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Improved Balance Confidence and Stability for Elderly After 6 Weeks of a Multimodal Self-Administered Balance-Enhancing Exercise Program: A Randomized Single Arm Crossover Study

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Abstract

Objective: To develop and assess the efficacy of a multimodal balance-enhancing exercise program (BEEP) designed to be regularly self-administered by community-dwelling elderly. The program aims to promote sensory reweighting, facilitate motor control, improve gaze stabilization, and stimulate continuous improvement by being constantly challenging. **Method:** Forty participants aged 60 to 80 years performed 6 weeks of BEEP training, on average for 16 min four times weekly, in a randomized one-arm crossover design. **Results:** One-leg standing time improved 32% with eyes open (EO), 206% with eyes closed (EC) on solid surface, and 54% EO on compliant surface ($p < .001$). Posturography confirmed balance improvements when perturbed on solid and compliant surfaces with EO and EC ($p \leq .033$). Walking, step stool, and Timed Up and Go speeds increased ($p \leq .001$), as did scores in Berg Balance and balance confidence scales ($p \leq .018$). **Discussion:** Multimodal balance exercises offer an efficient, cost-effective way to improve balance control and confidence in elderly.

Keywords

postural balance, exercise training, elderly, posturography, one-leg standing time

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Falls and resulting injuries in the aging population are common. Falls and injuries are also among the top geriatric health issues because falls are often devastating and costly (Rubenstein, 2006). About one third of elderly more than 65 years old experience at least one fall accident per year (Gillespie et al., 2012). The rate of falls and severity of the resulting complications increases dramatically with age (Rubenstein, 2006). The majority of falls occur due to multiple interacting factors. For community-dwelling elderly, the two most important intrinsic predictors for a fall accident are taking medications and having a poor balance (Gillespie et al., 2012).

Several factors contribute to an adequate balance confidence and control, and consequently promote mobility and prevent falls. Essential factors are reliable sensory information from the visual, vestibular, and proprioceptive and mechanoreceptive systems; a well-functioning central nervous system (CNS) with feedback and feed forward loops able to withstand external and internal volitions; as well as adequate musculoskeletal strength and sufficient range of motion in the joints for adequate movement (Horak, 2006). Factors that can impair balance control are, for example, pain, cognitive impairment, and fear of falling (Howe, Rochester, Neil, Skelton, & Ballinger, 2011). Moreover, age-related degeneration and a variety of diseases, more common with older age, can afflict all functions and

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systems involved in balance control (Li et al., 2015; Rosenhall, 1973).

Falls prevention exercise is currently considered the best approach for primary and secondary fall prevention at a population level, and well-designed exercise programs have been evidenced to prevent falls and injuries for community-dwelling elderly (El-Khoury, Cassou, Charles, & Dargent-Molina, 2013; Gillespie et al., 2012; Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011). The reported fall rate reduction for elderly who have participated in the Otago and the Otago-based fitness and mobility exercise programs has been 35% to 54% (Campbell et al., 1997; Robertson, Campbell, Gardner, & Devlin, 2002; Skelton, Dinan, Campbell, & Rutherford, 2005). These and other fall-preventive interventions are delivered by health care professionals either individually at home or in group sessions or with a mixed approach a few times a week, targeting strength and balance exercises, sometimes complemented by endurance exercise such as walking (Campbell et al., 1997; Clemson et al., 2012; Gillespie et al., 2012; Hektoen, Aas, & Luras, 2009; Robertson et al., 2002; Robitaille et al., 2012; Skelton et al., 2005). However, these earlier training programs do not specifically focus on exercises stimulating sensory reweighting, nor do they emphasize exercises improving gaze stabilization by challenging vestibulo-ocular and vestibulocervical interactions. These functions are crucial for a well-functioning postural control system, especially considering that degeneration and disease often afflict these systems with aging. Furthermore, performing balance exercises on an even more frequent basis than recommended by the Otago-based programs could instigate a more effective learning and consolidation process (Tjernstrom, Bagher, Fransson, & Magnusson, 2010).

The purpose of this study was to enhance and simplify existing fall intervention programs by including exercises that promote the reweighting capabilities in the postural control system, as well as challenge the vestibulo-ocular and vestibulocervical interactions and improve gaze stabilization. The intention was to develop a comprehensive balance-enhancing exercise program (BEEP) that could be customized to individual balance skills, and be performed safely and efficiently by relatively healthy elderly. An aim was also to make the BEEP so condensed in time that it would not be considered too bothersome and hence be accepted as habitually performed as a daily routine in the home environment without professional supervision. Another objective was to determine the efficiency of multimodal training to enhance static and dynamic balance control in community-dwelling people more than 60 years old.

Method

Participants

Forty community-dwelling elderly participants were recruited for the study. A minimum age of 60 years, as well as independent living, was required to participate. Exclusion criteria were severe medical or cognitive problems, hemiplegia, degenerative muscle disease, advanced Parkinson's disease, and the use of walking aids. Written informed consent was obtained from all participants before the tests, and they were informed that they could stop the tests and participation in the study for any reason and without explanation. The study was approved by the local ethics committee and performed in accordance with the revised version of the Helsinki declaration.

After interviewing participants regarding their medical and trauma history, they underwent a thorough medical examination with special attention to the head and neck region and the cranial nerves. Video equipment was used for the head impulse test (vHIT), smooth pursuit and saccades, as well as spontaneous, gaze-evoked, headshake, and positional nystagmus. Somatosensation in the lower extremities was assessed with a semi-quantitative test using a tuning fork (256 Hz) and a Biothesiometer (Goldberg & Lindblom, 1979; Kristinsdottir, Fransson, & Magnusson, 2001). Plantar tactile sensation of the feet was evaluated with the Semmes-Weinstein Monofilament Test (Dros, Wewerinke, Bindels, & van Weert, 2009).

Study Design and Protocol

A cross-professional team consisting of two otoneurologists, a physiotherapist with expertise in balance rehabilitation, two physical trainers, and one engineer developed the BEEP. The exercise program was designed to be self-administered in the home environment with the help of written instructions, and after initial instruction and practice with a test leader. In addition, the program was designed to include essential multimodal components and to adhere to evidence-based training principles as outlined by the American College of Sports Medicine (Thompson, Gordon, Pescatello, & American College of Sports Medicine, 2009). Only exercises that were simple to implement and safe to perform in a home environment were included. To minimize the risk of orthostatic hypotension and syncope, the program started with a 3-min warm up (Figure 1). This also allowed the participants to mentally focus on the training. The program included exercises facilitating the sensory reweighting processes because aging causes a multitude of degenerative processes affecting the ability of all the sensory systems to detect position and movements. Hence, the BEEP was comprised of exercises on solid (floor) and compliant surfaces (double-folded exercises mats) while having eyes open (EO) or eyes closed (EC).

Stability needs to be maintained during challenges in controlling a multisegmented structure, and where the control of each joint requires resources in terms of muscle force of sufficient magnitude and flexibility. Furthermore, muscle weakness of the lower limbs is associated with reduced walking speed, and increased

Warm up: Dance to your favorite song or jog in place for 3 minutes.

Exercises on solid surface

1a. Knee squats. Stand with feet shoulder width apart, eyes open, hands at your hips, and bend your knees and imagine that you are sitting down on a stool or chair. Then straighten your knees again. Repeat 10 times in an even pace. Go as deep as you manage - but no further than until your thighs are parallel to the floor. Keep in mind to put your weight on your heels (keep the contact between your heels and the floor) and to have your knees above or behind your toes. You should not feel any pain in your lower back from this exercise.

1b. Repeat the exercises with eyes closed.

2a. Heel /calf raising. Stand with your arms crossed over your chest, eyes open, and raise your heels and come up on your toes. Keep standing on your toes for as long as you can (or up to about 10 seconds) and then lower your heels again. If needed hold on for support with your hands on a door frame, chest, or table. Repeat three times with five seconds apart.

2b. Repeat the exercises with eyes closed. Please try to keep eyes closed under the five second break as well.

3a. One leg standing. Try to balance on one leg, eyes open, for as long as you can or up to 1 minute Have your hands at the hips and the other foot about 15 cm over the floor. Keep your eyes on a point about 1.5 meters in front of you. Then do the same thing on the other leg.

3b. When you feel that you are getting proficient with one leg standing with eyes open, try to perform the same exercises with eyes closed.

Exercises on compliant surface (e.g. double folded exercise mat)

4a. Knee squats on compliant surface. Repeat the same exercises as in 1a.

4b. Repeat the exercises with eyes closed.

5a. One leg standing compliant surface. Repeat the same exercises as in 3a.

5b. Repeat the exercises with eyes closed.

Rotations on solid surface.

6a. Head rotations. Stand with feet shoulder width apart, hands clasped behind your back, and look straight forward. Turn your head and look as far as you can over your right shoulder. Keep this position for a few seconds. Then turn your head quickly and smoothly to your left. Look over your left shoulder and keep this position for a few seconds. Then, quickly turn your head again to your right. Look as far as you can over your right shoulder and keep this position for a few seconds. Remember to keep your trunk as still as you can. Repeat the head rotations (one rotation = from right to left or left to right) for a total of 10 times.

6b. Repeat the exercises with eyes closed.

7. Rotational jumps. Stand straight, feet shoulder width apart, hands at your hips, and look straight ahead. Try to jump a quarter turn to the right or left (90 degrees) with your body, head and vision aligned in the direction of your feet. Find your balance. Jump a quarter turn back to the original position and find your balance. Jump a quarter turn in the opposite direction and find your balance. Jump a quarter turn back to the original position and find your balance. Repeat this sequence 5 times or until you get dizzy or tired.

Figure 1. The BEEP.
BEEP = balance-enhancing exercise program.

risk of disability and falls in older adults (Moreland, Richardson, Goldsmith, & Clase, 2004). Therefore, exercises facilitating strength, motor control, and coordination were also incorporated in the program. Exercises challenging gaze stabilization were included as well because the vestibular system senses head movement and spatial orientation, and produces reflexes to stabilize gaze and maintain posture.

Moreover, the BEEP could be individualized with progressive difficulty by the participants as their

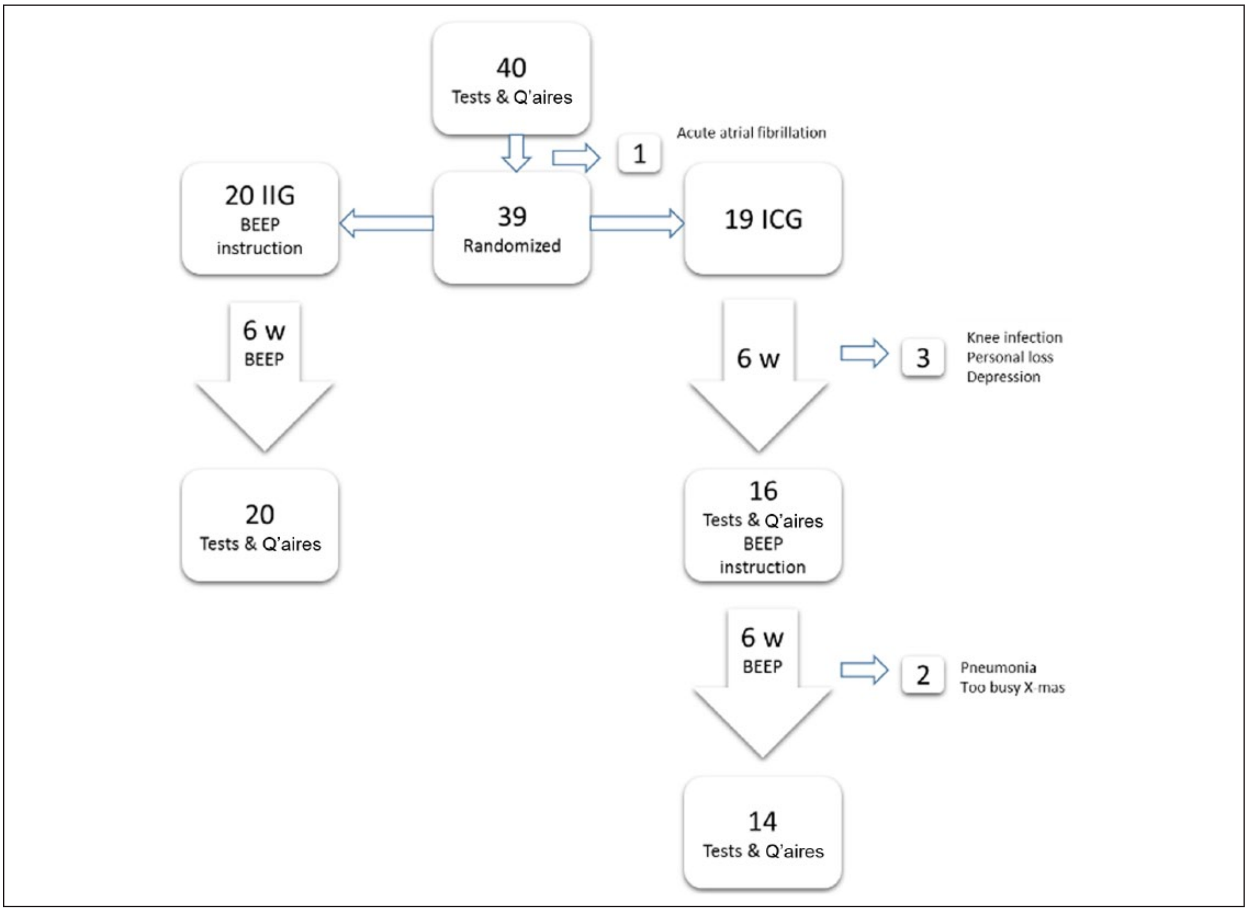

Figure 2. Flowchart of the study.
Note. BEEP = balance-enhancing exercise program; ICG = initial control group; IIG = initial intervention group; w = weeks.

balanced proficiency improved. The participants were recommended to perform the exercises daily if possible, preferably while standing in a corner, close to a wall or in a door opening, and, when needed, having a chair in front of them to provide support if necessary.

The study was conducted as a prospective randomized single-blind controlled trial with an arm crossover. Figure 2 depicts the study design and participant's flow throughout the study. The study involved data collection at three different points in time for the initial control group (ICG) and twice for the initial intervention group (IIG). Both groups were evaluated with a baseline (preintervention) and after 6 weeks. The ICG was reevaluated after another 6 weeks after having performed the BEEP. A phone checkup was conducted by a test leader after 3 weeks of training. All tests, except the posturography, were performed by a test leader who did not know which group the participants belonged to (ICG or IIG), except for the ICG when participants returned for their final evaluation.

To evaluate the efficacy of the BEEP, a battery of functional balance and psychometric outcome measures and questionnaires were chosen that relate to everyday activities.

One-leg standing time (OLST). Participants stood barefoot on solid surface (floor) or compliant surface (double-folded 2-cm-thick exercise mat) with EO or with EC up to 60 s until they put their foot down or repositioned the standing foot. The best of three attempts was used (Bohannon, Larkin, Cook, Gear, & Singer, 1984).

Tandem stance with EC (Sharpened Romberg). One foot was placed in front of the other, heel touching toe, and with arms crossed over the chest. Time was measured between closing the eyes and until losing balance and repositioning one of the feet. The best of three attempts up to 60 s was used. A result less than 10 s was considered pathological (Franchignoni, Tesio, Martino, & Ricupero, 1998).

Timed Up and Go (TUG) Test. Participants were timed from standing up from sitting in an arm chair, walking 3 m, turning around, walking back, and to sitting down again (Shumway-Cook, Brauer, & Woollacott, 2000).

Walking speed. Participants were instructed to walk as fast as possible for 30 m (Bohannon, 1997). Two attempts were allowed, and the fastest attempt was used.

Berg Balance Scale (BBS). The BBS is a 56-point scale of daily living balance-related activities deemed safe for elderly people to perform (Berg, Wood-Dauphinee, Williams, & Maki, 1992). Participants are scored 0 to 4 when performing 14 different tasks ranging from standing up from a chair to one-leg standing with EO. Higher scores indicate better balance ability.

Modified step stool test. Time was measured for participants stepping onto and off a 21-cm-high step stool 8 times as fast as they could, alternating putting the right or left foot up first with EO. This is a more difficult version of the clinical step or stool test included in BBS (Berg et al., 1992). Lower (faster) values indicate better balance ability.

Posturography with and without perturbations. Postural stability was assessed by means of anteroposterior torque variance. The participants were instructed to stand erect with bare feet at an angle of 30° open to the front feet, heels about 5 cm apart, and arms crossed over the chest. Torque variance was recorded during four different conditions, focusing on a visual target positioned at eye level on the wall at a distance of 1.5 m in front of them with EO on a solid and compliant surface, and standing with EC on a solid and compliant surface (Patel, Fransson, Johansson, & Magnusson, 2011). Perturbations were induced by proprioceptive stimuli applied as simultaneous vibrations (of 1.0 mm amplitude with 85 Hz frequency) to the right and left calf muscles. The posturography assessment sequence included recording quiet stance stability for 30 s, immediately followed by recording stability when exposed to balance perturbations for 200 s (Fransson, Kristinsdottir, Hafstrom, Magnusson, & Johansson, 2004). Force platforms allow the measurement of the movement of the center of pressure, and lower torque values indicate better balance ability.

Questionnaires. The impact of dizziness and unsteadiness on quality of life was measured with the 25-item Dizziness Handicap Inventory (DHI; Jacobson & Newman, 1990). Self-perceived balance ability and dizziness was measured with the Activities-Specific Balance Confidence (ABC) Scale (Powell & Myers, 1995). The Human Activity Profile (HAP) questionnaire with a maximum score of 94 was used to measure physical activity levels and energy expenditure, that is, rate the physical fitness (Davidson & de Morton, 2007). The mean physical activity pattern was also evaluated according to Mattiasson-Nilo questionnaire where a 6-point scale indicates the physical activity pattern ranging from hardly any physical activity at all (1 point) to hard or very hard exercise several times a week (6 points; Mattiasson-Nilo et al., 1990).

Subjective Evaluation

All participants were asked to report in a diary about the quality and quantity of the training, their experience of performing each exercise, if they had performed any other physical training, if they had encountered any adverse effects from the training, and if they had had any falls or near-fall incidents. The participants were contacted by phone at least once during the training period and were asked about the progress of the balance training, if they had noticed any improvements, if they need any help adjusting the difficulty of the exercises according to their individual needs, and if there had been any side effects or mishaps. After the training period, the participants were asked to fill in a written evaluation form of the program, and they were also interviewed about their experience of performing the training and if they had had any falls or near-fall incidents.

Statistical Evaluation

Nonparametric statistical tests were used because the data were not normally distributed as tested with the Shapiro–Wilk and Kolmogorov–Smirnov tests. The Wilcoxon Signed Rank exact two-tailed test was used for analyzing within-participant changes between repeated assessments, and the Mann–Whitney U test was used for between-group comparisons. The Fisher's Exact Test was used for categorical data. A p value < .05 was considered statistically significant. Bonferroni correction lowered the significance level to .025 in the test–retest comparisons. The SPSS® 21 program was used for the statistical analyses.

Results

As seen in Figure 2, 34 participants were available for the final analyses because six participants in the ICG did not complete the study (the reasons are outlined in Figure 2: atrial fibrillation, intra-articular knee infection, personal loss, clinical depression, pneumonia, and busy holiday schedule). None dropped out due to the exercises performed. The mean age of the 34 participants completing the study was 69 (range = 60-78) years, mean body mass index (BMI) was 24.5 (range = 19.1-37.9), 53% were women, and 47% were still professionally active. The participants considered themselves as relatively healthy though 50% used hearing aids, 32% had arthroses or arthritis, and 18% had ongoing or earlier treatment for a malignancy. Of the participants, 32% were medicated for hypertension, 29% for glaucoma or cataract, 12% for osteoporosis, 9% for orthostatic hypotension, and 6% for diabetes. Twenty-six percent used opioids or sedatives regularly. Nine participants reported some type of dizziness and unsteadiness, five mild and four moderate, according to the DHI questionnaire. Upon being asked, seven additional participants described that they had "balance issues." Thus, in total, 47% of the participants reported some type of balance problems. Three women recounted minor fall accidents, like tripping in the woods when jogging or when digging in the yard, without any major injuries the previous year. When investigating the vestibular system, one participant was found to have a bilateral abnormal vHIT response. Six participants had distinct, and two had a slight, headshake nystagmus, suggesting vestibular asymmetries.

Although asked to perform training daily, the participants performed the BEEP intervention on average for 16 min 4 times per week. None of the participants reported any incidents or side effects from the training. In the posttraining interviews, the participants described that their balance had improved when walking and that it was easier for them to get dressed, especially putting on socks.

OLST

On solid surface with EO, the mean OLST improved by 13 s (+32%, $p < .001$) after 6 weeks of training (Table 1 and Figure 3). Before the intervention, 29% of the participants could balance with EO on solid surface on either foot for 60 s, and 15% could balance on one of the feet for 60 s. After 6 weeks of intervention, 56% could balance on either foot for 60 s and 26% could balance on one of the feet for 60 s during the same conditions. The mean OLST on solid surface improved by 10 s (+206%, $p < .001$) with EC after 6 weeks of training (Table 1 and Figure 3). None of the participants could balance on one foot for 60 s with EC before the intervention, whereas 12% could do so after the intervention. On the compliant surface with EO, only 29 of 34 participants managed the OLST test for more than 1 s before the training. Six of the 34 participants (17%) could balance for 60 s on both right and left feet. After the training, 17 of the 34 participants (50%) could do so. Before the training, five participants could balance for 60 s on only one of their feet. But after the training, four of them could balance for 60 s on both their right and left feet, whereas five additional participants were able to balance on one foot for 60 s. Thus, the mean OLST on either foot had improved by about 17 s (+54%, $p < .001$) after the training. On the compliant surface with EC, only 12 of the 34 participants managed the OLST test more than 1 s before the training. The recorded mean improvements after the training were small, less than 1 s (7%, $p = ns$). None of the participants could balance on one foot on compliant surface for 60 s with EC before or after the training.

Posturography Tests

Before the intervention, 34 participants were able to perform the posturography under the easiest condition (EO on solid surface) and 31 participants during the most difficult condition (EC on compliant surface). After 6 weeks of BEEP intervention, the mean stability had improved by 15% on solid surface with EO ($p = .027$), by 12% with EO on compliant surface ($p = .013$), by 30% with EC on solid surface ($p = .001$), and by 11% with EC on compliant surface ($p = .033$).

Functional Balance Tests and Questionnaires

As seen in Table 1, after the intervention, the 30-m walking speed, performing the TUG, and the modified step stool tests, as well as the scores in BBS, had improved for all the participants ($p \leq .018$). The scores in the ABC questionnaire also improved ($p = .013$).

Age and Balance Control

Prior to the intervention, the younger elderly performed better than the older when standing on two legs while being perturbed, and on one leg in most of the tests with EC and EO and on different surfaces. The older elderly were slower walking 30 m and had lower HAP scores (Table 2). After the intervention, many of the significant correlations with age remained. Age only correlated significantly with the improvement after BEEP for OLST on the right foot on solid surface with EO and compliant surface with EC, as well as with sway standing perturbed on solid surface with EO and unperturbed on compliant surface with EC.

Test–Retest Effects

The only significant improvement for the ICG not related to performing the BEEP were walking 30 m and performing the step stool test. In both these tests, speed significantly improved between the first evaluation and the test–retest session—ICG 1:2 ($p = .016$; Table 1). The scores in the HAP questionnaire had declined in the test–retest evaluation ($p = .011$).

Discussion

This study illustrates how relatively healthy and active elderly can benefit from performing comprehensive multimodal balance exercises that stimulate sensory reweighting and challenge the vestibulo-ocular, vestibulocervical, and vestibulospinal postural systems. The intention was to develop exercises that could be customized to individual balance skills, and could be performed safely and efficiently at home by community-dwelling elderly without professional supervision, consuming so little time and effort that it would be acceptable for senior citizens to use the BEEP as a daily routine.

The Rationale for a Multimodal Training Paradigm

The BEEP was developed with the aim of enhancing postural control with the following rationale and properties of the included exercises (Figure 1).

Exercises to warm up. Warm muscles increase pliability and reduce the potential to strain or tear muscles through increased blood flow resulting in increased speed of contraction and relaxation of warmed muscles, as well

Table 1. Results Before and After the BEEP Intervention for All the Participants, the IIG, and the Three Different Evaluations for the ICG.

	All participants (*n* = 34)				IIG (*n* = 20)				ICG (*n* = 14)						
	Before	After BEEP			Before	After BEEP			After BEEP	Test–retest	ICG 1:2	After BEEP	ICG 2:3	ICG 3:1	
Balance outcome measures	*M*	*M*	*p* value	*n*	*M*	*M*	*p* value	*n*	*M*	*M*	*p* value	*M*	*p* value	*p* value	*n*
OLST (s)															
Solid surface															
Right foot EO	36.5	51.0	**<.001**	34	42.4	54.3	**.028**	20	31.0	36.0	*ns*	46.2	.038	**.004**	**14**
Left foot EO	38.5	49.5	**<.001**	34	43.0	55.8	**.004**	20	32.1	32.1	*ns*	40.6	.011	**.021**	**14**
Right foot EC	4.1	14.0	**<.001**	33	4.0	15.0	**.002**	19	5.0	5.1	*ns*	13.8	.010	**<.001**	**14**
Left foot EC	5.2	15.2	**<.001**	33	6.0	18.8	**.006**	19	4.0	6.1	*ns*	11.4	.008	**<.001**	**14**
Compliant surface															
Right foot EO	28.0	46.4	**<.001**	29	30.5	50.0	**.005**	15	27.5	28.0	*ns*	42.0	.004	**.002**	14
Left foot EO	29.9	44.6	**<.001**	29	35.3	51.0	**.005**	15	24.0	24.0	*ns*	37.5	.012	**.002**	14
Posturography tests (N m/s^2)															
Solid surface															
Unperturbed EO	0.57	0.68	*ns*	34	0.50	0.64	*ns*	20	0.67	0.54	*ns*	0.74	*ns*	*ns*	14
Perturbed EO	4.82	4.10	**.027**	34	4.19	3.87	*ns*	20	5.71	4.85	*ns*	4.42	*ns*	**.017**	14
Unperturbed EC	0.89	0.86	*ns*	31	1.34	1.22	*ns*	20	1.34	1.36	*ns*	1.6	*ns*	*ns*	11
Perturbed EC	7.21	5.06	**.001**	31	2.29	2.64	*ns*	20	4.23	3.93	*ns*	3.59	*ns*	**.010**	11
Compliant surface															
Unperturbed EO	1.34	1.35	*ns*	31	0.96	0.88	*ns*	20	0.77	0.97	*ns*	0.82	*ns*	*ns*	11
Perturbed EO	3.37	2.98	**.013**	31	6.75	4.49	**.003**	20	8.05	7.03	*ns*	6.09	*ns*	*ns*	11
Unperturbed EC	3.13	2.48	*ns*	31	3.11	2.52	*ns*	20	3.18	2.7	*ns*	2.42	*ns*		11
Perturbed EC	7.41	6.61	**.033**	31	6.83	6.31	*ns*	20	8.45	7.41	*ns*	7.16	*ns*	*ns*	11
Functional balance tests															
BBS (*p*)	54.6	55.1	**.018**	34	55.1	55.7	*ns*	20	53.8	54.4	*ns*	55.1	*ns*	**.008**	14
Pathologic tandem EC (%)	47%	35%	*ns*	34	30%	20%	*ns*	20	71%	71%	*ns*	57%	*ns*	*ns*	14
TUG (s)	10.5	9.3	**<.001**	33	9.7	9.0	*ns*	19	11.7	10.8	*ns*	9.6	.019	**<.001**	14
Walking speed (m/s)	1.6	1.7	**<.001**	34	1.72	1.89	**.001**	20	1.40	1.48	.016	1.54	*ns*	**.005**	14
Step stool test (s)	20	19	**.001**	30	19.6	18.4	**.002**	19	21.5	19.9	.016	19.7	*ns*	*ns*	11
Questionnaires															
Mattiasson-Nilo (*p*)	4.2	4.3	*ns*	32	4.6	4.5	*ns*	20	3.5	3.5	*ns*	3.8	*ns*	*ns*	12
HAP (*p*)	77.5	76.3	*ns*	28	82.4	80.1	*ns*	17	71.2	66.4	.011	68.8	*ns*	*ns*	11
ABC (%)	82.7	86.1	**.013**	32	87.3	89.9	**.035**	19	76.5	74.7	*ns*	82.1	*ns*	*ns*	13

Note. The bold *p* values denote significant changes between the different evaluations. Care was taken to Bonferroni corrections in the three comparisons for the ICG participants. ICG 1:2 is between the first (before the BEEP) and the second evaluation (test–retest), ICG 2:3 is between the second (test–retest) and the third evaluation (after 6 weeks of BEEP). BEEP = balance-enhancing exercise program; IIG = initial intervention group; ICG = initial control group; OLST = one-leg standing time; EO = eyes open; EC = eyes closed; BBS = Berg Balance Scale; TUG = Timed Up and Go; HAP = Human Activity Profile; ABC = Activities-Specific Balance Confidence; *n* = the number of participants able to perform the tests before the BEEP training.

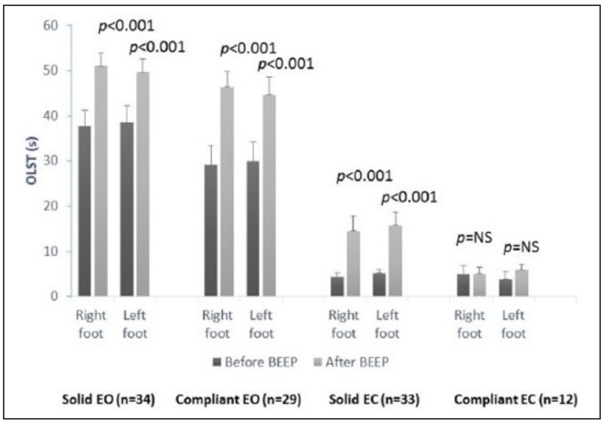

Figure 3. Mean and SEM for OLST before and after the BEEP training on solid surface with EO and EC, and on compliant surface with EO and EC.

Note. SEM = standard error of the mean; OLST = one-leg standing time; *ns* = nonsignificant improvements; BEEP = balance-enhancing exercise program; EO = eyes open; EC = eyes closed.

as facilitated nerve transmission performance. Thus, before the specific balance training started, the participants were asked to do a short warm up by dancing or jogging in place for 3 min.

Exercises facilitating sensory reweighting processes. Age causes sarcopenia with loss of muscle strength and contraction speed (Cruz-Jentoft et al., 2014; Morley, Baumgartner, Roubenoff, Mayer, & Nair, 2001), increased joint stiffness, diminished nerve transmission speed and sensory thresholds, as well as reduced speed with which information is processed by the CNS to yield appropriate balance corrections (Hall, Heusel-Gillig, Tusa, & Herdman, 2010; Li et al., 2015; Tinetti, Williams, & Mayewski, 1986). All these impairments increase the risk of becoming unbalanced and falling. Thus, most elderly must use other postural control strategies. They need to reweight sensory information and execution of movements to the components in the postural system that function better.

Table 2. Correlations Between Age and Balance Outcome Measures.

	Before BEEP		After BEEP		Improvement after BEEP		
Balance outcome measures	Pearson	*p* value	Pearson	*p* value	Pearson	*p* value	*n*
OLST							
Solid surface							
Right foot EO	−.564**	**.001**	−.324	.062	.369*	**.032**	34
Left foot EO	−.355*	**.039**	−.445**	**.008**	.001	.998	34
Right foot EC	−.241	.177	−.328	.062	−.250	.160	33
Left foot EC	−.508**	**.003**	−.319	.071	−.195	.277	33
Compliant surface							
Right foot EO	−.314	.097	−.438*	**.018**	.047	.811	29
Left foot EO	−.401*	**.031**	−.259	.175	.215	.262	29
Right foot EC	−.738**	**.006**	−.383	.220	.591*	**.043**	12
Left foot EC	−.622*	**.031**	−.321	.310	.348	.268	12
Posturography tests							
Solid surface							
Unperturbed EO	.259	.140	.131	.460	.226	.198	34
Perturbed EO	.578**	**.000**	.466**	**.006**	.441**	**.009**	34
Unperturbed EC	.129	.488	.105	.573	.147	.227	31
Perturbed EC	.455*	**.010**	.501**	**.004**	.429	.219	31
Compliant surface							
Unperturbed EO	.190	.306	.422*	**.018**	−.064	.730	31
Perturbed EO	.513**	**.003**	.435*	**.014**	.294	.108	31
Unperturbed EC	.517**	**.003**	.498**	**.004**	.379*	**.036**	31
Perturbed EC	.545**	**.002**	.558**	**.001**	.035	.852	31
Functional balance tests							
BBS	−.242	.167	−.216	.219	.191	.279	34
TUG	.294	.097	.131	.467	−.342	.052	33
Walking speed	−.402*	**.018**	−.346*	**.045**	−.051	.773	34
Step stool test	−.052	.785	.065	.733	.419	.231	30
Questionnaires							
Mattiasson-Nilo	−.163	.371	−.220	.227	−.098	.593	32
HAP	−.502**	**.007**	−.533**	**.003**	−.085	.653	28
ABC	−.249	.177	−.212	.251	.138	.451	31

Note. The bold *p* values denote significant correlations. * = p<.05; ** = p<.01. BEEP = balance-enhancing exercise program; OLST = one-leg standing time; EO = eyes open; EC = eyes closed; BBS = Berg Balance Scale; TUG = Timed Up and Go; HAP = Human Activity Profile; ABC = Activities-Specific Balance Confidence; *n* = the number of participants able to perform the tests before the BEEP training.

To promote CNS plasticity to change and evaluate different information sources, the BEEP was designed to include stability exercise sequences where the individual sensory systems in systematic combinations provide less information and the balance feedback loops are reweighted to the remaining functional balance systems (Tjernstrom, Fransson, Patel, & Magnusson, 2010). Consequently, balance exercises with EO and EC on both solid and compliant surfaces with less foot support and sensory information were included: squats (Exercises 1a, 1b, 4a, 4b), heel/calf raising (Exercises 2a, 2b), one-leg standing (Exercises 3a, 3b, 5a, 5b), and head rotations (Exercises 6a, 6b).

Exercises improving gaze stabilization. The peripheral and central vestibular systems deteriorate with age, which may cause poor balance and dizziness in the elderly (Rosenhall, 1973). However, it seems likely that the CNS is capable of compensating for a certain degree of decline in function because not all elderly are impaired to the extent that the clinical signs of vestibular dysfunction are apparent (Matheson, Darlington, & Smith, 1999). The addition of vestibular-specific gaze stability exercises to standard balance rehabilitation reduces fall risk in older adults with normal vestibular function (Hall et al., 2010). Thus, head rotation exercises with EO and EC as well as rotational jumps with EO were included (Exercises 6a, 6b, 7).

Exercises facilitating strength. On average, the amount of force that can be produced by a muscle is about 40% less for 80 year olds compared with those in their 20s (Doherty, Vandervoort, & Brown, 1993). Strength training for individuals 60 years and older can induce large improvements in muscle strength as evidenced by both micro- and macroscopic muscle hypertrophy (Frontera, Meredith, O'Reilly, Knuttgen, & Evans, 1988). Accordingly, regular exercise has been recommended to improve balance, strength, and coordination in elderly, and exercise may also play a role in improving a number of sensorimotor systems that contribute to stability in elderly (Lord, Ward, Williams, & Anstey, 1994). Thus, strength exercises such as two-legged squats (Exercises 1 and 4), heel/calf raisings (Exercise 2), and rotational jumps (Exercise 7) were included.

Exercises facilitating motor control and coordination. Postural control is needed to both maintain static posture and ensure body stability during movement. Thus, exercises controlling stability during various biomechanical challenging conditions were included in the BEEP. The exercises varied from performing the easier two-feet exercises like the squats in Exercises 1 and 4 to the more challenging rotational jumps in Exercise 7, as well as one-leg standing exercises on a compliant surface with EC as in Exercise 5b.

Motivating exercises with progressive difficulty that could be individually customized by the participants. Continuous challenge is required to facilitate the CNS processes to find new sensorimotor solutions to enhance balance performance. Accordingly, the program included sufficiently difficult balance exercises, which could be individually adjusted, to challenge the postural control system and instigate learning processes (Tjernstrom, Fransson, et al., 2010). Furthermore, the exercises were constructed so that they could provide motivational qualitative and quantitative feedback of balance improvements. The intention was that the elderly individuals would first learn to master a simpler exercise, and when their balance proficiency increased, it would be possible to proceed to more difficult and complex exercises, that is, use combinations of motor control and the sensory reweighting processes (e.g., one-leg standing with EC on a compliant surface for a longer time, as in Exercise 5). This ensured that the participants were exposed to challenging exercises facilitating sensorimotor control training.

Training Outcome

The multimodal intervention approach significantly improved balance when standing on two feet while being perturbed both with EO and EC, and on different surfaces. Balance control also increased when balancing on one foot, both with EO and EC on solid surface and with EO on compliant surface. There were improvements in other balance measures, as well as in balance confidence.

The improvements might be due to the BEEP included exercises (e.g., one-leg standing and knee squats) with both EO and EC, first on solid surfaces, and, with increasing balance proficiency, progressing to completing the exercises on compliant surfaces. This facilitates the sensory reweighting process that is indeed necessary when one tries to balance without visual information when vibrations are causing perturbations or even more so when standing on compliant surfaces. The improvements in balance control, as well as in balance confidence, might also be attributed to the BEEP including exercises facilitating strength, motor control, and coordination. These were knee squats, heel/calf raises, as well as rotational jumps and head rotations, which also stimulated the vestibulo-ocular, vestibulocervical, and vestibulospinal postural systems. The improvements were corroborated by the participants noting that they were more balance confident when performing regular daily activities such as getting dressed, especially when putting on socks. Furthermore, the addition of vestibular-specific gaze stability exercises might also have increased the efficacy of the program. It has been shown that adding these type of exercises to standard balance rehabilitation results in greater reduction in fall risk in older adults with normal vestibular function who report dizziness (Hall et al., 2010).

The improvements in balance control were confirmed with posturography as well as OLST and several other functional balance assessment tests (Howe et al., 2011). Thus, the substantial improvements in balancing on one leg were corroborated with less sway recorded by the posturography when perturbed while standing on two legs on both solid and compliant surfaces. Including posturography as a measure of balance control is an advantage because functional balance measures usually lack the ability to detect balance impairment at its early phase when manifested problems do not yet exist (Pajala et al., 2008). Increased anteroposterior sway, that is, center of pressure movement measured by posturography, has been shown, however, to predict subsequent falls for elderly community-dwelling women (Bergland, Jarnlo, & Laake, 2003). Moreover, it was imperative to verify the improvements in balance control after the intervention by the objective posturography method because one-leg standing was also included in the BEEP.

Another key objective of the study was to ensure that the intervention itself improved balance control and confidence, and not by the potential bias of the participants being made aware of their balance performance as they executed the tests and answered questionnaires. Thus, a randomized crossover design was utilized. After 6 weeks of exercises, the IIG had significantly improved in most balance tests, whereas the ICG only showed nonsignificant improvements when evaluated without having performed the BEEP.

It was important to involve participants who were relatively healthy to reflect the broader aging population. Thus, the BEEP is intended to be used as a complement to other physical activities focusing on balance improvement. As indicated by the high score in BBS, HAP, ABC, and the Mattiasson-Nilo questionnaires, our participants were relatively high functioning, mobile seniors who probably did not have high fall-risk levels.

The study is thus highly relevant to the increasingly aging population. Hence, the BEEP has a potential to be applied before balance dysfunction becomes too advanced. Hopefully, the intervention has the potential to prevent fall accidents in the long term by successfully improving balance and promoting health. The program may assist and help maintain the functional capability and mobility performance of community-dwelling older adults with relatively low risk for falls.

When the participants had completed 6 weeks of intervention, the ability to balance on one leg with available visual information had increased by more than 30%. This improvement could have a significant positive impact in preventing fall-related fractures because this balance measurement has been validated for predicting frailty and hip fractures in community-dwelling elderly populations (Lundin et al., 2014; Michikawa, Nishiwaki, Takebayashi, & Toyama, 2009).

When comparing the BEEP intervention results with a recent systematic review of "Exercise for Improving Balance in Older People" that included 43 studies using multiple exercise types, some differences are notable (Howe et al., 2011). The intervention resulted in greater improvement in walking speed—mean difference (MD) 0.16 m/s versus 0.04 m/s (15 studies)—and increased ability to balance on one leg on solid surface when visual information was available—MD 13 s versus 5 s (nine studies). On the contrary, the improvement from the BEEP was lower in the TUG test—MD −1.2 s versus −1.6 s (12 studies)—and in the BBS—MD 0.85 p versus 1.84 p (two studies). One possible explanation for these differences might be that the BEEP participants were slightly younger than in the Cochrane review (mean age 70 vs. 75) and thus might have had better balance before the intervention. Younger elderly with better balance can probably improve more in the OLST and walking speed tests, which are more challenging than the easier BBS and TUG tests. However, improvements in stability after the intervention, according to the posturography results, were not significantly correlated to age. Consequently, participants of all ages seemed to benefit from the BEEP intervention. The older participants improved their stability more than the younger participants during balance perturbations with EO on solid surface, which is one of the easier posturography tests, and during quiet stance with EC on compliant surface, which is more challenging.

Considering that elderly often have impaired or reduced visual acuity, the more than 200% improvement in balancing on one leg without visual information after the intervention is particularly noteworthy. Prior studies have shown that there is a significant age-dependent decrease in the ability to balance on leg with closed eyes (Bohannon et al., 1984; Springer, Marin, Cyhan, Roberts, & Gill, 2007). In the above-mentioned systematic review by Howe et al. (2011), only two studies were presented that investigated balancing skills on one leg with closed eyes on solid surface where participants improved 1.60 s after "multiple exercise types" compared with control participants (Arai et al., 2007; Howe et al., 2011; Suzuki, Kim, Yoshida, & Ishizaki, 2004). However, after the intervention, the mean improvement was 10.25 s. A substantial difference though the mean preintervention time in the present study was 4.15 s, which is comparable with the mean 4.14 s presented for the participants in the Arai and Suzuki studies (Arai et al., 2007; Suzuki et al., 2004). The present cohort being slightly younger than in the above might again explain some of the disparities in improvements. However, in our study, age only correlated significantly with the improvement after the intervention for OLST on compliant surface with EC, as well as with sway standing unperturbed on compliant surface with EC. Accordingly, one of the distinctive strengths in the intervention may be that it includes exercises designed to train balance when vision is lacking. Balancing with EC is particularly difficult and thus appears to be an appropriate balance exercise to challenge the relatively healthy elderly.

Most other balance exercise interventions have been delivered by health care professionals either individually at home or in group sessions or with a mixed approach a few times week and are thus relatively costly compared with self-training (Campbell et al., 1997; Clemson et al., 2012; Hektoen et al., 2009; Robertson et al., 2001; Robitaille et al., 2012; Skelton et al., 2005). The BEEP is a purely home-based intervention where the exercises can be individually tailored by the participants as their balance proficiency increases. The improved balance results indicate that the exercises could be made sufficiently difficult by the participants to challenge their postural control system and instigate learning processes (Tjernstrom, Fransson, et al., 2010). Furthermore, it seems like relatively little time and effort had to be spent by the participants to accomplish the improvements compared with other exercise interventions. The roughly 16 min a day 4 times a week the participants spent only adds up to about half the weekly amount recommended by most other balance exercise intervention programs, that is, of at least 2 hr of balance exercises per week for at least 3 months on an ongoing basis (Campbell et al., 1997; Clemson et al., 2012; Hektoen et al., 2009; Robertson et al., 2001; Robitaille et al., 2012; Skelton et al., 2005). Moreover, the mean total training time during the six weeks only adds up to about 6½ hr, which is quite lower than the, at least, 50 hr that has been considered necessary to reduce falls (Sherrington et al., 2011).

Study Limitations

A potential study limitation is recruitment bias of the participants. The participants recruited were already, or were made, health and balance conscious by first accepting and then participating in the study. One can question if the recruited participants are representative of the study objectives—that is—to improve balance in relatively healthy community-dwelling elderly without professional supervision. The participants in this cohort considered themselves relatively healthy despite that many of them had several concurrent medical conditions, some severe. Hence, they can be considered as being rather representative for the large group of active elderly who would be possible candidates for this type of intervention.

The participants were instructed to perform the training regularly and did so for a mean of 16 min 4 times a week. Furthermore, there were no dropouts due to lack of commitment or interest, except for one participant due to the coming holiday season. The dropouts had similar demographic and balance characteristics as the participants. The enthusiasm of all the other participants might be representative for many of the increasingly healthy and active elderly.

Relatively few participants in the cohort may explain the lack of improvement in some of the balance outcome measurements as well as in the questionnaires after the intervention for both the initial intervention and control groups. Another reason for lack of improvement could be the ceiling effect, particularly when interpreting OLST and tandem stance results because a maximum time limit was set to 60, respectively 10 s. The ceiling effect could also play a role when evaluating the result of the easier balance tests as the present cohort was relatively highly functioning elderly. Another bias to consider was that the participants performed the OLST and posturography tests in a nonrandomized order, that is, with EO and EC first on a solid and then on a compliant surface.

Conclusion

Multimodal balance exercises offer an efficient, cost-effective way to improve balance control and confidence in elderly. The study evidenced that it is possible to enhance balance control and stability in relatively healthy community-dwelling elderly by regularly performing a few balance exercises that combine the reweighting possibilities in the postural control system with exercises challenging the vestibular systems, stimulating coordination, as well as leg strength, ankle mobility, turning, and vestibular-ocular reflex training.

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