed wearing their own footwear. Each walk was initiated and terminated a minimum of 2 m before and after the walkway to allow sufficient distance to accelerate and decelerate. Stride velocity (distance in meters covered per second during one stride) and stride length (distance in cm between successive heel contacts of the same foot) as well as the corresponding coefficients of variation [CV; standard deviation (SD)/mean × 100] were analyzed. The higher the CV value, the more unstable the walking pattern. Since motor-cognitive integration is impaired in old age, dynamic steady-state balance was tested under single and dual task conditions. For the dual task condition, participants had to recite out loud subtractions by three starting from a randomly selected number between 300 and 900. One test trial was performed for each condition. The OptoGait System demonstrated high test-retest reliability [24] as well as high discriminant and concurrent validity [25].

Proactive balance was measured using the Functional Reach Test (FRT) [26] and the Timed Up and Go Test (TUG) [27]. The FRT measures the ability to reach forward while maintaining a fixed base of support in the standing position. Participants stood with their feet shoulder width apart on a force plate (Leonardo 105 Mechanograph). They were asked to lift their dominant arm and make a fist. Following an acoustic signal, they reached forward as far as they could along a height-adjustable tape measure. Three tests of 12 s were performed. A trial was terminated, if subjects took a step or touched the tape measure. Maximal reach distance (cm) and the path velocity (mm/s) of the CoF were assessed. The FRT proved to be reliable [26] and valid [28]. For the TUG, participants were asked to sit down in a chair (height: 46 cm) and place their arms on the armrests. After the command 'ready-set-go', they had to stand up, walk 3 m at their habitual walking speed, turn around and sit down again. Two test trials were performed. Time was recorded with a stopwatch to the nearest 0.01 s. The TUG showed excellent test-retest reliability in older adults [27].

To test reactive balance, a mediolateral (ML) perturbation impulse was applied while participants stood on a two-dimensional balance platform (Posturomed; Haider Bioswing, Pullenreuth, Germany). The platform was free to move in the transversal plane. The mechanical constraints and the reliability of the system were described earlier [29]. During the experiment, the platform was moved 2.5 cm from the neutral position and magnetically fixed. Participants were asked to stand on the platform in a narrow step stance, hands placed on their hips and gaze fixated on a cross at the nearby wall. The perturbation impulse was unexpectedly applied by detaching the magnet. Participants' task was to stand as still as possible over a period of 10 s. A trial was skipped if the subject changed the position of the feet or took the hands off the hips. Three test trials were performed. Summed oscillations of the platform in ML and anterior-posterior (AP) directions were assessed in centimeters.

Reactive balance was additionally tested using the clinical Push and Release Test (PRT) [30]. The PRT rates the postural response to a sudden release. Subjects were asked to stand barefooted in comfortable stance. They had to push backward against the palms of the examiner's hands placed on the subject's scapulae. When the shoulders and hips moved to a stable position just behind the heels, the examiner suddenly removed the hands, requiring the participant to take at least one backward step to regain balance. The amount of steps and the quality of the recovery was rated according to the following scale: 0 = 1 step, 1 = 2–3 small steps with independent recovery, 2 = ≥4 steps with independent recovery, 3 = steps with assistance for recovery, 4 = fall or unable to stand without assistance. Three test trials were conducted. The PRT proved to be reliable and valid [30].

Assessment of Lower Extremity Muscle Power

Lower extremity muscle power was assessed using the Chair Stand Test (CST) while standing on a force plate (Leonardo 105 Mechanograph) [31]. In addition, the Stair Ascent and Descent Test (SADT) was applied [32]. To perform the CST, subjects had to sit on a chair with arms folded across the chest. After an acoustic signal, participants had to stand up and sit down five times as quickly as they could. A trial was cancelled if an upright stance was not achieved, the subject did not touch the chair after the downward movement, the feet left the initial position or the arms were used to stand up. Performance was measured with the force plate and the associated software to the nearest 0.01 s as the time from the initial to the final seated position. Additionally, the average (five rises) maximum power per kilogram body weight (P_{max}; W/kg) was recorded. Three test trials were conducted. An excellent test-retest reliability was reported [32].

For the SADT, participants were instructed to ascend an eight-stair flight at a fast but safe velocity (stair height: 17.1 cm). Time for ascending and descending the stairs was registered separately to the nearest 0.01 s. Timing for the Stair Ascent Test (SAT) began after the subject lifted the foot off the ground and stopped when both feet were placed on the eighth step. Accordingly, timing for the Stair Descent Test (SDT) stopped when both feet reached ground level. Additionally, stair climb power was calculated using the formula: power = force × velocity and reported in W/kg [33]. One test trial was conducted. Test-retest reliability was reported and proved to be good [32].

At baseline, handgrip strength of the dominant hand was measured using a Jamar hand dynamometer (Sammons Preston Inc., Bolingbrook, Ill., USA). Participants had to sit with both arms parallel to the body. After the instruction 'ready-set-go', subjects had to continuously increase their grip until maximal force was reached.

Assessment of Body Composition

A noninvasive bioelectrical impedance analysis was conducted using an eight-electrode impedance meter (InBody 720; BioSpace, Seoul, Korea). Alternating currents of 100 and 500 μA at frequencies of 1, 5, 50, 250, 500, and 1,000 kHz were applied to measure impedance of arms, trunk, and legs. Body mass (kg), body mass index (kg/m^2), total body water (liters), lean tissue mass of the legs (sum of left plus right leg; kg), and total skeletal muscle mass (kg) were assessed. Subjects stood barefoot on the device with arms abducted to approximately 40°. They held electrodes in both hands while the feet were placed on the appropriate electrodes. Participants were instructed to abstain from caffeine and alcohol for 24 h, and exercise for 12 h prior to testing. The InBody 720 proved to be a valid estimator of lean body mass in men and women (R^2 = 0.52–0.95) [34].

Statistical Analyses and Sample Size

Data are presented as group mean values ± SD or medians and interquartile ranges. An a priori power analysis using G*Power [35] with the following input parameters was conducted to obtain medium-sized group × time interaction effects: effect size (i.e., f = 0.25), type I error (i.e., 0.05), type II error (i.e., 0.90), number of groups (i.e., 3), number of measurements (i.e., 3), and correlation among groups (i.e., 0.40). In addition, a dropout rate of 20% was considered. The use of a medium effect size was based on a similar study conducted by Granacher et al. [22] who investigated the effects of BST on measures of balance (e.g., gait velocity) and lower extremity muscle strength in middle-aged adults. Our analysis revealed a total sample size of 65–66 (i.e., 22 participants per group).

To analyze baseline differences, a multivariate analysis of variance (ANOVA) was computed. Measures of balance and muscle power as well as questionnaires and body composition parameters were analyzed in separate 3 (group: SUP, UNSUP, CON) × 3 (time: pre, post, follow-up) ANOVA with repeated measures on time. If baseline differences were computed, pretest values were used as covariates. Bonferroni-adjusted post hoc tests (t tests, Wilcoxon tests) were performed to detect statistically significant time differences in the groups. Kruskal-Wallis one-way ANOVA and Friedman tests were used for nonparametrical variables and to control results of parametrical tests if normal distribution (Kolmogorov-Smirnov test) and homogeneity of variances (Levene's test) could not be assumed. If differences occurred, nonparametrical data were outlined. Effect sizes (Cohen's d) were determined which are indicative of the effectiveness of a treatment and help to assess whether a statistically significant difference is of practical concern. Cohen's d values ≤0.49 indicate small, $0.50 \le d \le 0.79$ medium, and ≥0.80 large effects [36]. Changes within groups were calculated by the formula $d = mean_{pre} - mean_{post}/SD_{pre}$ [37] to allow comparison with former studies. Depending on the outcome parameter, d can turn out to be positive or negative. To improve readability, any performance improvement within a group was reported with a positive d and performance deteriorations with a negative d. Additionally, PS_{dep} scores (probability of superiority for dependent samples) were computed as an estimate of effect sizes in nonparametrical post hoc tests [38]. Analyses were performed with the Statistical Package for Social Sciences version 22. The significance level was set at $p < 0.05$.

Results

The baseline characteristics (table 1) indicate that the older adults of this study were physically active with an activity level of more than 14 h per week in each group. ANOVA revealed no significant baseline differences for age, anthropometric data, body composition, cognitive performance, physical activity, and handgrip strength between groups (all $p > 0.05$). None of the participants reported any training or test-related injuries. Both IGs showed high attendance rates during the training period [SUP: 91.7% (unsupervised sessions: 94.7%); UNSUP: 97.4%]. Means and SDs for all primary outcome variables are shown in tables 3 and 4. Tables 5 and 6 display the repeated-measure ANOVA results.

Static Steady-State Balance

The statistical analysis for the ROM revealed a significant group × time interaction effect for standing time (d = 1.04), but not for path velocity (d = 0.36). Post hoc analyses revealed significant increases in standing time from pre to post for SUP (d = 1.00) and from pre to follow-up (d = 0.80), but no significant changes in UNSUP (pre–post: d = 0.33; pre–follow-up: d = 0.09) and CON (pre–post: d = –0.37; pre–follow-up: d = –0.01). No significant changes were found from post to follow-up testing.

Dynamic Steady-State Balance (Single Task Walking)

For the parameters stride velocity and stride length, significant group × time interactions were found (stride velocity: d = 0.74; stride length: d = 0.60). Post hoc tests showed significant improvements from pre to post in stride velocity for SUP (d = 0.62), but not in stride length (d = 0.26). From pre to follow-up, significant increases were found for SUP in both parameters (stride velocity: d = 0.69; stride length: d = 0.33). No significant changes were detected for UNSUP from pre to post (stride velocity: d = 0.24; stride length: d = 0.06) and from pre to follow-up (stride velocity: d = 0.35; stride length: d = 0.13). Similarly, no significant changes were found for CON from pre to post (stride velocity: d = –0.17; stride length: d = –0.13) and from pre to follow-up (stride velocity: d = –0.01; stride length: d = –0.01). No significant changes occurred from post to follow-up testing.

For stride velocity and stride length CV, group × time interactions reached the level of significance for both parameters, stride velocity (d = 0.86) and stride length (d = 0.65). Post hoc tests revealed a significant decrease in the SUP (i.e., performance enhancement) for both parameters from pre to post (CV stride velocity: d = 0.73; CV stride length: d = 0.72), but not from pre to follow-up (CV stride velocity: d = 0.16; CV stride length: d = 0.38). Additionally, SUP significantly decreased performance in stride velocity CV from post to follow-up (d = –1.09). No significant performance changes were found for UNSUP from pre to post (CV stride velocity: d = –0.74; CV stride length: d = –0.33) and from pre to follow-up (CV stride velocity: d = –0.28; CV stride length: d = –0.24). Likewise, no performance changes were observed for CON from pre to post (CV stride velocity: d = –0.18; CV stride length: d = –0.19) and from pre to follow-up (CV stride velocity: d = 0.05; CV stride length: d = –0.03). No significant changes were found for UNSUP and CON from post to follow-up testing.

Dynamic Steady-State Balance (Dual Task Walking)

For the parameters stride velocity and stride length, the statistical analysis did not reveal significant group × time interactions (stride velocity: d = 0.43; stride length:

Table 3. Effects of the combined BST program on balance performance in healthy older adults

Measure	SUP (n = 21)				UNSUP (n = 19)				CON (n = 20)			
	pre	post	follow-up	d pre–post/ follow-up	pre	post	follow-up	d pre–post/ follow-up	pre	post	follow-up	d pre–post/ follow-up
Static steady-state balance												
ROM, s[a]	12.8 (8.7)	21.5 (8.6)	19.7 (9.3)	1.00[b]/0.80[b]	6.4 (5.7)	8.2 (5.7)	6.9 (6.2)	0.33/0.09	16.0 (9.4)	12.5 (9.3)	15.9 (9.3)	–0.37/–0.01
ROM, mm/s	102.7 (30.9)	100.5 (27.5)	91.4 (24.3)	0.07/0.37	137.8 (34.6)	137.9 (42.2)	130.1 (38.5)	–0.003/0.22	110.9 (34.5)	109.1 (34.1)	101.8 (32.9)	0.05/0.26
Dynamic steady-state balance												
Stride velocity, m/s[a]	1.38 (0.13)	1.46 (0.12)	1.47 (0.13)	0.62[b]/0.69[b]	1.37 (0.17)	1.41 (0.16)	1.43 (0.14)	0.24/0.35	1.37 (0.18)	1.34 (0.17)	1.37 (0.13)	–0.17/–0.01
Stride length, cm[a]	141.4 (14.9)	145.3 (12.4)	146.3 (13.5)	0.26/0.33[b]	142.7 (17.6)	143.7 (19.3)	144.9 (16.6)	0.06/0.13	140.6 (15.2)	138.7 (15.0)	140.5 (12.4)	–0.13/–0.01
CV stride velocity, %[a]	2.91 (1.32)	1.94 (0.70)	2.70 (1.10)	0.73[b]/0.16	2.58 (0.78)	3.16 (1.22)	2.80 (0.85)	–0.74/–0.28	2.27 (0.79)	2.41 (1.17)	2.23 (0.97)	–0.18/0.05
CV stride length, %[a]	2.26 (0.81)	1.68 (0.79)	1.95 (0.88)	0.72[b]/0.38	2.05 (0.82)	2.32 (1.16)	2.25 (0.71)	–0.33/–0.24	1.74 (0.58)	1.85 (0.95)	1.76 (0.80)	–0.19/–0.03
Stride velocity dual task, m/s	1.24 (0.16)	1.31 (0.17)	1.35 (0.17)	0.44/0.69[b]	1.22 (0.22)	1.20 (0.22)	1.26 (0.17)	–0.09/0.18	1.17 (0.23)	1.16 (0.18)	1.23 (0.14)	–0.04/0.26
Stride length dual task, cm	135.5 (15.7)	137.7 (13.4)	139.5 (14.6)	0.14/0.25	135.4 (21.0)	133.3 (19.6)	136.2 (17.8)	–0.10/0.04	130.5 (13.8)	130.3 (16.0)	133.2 (13.5)	–0.01/0.20
CV stride velocity dual task, %	3.83 (1.67)	3.31 (1.50)	3.56 (1.28)	0.31/0.16	3.99 (1.44)	4.36 (2.76)	3.91 (1.73)	–0.26/0.06	4.18 (2.24)	4.18 (1.89)	3.35 (1.61)	–0.001/0.37
CV stride length dual task, %	2.71 (0.92)	2.37 (0.91)	2.51 (1.10)	0.37/0.22	2.90 (0.75)	2.89 (1.5)	2.94 (1.19)	0.01/–0.05	2.27 (0.70)	2.52 (1.12)	2.14 (0.81)	–0.36/0.19
Proactive balance												
TUG, s[a]	9.91 (1.33)	8.78 (1.08)	8.74 (1.38)	0.85[b]/0.88[b]	9.80 (0.84)	9.43 (1.02)	9.27 (1.01)	0.44/0.63[b]	9.87 (1.35)	9.66 (1.19)	9.62 (0.98)	0.16/0.19
FRT, cm[a]	30.2 (3.2)	36.1 (3.8)	35.5 (3.7)	1.82[b]/1.65[b]	28.3 (4.7)	31.4 (4.8)	32.1 (4.3)	0.65[b]/0.79[b]	32.9 (3.6)	32.2 (3.9)	31.1 (3.8)	–0.18/–0.48
FRT, mm/s[a]	34.6 (4.8)	40.0 (7.6)	40.3 (5.5)	1.12[b]/1.18[b]	34.5 (6.0)	37.3 (9.5)	44.0 (13.6)	0.46/1.57[b]	36.1 (7.0)	39.3 (8.5)	39.6 (8.6)	0.46/0.50
Reactive balance												
PRT score [Md, IQR][c]	1.33 (0.67)	0.67 (1.0)	1.0 (0.67)	PS_{dep} = 0.98[d]/0.95[d]	1.67 (1.0)	1.0 (0.33)	1.0 (0.33)	PS_{dep} = 0.95[d]/0.84[d]	1.33 (0.67)	1.0 (0.67)	1.0 (0.33)	PS_{dep} = 0.58/0.66
Posturomed ML, cm	14.6 (12.1)	14.2 (9.5)	11.1 (6.0)	0.03/0.29	18.7 (13.2)	14.0 (11.7)	12.7 (7.7)	0.36[b]/0.45	15.5 (9.2)	9.8 (4.4)	12.6 (6.9)	0.62[b]/0.32
Posturomed AP, cm	4.9 (7.9)	5.4 (7.6)	4.2 (7.0)	–0.06/0.09	6.4 (5.2)	5.1 (6.6)	4.8 (4.8)	0.25/0.31	4.3 (3.6)	3.2 (2.8)	3.8 (2.9)	0.31/0.14

Values are presented as means (SD). d = Cohen's d. [a] Significant group × time interaction effect, $p < 0.05$ (ANOVA with repeated measures on time). [b] Significant difference pre vs. post or pre vs. follow-up, $p < 0.017$ (post hoc test: dependent t test). [c] Significant group × time interaction effect, $p < 0.001$ (Kruskal-Wallis test). [d] Significant difference pre vs. post or pre vs. follow-up, $p < 0.01$ (post hoc test: Wilcoxon test).

Table 4. Effects of the combined BST program on power performance in healthy older adults

Measure	SUP (n = 21)				UNSUP (n = 18)				CON (n = 20)			
	pre	post	follow-up	d pre–post/ follow-up	pre	post	follow-up	d pre–post/ follow-up	pre	post	follow-up	d pre–post/ follow-up
Lower extremity power												
CST, s[a]	12.86 (1.86)	9.87 (1.64)	9.98 (1.56)	1.61[b]/1.55[b]	13.39 (1.85)	11.83 (1.78)	11.52 (1.81)	0.84[b]/1.01[b]	11.53 (1.48)	11.67 (1.19)	11.45 (1.12)	–0.09/0.05
CST, W/kg[a]	8.32 (1.55)	10.06 (1.77)	9.86 (1.83)	1.12[b]/0.99[b]	8.45 (1.43)	9.47 (2.06)	9.30 (1.78)	0.71[b]/0.59[b]	9.24 (1.87)	9.23 (1.95)	9.23 (1.80)	–0.01/–0.01
SAT, s[a]	5.48 (0.54)	4.57 (0.38)	4.49 (0.38)	1.69[b]/1.83[b]	5.66 (0.82)	4.99 (0.54)	4.93 (0.68)	0.82[b]/0.89[b]	5.07 (0.36)	4.86 (0.33)	4.72 (0.43)	0.58[b]/0.97[b]
SAT, W/kg[a]	2.53 (0.27)	3.02 (0.25)	3.08 (0.26)	1.81[b]/2.04[b]	2.46 (0.32)	2.77 (0.28)	2.83 (0.35)	0.97[b]/1.16[b]	2.71 (0.20)	2.83 (0.22)	2.92 (0.26)	0.60[b]/1.05[b]
SDT, s[a]	5.10 (0.66)	3.94 (0.42)	3.94 (0.42)	1.76[b]/1.76[b]	5.16 (0.48)	4.32 (0.50)	4.16 (0.35)	1.75[b]/2.08[b]	4.59 (0.48)	4.39 (0.47)	4.32 (0.46)	0.42/0.56[b]
SDT, W/kg[a]	2.72 (0.28)	3.52 (0.39)	3.51 (0.36)	2.86[b]/2.82[b]	2.68 (0.23)	3.21 (0.37)	3.31 (0.30)	2.30[b]/2.74[b]	3.02 (0.33)	3.16 (0.38)	3.21 (0.38)	0.42/0.58[b]

Values are presented as means (SD). d = Cohen's d. [a] Significant group × time interaction effect, $p < 0.001$ (ANOVA with repeated measures on time). [b] Significant difference pre vs. post or pre vs. follow-up, $p < 0.017$ (post hoc test: dependent t test).

Table 5. Results for balance parameters (ANOVA with repeated measures on time)

Test	Main effect of time	Main effect of group	Group × time interaction effect
Static steady-state balance			
ROM (s)	<0.001 [1.04]	<0.001 [1.47]	<0.001 [1.04]
ROM (mm/s)	0.044 [0.49]	0.256 [0.45]	0.459 [0.36]
Dynamic steady-state balance			
Stride velocity (m/s)	0.001 [0.71]	0.204 [0.48]	0.006 [0.74]
Stride length (cm)	0.022 [0.53]	0.595 [0.27]	0.047 [0.60]
CV stride velocity (%)	0.830 [0.16]	0.098 [0.59]	0.001 [0.86]
CV stride length (%)	0.845 [0.11]	0.177 [0.51]	0.023 [0.65]
Stride velocity dual task (m/s)	0.002 [0.75]	0.095 [0.59]	0.281 [0.43]
Stride length dual task (cm)	0.035 [0.51]	0.445 [0.34]	0.533 [0.33]
CV stride velocity dual task (%)	0.263 [0.31]	0.509 [0.31]	0.369 [0.39]
CV stride length dual task (%)	0.01 [0.59]	0.368 [0.39]	0.442 [0.37]
Proactive balance			
TUG (s)	<0.001 [1.26]	0.229 [0.47]	0.002 [0.82]
FRT (cm)	<0.001 [0.93]	<0.001 [1.65]	<0.001 [1.31]
FRT (mm/s)	<0.001 [1.32]	0.993 [0.03]	0.012 [0.69]
Reactive balance			
PRT score	Friedman: <0.001 [$\chi^2 = 50.96$]	Kruskal-Wallis: 0.012 [$\chi^2 = 8.84$]	Kruskal-Wallis: pre–post: <0.001 [$\chi^2 = 24.41$] pre–follow-up: <0.001 [$\chi^2 = 17.38$]
Posturomed ML (cm)	<0.001 [0.81]	0.615 [0.26]	0.096 [0.53]
Posturomed AP (cm)	0.081 [0.43]	0.621 [0.26]	0.280 [0.42]

Data indicate p values [Cohen's d].

d = 0.33). Similarly, no significant group × time interactions were found for CV parameters (stride velocity: d = 0.39; stride length: d = 0.37).

Proactive Balance

Group × time interaction reached the level of significance for the TUG (d = 0.82). Post hoc tests revealed a significant reduction in time needed to complete the test for the SUP from pre to post (d = 0.85) and from pre to follow-up (d = 0.88). No significant improvements were found for UNSUP from pre to post (d = 0.44), but from pre to follow-up (d = 0.63). No statistically significant performance changes were found for CON (pre–post: d = 0.16; pre–follow-up: d = 0.19). Additionally, none of the experimental groups changed performance significantly from post to follow-up.

For the FRT, our analysis revealed a significant group × time interaction for reach distance (d = 1.31). SUP and UNSUP significantly increased their reach distance from pre to post (SUP: d = 1.82; UNSUP: d = 0.65) and from pre to follow-up (SUP: d = 1.65; UNSUP: d = 0.79). No significant changes were detected for CON (pre–post: d = –0.18; pre–follow-up: d = –0.48). From post to follow-up, no significant performance changes were found for all groups.

Reactive Balance

Given that PRT scores are ordinal, nonparametrical Kruskal-Wallis tests were applied. Therefore, delta values (post – pre, follow-up – pre, follow-up – post) were computed. Our statistical analyses revealed significant differences between groups from pre to post ($\chi^2 = 24.41$), as well as from pre to follow-up ($\chi^2 = 17.38$). No differences were found for post to follow-up changes ($\chi^2 = 3.58$). Wilcoxon tests yielded significant improvements for SUP and UNSUP from pre to post (SUP: PS_{dep} 0.98; UNSUP: PS_{dep} 0.95) and from pre to follow-up (SUP: PS_{dep} 0.95; UNSUP: PS_{dep} 0.84), whereas CON did not change significantly (pre–post: PS_{dep} 0.58; pre–follow-up: PS_{dep} 0.66). For the perturbation impulse on the Posturomed, no significant group × time interactions were found (ML: d = 0.53; AP: d = 0.42).

Table 6. Results for power parameters (ANOVA with repeated measures on time)

Test	Main effect of time	Main effect of group	Group × time interaction effect
Lower extremity power			
CST (s)	<0.001 [0.81]	<0.001 [1.96]	<0.001 [1.66]
CST (W/kg)	<0.001 [1.74]	0.828 [0.17]	<0.001 [1.40]
SAT (s)	<0.001 [1.05]	<0.001 [1.40]	<0.001 [0.99]
SAT (W/kg)	<0.001 [1.01]	<0.001 [1.40]	<0.001 [0.96]
SDT (s)	<0.001 [1.04]	<0.001 [1.54]	<0.001 [1.02]
SDT (W/kg)	0.001 [0.72]	<0.001 [1.72]	<0.001 [1.07]

Data indicate p values [Cohen's d].

Lower Extremity Muscle Power

For the CST, the analysis showed significant group × time interactions (rise time: d = 1.66; P_{max}: d = 1.40). Post hoc analyses revealed significant improvements for the SUP from pre to post (reduction in rise time: d = 1.61; enhancement in P_{max}: d = 1.12) and from pre to follow-up testing (rise time: d = 1.55; P_{max}: d = 0.99). Significant improvements were found also for UNSUP from pre to post (rise time: d = 0.84; P_{max}: d = 0.71) and from pre to follow-up (rise time: d = 1.01; P_{max}: d = 0.59). CON did not change significantly from pre to post (rise time: d = –0.09; P_{max}: d = –0.01) and pre to follow-up (rise time: d = 0.05; P_{max}: d = –0.01). From post to follow-up, no significant changes were observed for any of the experimental groups.

For the parameters total time and power in the SAT, significant group × time interactions were computed (total time: d = 0.99; power: d = 0.96). Post hoc analyses revealed significant improvements for SUP from pre to post (reduction of total time: d = 1.69; enhancement of power: d = 1.81) and from pre to follow-up (total time: d = 1.83; power: d = 2.04). Significant improvements also occurred for UNSUP from pre to post (total time: d = 0.82; power: d = 0.97) and from pre to follow-up (total time: d = 0.89; power: d = 1.16). Additionally, CON significantly enhanced performance from pre to post (total time: d = 0.58; power: d = 0.60) and pre to follow-up (total time: d = 0.97; power: d = 1.05). From post to follow-up, none of the groups changed the performance significantly.

Significant group × time interactions were observed for both parameters in the SDT (total time: d = 1.02; power: d = 1.07). In the post hoc tests, SUP significantly improved from pre to post (total time: d = 1.76; power: d = 2.86) and from pre to follow-up (total time: d = 1.76; power: d = 2.82). Similarly, UNSUP significantly improved from pre to post (d = 1.75; power: d = 2.30) and from pre to follow-up (total time: d = 2.08; power: d = 2.74). CON did not enhance performance significantly from pre to post (total time: d = 0.42; power: d = 0.42), but from pre to follow-up (total time: d = 0.56; power: d = 0.58). No significant changes were found from post to follow-up testing.

Body Composition

Group × time interaction turned out to be significant for lean tissue mass of the legs (d = 0.61). Post hoc tests showed no significant changes in SUP and CON. UNSUP significantly decreased lean tissue mass of the legs from pre to post (d = 0.08), but not from pre to follow-up (d = 0.04). No significant group × time interactions were detected for other body composition parameters (i.e. total body water, total skeletal muscle mass).

Questionnaires

No significant group × time interactions were found for FES-I and QoL (Kruskal-Wallis tests), as well as for DSST (ANOVA).

Discussion

This is the first study that evaluated the effects of a BST in healthy older adults on measures of balance, lower extremity muscle power, body composition, falls efficacy, cognitive function, and quality of life in a SUP versus an UNSUP group. The main findings can be summarized as follows: (1) 12 weeks of BST proved to be safe (i.e., no training or test-related injuries) and feasible with high attendance rates (92 and 97%) and low dropout rates (SUP: 5%, UNSUP: 14%, CON: 9%); (2) BST was effective and resulted in significant improvements in intrinsic fall risk factors [i.e., primary outcomes: static steady-state balance (ROM), dynamic steady-state balance (stride velocity, CVs), proactive balance (TUG, FRT), reactive balance (PRT) and lower extremity muscle power (CST, SAT, SDT)]; (3) BST failed to improve spatiotemporal gait parameters during dual task walking and the ability to compensate for ML perturbation impulses; (4) the SUP group showed larger effects in most investigated variables compared to UNSUP; (5) after 12 weeks of detraining, most balance and power variables were robust and remained above baseline values.

Effects of the BST Program on Balance and Muscle Power

Our hypothesis that BST results in significant improvements in balance and muscle power was confirmed. For all primary outcome parameters, significant group × time interactions in favor of the training groups were found. Significant performance enhancements from pre to post (post hoc) in the training groups showed effects of $0.62 \leq d \leq 1.82$ (6–68%) for balance outcomes and $0.71 \leq d \leq 2.86$ (12–29%) for lower extremity power outcomes. These balance and power improvements are similar to those reported in the literature following a BST. For example, Park et al. [39] investigated the impact of a 48-week (three times per week) BST with 65- to 70-year-olds on measures of static/dynamic steady-state balance. Following training, the IG showed significant improvements compared to a CON group with regard to CoF displacements (post hoc test: $d = 2.03$), one-leg standing time (post hoc test: $d = 1.06$), and 10-meter rapid walking time (post hoc test: $d = 1.35$). No differences were observed for maximal step length, which is in line with our findings for habitual stride length. In another study, Suzuki et al. [40] performed a 6-month exercise intervention (supervised once every 2 weeks) with unsupervised exercises three times weekly in elderly adults (>73 years). After training, the IG significantly improved performance for steps in tandem gait ($d = 0.54$) and the FRT ($d = 1.01$), whereas the CON group did not improve significantly. In line with our approach, Zhuang et al. [41] evaluated the effects of a 12-week supervised BST (three times per week) in older adults (60–80 years) compared to a CON group on measures of balance and leg strength. Significant improvements in favor of the IG were found for spatiotemporal gait parameters (post hoc test: $d = 0.59–1.06$), the TUG (post hoc test: $d = 0.73$), isometric strength of leg muscles (i.e., knee flexor/extensor, ankle dorsiflexor/plantarflexor; post hoc test: $d = 0.80–1.12$), and the 30-second CST (post hoc test: $d = 2.05$). Additionally, after a 6-month multimodal exercise program (three times weekly) including strength and balance exercises for older adults (67 ± 6 years), Gianoudis et al. [42] found significant gains compared to a CON group in the 30-second Sit to Stand Test (gain for IG: 11%, gain in the CST in our study: 19%) and the Timed Stair Climb (IG: 5%; our study: 10%). The underlying neuromuscular mechanisms responsible for performance enhancements cannot clearly be elucidated with our experimental approach. Since the lean tissue mass of the legs and total skeletal muscle mass did not significantly increase in SUP and UNSUP, neural adaptations (i.e. increased activation of prime movers, improved coactivation of synergists, reduced coactivation of antagonists [43]) appear to be a likely agent for the observed significant improvements in lower extremity strength/power.

Our program did not influence gait performance under dual task conditions. Training programs that specifically aim at improving balance under dual task conditions seem to have effects [44]. Thus, an explanation for absent effects could be an insufficient amount of exercises under dual task conditions. Of note, this study examined intrinsic risk factors for falls and not number of falls or fall rate. Since CST, SAT, and SDT were improved above limits which mark an increased fall risk in both SUP and UNSUP (limits: CST ≥12 s; SAT/SDT ≥5 s) and SUP additionally improved above the limit in ROM (10–19 s) [21], our program could still be a helpful tool for fall prevention.

Effects of Supervision

The hypothesis that the SUP group shows larger enhancements as compared to the UNSUP group was correct for most of the variables. This is partly in accordance with previous studies investigating a BST in older adults [11–13]. For example, Donat and Oezcan [11] investigated the effects of an 8-week (three times per week) combined balance/strength/flexibility training in an SUP versus an UNSUP group on balance, trunk flexibility, position sense of the knee joint, and isometric leg extensor strength in elderly (>65 years). Training resulted in significant improvements in one-leg standing time, tandem standing time, Berg Balance Scale scores, trunk flexibility (cm), and TUG in both groups, whereas leg strength and knee position sense (degree) only improved in the SUP group (all $p < 0.05$). However, no inactive CON group was involved and no interaction effects were computed, which is why findings have to be interpreted with caution. In the present study, the UNSUP group mainly improved in the proxies of leg power. This can be most likely explained by the high training intensity, which showed to evoke large improvements in previous studies [45]. In another study, Cyarto et al. [12] reported that a 20-week (twice weekly) BST in elderly (65–96 years) significantly improved static balance (one-leg standing time) in an SUP group compared to an UNSUP group (interaction effect: p = 0.05). Performance in other balance measures (e.g. TUG) did not change significantly between groups, although tendencies were observed in favor of the SUP group. A limitation of the study of Cyarto and colleagues is that the UNSUP group received nine home visits by a coach, which could have biased their findings. Finally, Wu et al. [13] reported that 15 weeks of supervised tai chi versus unsupervised tai chi exercises did not cause significant interaction effects for one-leg standing time and TUG, but for body sway in quiet stance with eyes open in favor of the SUP group (post hoc test SUP group: d = 0.48).

In summary, previous studies [11–13] found tendencies indicating that supervised training is more effective as compared to unsupervised training, but not to the same extent as in our study. An explanation for larger effects of SUP compared to UNSUP in our study could be a higher quality in the execution of exercises due to supervision. In fact, evaluation of the exercise diaries revealed similar mean stages of progression between groups. This implies that a higher rate of exertion and consequently a larger adaptation was achieved in the SUP group. Especially the selection of an appropriate line of progression during balance training may have influenced the outcomes of the UNSUP group. In our study, UNSUP mainly improved in power variables. In strength/power training exercises, perceived intensity is easier to control since the Borg scale was developed to detect perceived exertion rather than a perceived difficulty level. UNSUP participants may have exercised below an effective threshold to elucidate adaptations regarding balance. The question remains as to why UNSUP improved performance in the FRT and the PRT. Joshua et al. [46] demonstrated that resistance training is more effective compared to balance training in improving performance in the FRT. Thus, the observed improvements may partially be explained by gains in strength/power. It is possible that a higher dose needs to be applied in order to improve all dimensions of balance-related fall risk factors in unsupervised programs, where a high perceived intensity cannot be ensured due to its uncontrolled character.

Detraining Effects

As hypothesized, training-related improvements remained above baseline values for most of the variables. Regarding balance performance, only few studies investigated detraining effects in older adults after a BST. Seco et al. [15] reported that after a 9-month BST and a 3-month detraining period, participants in the IG (65–74 years) were able to maintain balance (i.e., postural sway) from pre to follow-up. Participants older than 75 years were not able to maintain the improved level. Consequently, age may have an impact on detraining effects. Several previous studies examined detraining effects on strength/power variables in elderly persons [14–16]. For example, Carvalho et al. [16] investigated detraining effects after an 8-month multicomponent training (balance/strength/endurance exercises) in older women. After 12 weeks of detraining, performance improvements in the IG remained significantly above baseline value for 30-second CST, whereas the CON group did not significantly improve. In summary, results regarding detraining effects in older adults are heterogeneous.

This is the first RCT that proved the effectiveness of a BST in healthy older adults on balance and lower extremity power performance in a SUP versus an UNSUP group and an inactive CON group. Based on the high adherence rates, low dropout rates and no training-related injuries, our training program seems safe and may therefore be implemented into clinical practice to mitigate important intrinsic fall risk factors in healthy older adults. Given the larger effects of the SUP as compared to the UNSUP group in most of the tested variables, we recommend training with at least three sessions per week with two being supervised by professional staff. Although performance enhancements showed to be relatively stable over a 12-week period, it is suggested that BST should be conducted permanently to avoid performance decrements after training.

This study has a few limitations. First, the assessor was not blinded for group allocation. However, to minimize bias, the assessor strictly adhered to a predefined test protocol and gave the same instructions to every participant without any feedback on performance. Second, this study cannot illustrate possible adaptations in the central nervous and neuromuscular systems due to methodological constraints (e.g., no electrophysiological tests or imaging techniques). Third, our study findings cannot be generalized to less active or even sedentary cohorts because the examined population was classified as physically active. Future studies should evaluate the program in high-risk populations (e.g., institutionalized persons).

Acknowledgements

This study was funded by the Swiss Council for Accident Prevention (bfu, Bern, Switzerland). We thank Frank I. Michel for enabling this work and THERABAND™ for providing us with training material.

Disclosure Statement

All authors report no conflicts of interest in this work.

References

1 Granacher U, Zahner L, Gollhofer A: Strength, power, and postural control in seniors: considerations for functional adaptations and for fall prevention. Eur J Sport Sci 2008;8:325–340.

2 Schott N, Kurz A: Falls in older adults: risk factors assessment prevention. A review. Z Sportpsychol 2008;15:45–62.

3 Rubenstein LZ: Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing 2006;35(suppl 2):ii37–ii41.

4 Rapp K, Freiberger E, Todd C, Klenk J, Becker C, Denkinger M, Scheidt-Nave C, Fuchs J: Fall incidence in Germany: results of two population-based studies, and comparison of retrospective and prospective falls data collection methods. BMC Geriatr 2014;14:105.

5 Tinetti ME: Clinical practice. Preventing falls in elderly persons. N Engl J Med 2003;348:42–49.

6 Liu C, Latham NK: Progressive resistance strength training for improving physical function in older adults. Cochrane Database Syst Rev 2009;CD002759.

7 Gillespie LD, Robertson MC, Gillespie WJ, Sherrington C, Gates S, Clemson LM, Lamb SE: Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev 2012;CD007146.

8 Cohen-Mansfield J, Marx MS, Guralnik JM: Motivators and barriers to exercise in an older community-dwelling population. J Aging Phys Act 2003;11:242–253.

9 Franco MR, Howard K, Sherrington C, Ferreira PH, Rose J, Gomes JL, Ferreira ML: Eliciting older people's preferences for exercise programs: a best-worst scaling choice experiment. J Physiother 2015;61:34–41.

10 Tuunainen E, Rasku J, Jaentti P, Moisio-Vilenius P, Maekinen E, Toppila E, Pyykkoe I: Postural stability and quality of life after guided and self-training among older adults residing in an institutional setting. Clin Interv Aging 2013;8:1237–1246.

11 Donat H, Oezcan A: Comparison of the effectiveness of two programmes on older adults at risk of falling: unsupervised home exercise and supervised group exercise. Clin Rehabil 2007;21:273–283.

12 Cyarto EV, Brown WJ, Marshall AL, Trost SG: Comparative effects of home- and group-based exercise on balance confidence and balance ability in older adults: cluster randomized trial. Gerontology 2008;54:272–280.

13 Wu G, Keyes L, Callas P, Ren X, Bookchin B: Comparison of telecommunication, community, and home-based Tai Chi exercise programs on compliance and effectiveness in elders at risk for falls. Arch Phys Med Rehabil 2010;91:849–856.

14 Helbostad JL, Sletvold O, Moe-Nilssen R: Effects of home exercises and group training on functional abilities in home-dwelling older persons with mobility and balance problems. A randomized study. Aging Clin Exp Res 2004;16:113–121.

15 Seco J, Abecia LC, Echevarría E, Barbero I, Torres-Unda J, Rodriguez V, Calvo JI: A long-term physical activity training program increases strength and flexibility, and improves balance in older adults. Rehabil Nurs 2013;38:37–47.

16 Carvalho MJ, Marques E, Mota J: Training and detraining effects on functional fitness after a multicomponent training in older women. Gerontology 2009;55:41–48.

17 Gschwind YJ, Kressig RW, Lacroix A, Muehlbauer T, Pfenninger B, Granacher U: A best practice fall prevention exercise program to improve balance, strength/power, and psychosocial health in older adults: study protocol for a randomized controlled trial. BMC Geriatr 2013;13:105.

18 Folstein MF, Folstein SE, McHugh PR: 'Mini-mental state'. A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–198.

19 Thalmann B, Spiegel R, Staehelin H, Brubacher D, Ermini-Fuenfschilling D, Blaesi S, Monsch AU: Dementia screening in general practice: optimised scoring for the Clock Drawing Test. Brain Aging 2002;2:36–43.

20 Borg GA: Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982;14:377–381.

21 Granacher U, Muehlbauer T, Gschwind YJ, Pfenninger B, Kressig RW: Assessment and training of strength and balance for fall prevention in the elderly: recommendations of an interdisciplinary expert panel. Z Gerontol Geriatr 2014;47:513–526.

22 Granacher U, Wick C, Rueck N, Esposito C, Roth R, Zahner L: Promoting balance and strength in the middle-aged workforce. Int J Sports Med 2011;32:35–44.

23 Agrawal Y, Carey JP, Hoffman HJ, Sklare DA, Schubert MC: The modified Romberg Balance Test: normative data in US adults. Otol Neurotol 2011;32:1309–1311.

24 Lee MM, Song CH, Lee KJ, Jung SW, Shin DC, Shin SH: Concurrent validity and test-retest reliability of the OPTOGait photoelectric cell system for the assessment of spatio-temporal parameters of the gait of young adults. J Phys Ther Sci 2014;26:81–85.

25 Lienhard K, Schneider D, Maffiuletti NA: Validity of the Optogait photoelectric system for the assessment of spatiotemporal gait parameters. Med Eng Phys 2013;35:500–504.

26 Duncan PW, Weiner DK, Chandler J, Studenski S: Functional reach: a new clinical measure of balance. J Gerontol 1990;45:M192–M197.

27 Podsiadlo D, Richardson S: The timed 'Up & Go': a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991;39:142–148.

28 Newton RA: Validity of the multi-directional reach test: a practical measure for limits of stability in older adults. J Gerontol A Biol Sci Med Sci 2001;56:M248–M252.

29 Muller O, Gunther M, Krauss I, Horstmann T: Physical characterization of the therapeutic device Posturomed as a measuring device – presentation of a procedure to characterize balancing ability. Biomed Tech (Berl) 2004;49:56–60.

30 Jacobs JV, Horak FB, van Tran K, Nutt JG: An alternative clinical postural stability test for patients with Parkinson's disease. J Neurol 2006;253:1404–1413.

31 Csuka M, McCarty DJ: Simple method for measurement of lower extremity muscle strength. Am J Med 1985;78:77–81.

32 Tiedemann A, Shimada H, Sherrington C, Murray S, Lord S: The comparative ability of eight functional mobility tests for predicting falls in community-dwelling older people. Age Ageing 2008;37:430–435.

33 Bean JF, Kiely DK, LaRose S, Alian J, Frontera WR: Is stair climb power a clinically relevant measure of leg power impairments in at-risk older adults? Arch Phys Med Rehabil 2007;88:604–609.

34 Anderson LJ, Erceg DN, Schroeder ET: Utility of multifrequency bioelectrical impedance compared with dual-energy X-ray absorptiometry for assessment of total and regional body composition varies between men and women. Nutr Res 2012;32:479–485.

35 Faul F, Erdfelder E, Lang A, Buchner A: G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175–191.

36 Cohen J: Statistical Power Analysis for the Behavioral Sciences. London, Routledge Academic, 1988.
37 Leonhart R: Estimating effect sizes in clinical trials. Rehabilitation (Stuttg) 2004;43:241–246.
38 Grissom RJ, Kim JJ: Effect Sizes for Research: Univariate and Multivariate Applications. London, Routledge, 2012.
39 Park H, Kim KJ, Komatsu T, Park SK, Mutoh Y: Effect of combined exercise training on bone, body balance, and gait ability: a randomized controlled study in community-dwelling elderly women. J Bone Miner Metab 2008;26:254–259.
40 Suzuki T, Kim H, Yoshida H, Ishizaki T: Randomized controlled trial of exercise intervention for the prevention of falls in community-dwelling elderly Japanese women. J Bone Miner Metab 2004;22:602–611.
41 Zhuang J, Huang L, Wu Y, Zhang Y: The effectiveness of a combined exercise intervention on physical fitness factors related to falls in community-dwelling older adults. Clin Interv Aging 2014;9:131–140.
42 Gianoudis J, Bailey CA, Ebeling PR, Nowson CA, Sanders KM, Hill K, Daly RM: Effects of a targeted multimodal exercise program incorporating high-speed power training on falls and fracture risk factors in older adults: a community-based randomized controlled trial. J Bone Miner Res 2014;29:182–191.
43 Haekkinen K: Ageing and neuromuscular adaptation to strength training; in Komi PV (ed): Strength and Power in Sport, ed 2. Oxford, Blackwell Science, 2003, pp 409–425.
44 Silsupadol P, Shumway-Cook A, Lugade V, van Donkelaar P, Chou L, Mayr U, Woollacott MH: Effects of single-task versus dual-task training on balance performance in older adults: a double-blind, randomized controlled trial. Arch Phys Med Rehabil 2009;90:381–387.
45 Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA, Evans WJ: High-intensity strength training in nonagenarians. Effects on skeletal muscle. JAMA 1990;263:3029–3034.
46 Joshua AM, D’Souza V, Unnikrishnan B, Mithra P, Kamath A, Acharya V, Venugopal A: Effectiveness of progressive resistance strength training versus traditional balance exercise in improving balance among the elderly – a randomised controlled trial. J Clin Diagn Res 2014;8:98–102.