Strength training in elderly people improves static balance: a randomized controlled trial

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Abstract

Aim of this study was to investigate the effects of two different types of strength training programs on static balance in elderly subjects. Subjects older than 65 years of age were enrolled and assigned to control group (CG, n =19), electrical stimulation group (ES, n = 27) or leg press group (LP, n = 28). Subjects in both the training groups were exposed to training (2-3x/week) for a period of 9 weeks. In the ES group the subjects received neuromuscular electrical stimulation of the anterior thigh muscles. In the LP group the subjects performed strength training on a computer-controlled leg press machine. Before and after the training period, static balance of the subject was tested using a quiet stance task. Average velocity, amplitude and frequency of the center-of-pressure (CoP) were calculated from the acquired force plate signal. The data was statistically tested with analysis of (co)variance and t-tests. The three groups of subjects showed statistically significant differences ($p < 0.05$) regarding the pre-training vs. post-training changes in CoP velocity, amplitude and frequency. The differences were more pronounced for CoP velocity and amplitude, while they were less evident in case of mean frequency. The mean improvements were higher in the LP group than in the ES group. Our results provide supportive evidence to the existence of the strength-balance relationship. Additionally, results indicate the role of recruiting central processes and activation of functional kinetic chains for the better end effect.

Key Words: aging, falls, balance, strength, training

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Falls and their consequences are a major health problem in elderly population [26]. Poor balance has been recognized as one of many precursors of falls [9,21]. Sustaining postural equilibrium during an upright stance and during locomotion is, by itself, a major concern for the human neuromuscular system. Moreover, secondary functional goals, such as performance of powerful or precise movements, can be compromised in case balance has been lost. Poor balance can affect even daily tasks such as standing, reaching for objects, rising from a bed, and other [7]. Balance therefore represents an important pillar for the quality of body motion and for the quality of life. On one hand, impaired balance can be a result of several reasons such as injury [20], disease [5, 15] or aging [30]. On the other hand, growing body of literature shows that balance can be improved through sensory-motor (i.e. proprioceptive) training [7, 13].

The population of elderly people is probably among the most sensitive groups of people regarding the decline of postural stability and general mobility. This comes as a combined effect of a less active lifestyle and of biological processes. The latter encompass also loss of muscle mass (i.e. sarcopenia) [28] and decreased ability for voluntary neuromuscular activation [16] which in turn result in the drop of muscle strength and power [14, 23]. The relationship between balance and strength has been identified, although the reports on that are somehow contrasting and the cause-effect relationship cannot be simply defined. Therefore, the aim of this study was to find out the effects of nine-week strength training on static balance in elderly subjects. Additionally, two types of

Table 1. Training plan for the LP group

Week	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**
Sessions/week	2	2	3	3	3	3	3	3	3
Sets/session	4	4	4	4	5	5	5	5	5
Time/set [s]	8-10	8-10	8-10	8-10	8-10	10-12	10-12	12-14	12-14
Inter-set break [s]	120	120	120	120	120	120	120	120	120

training (electrical stimulation vs. voluntary exercise) were used and specific effects were searched for.

Materials and Methods

2.1. Subjects

Altogether, 87 subjects volunteered to take part and 74 subjects (74.3 ± 7.0 years, 169.6 ± 10.3 cm, 78.5 ± 16.1 kg) completed it. 13 subjects did not complete the training from personal reasons not related to the study. They were randomly assigned to control group (CG, n =19), electrical stimulation group (ES, n = 27) or leg press group (LP, n = 28). Study design, measurement procedures, benefits and potential risks were explained to the subjects prior to their enrolment. The study protocol was approved by the national medical ethics committee (Ethic committee of the city of Vienna nr. 08-102-0608) and subjects gave their written informed consent before the inclusion.

2. Study Design

A randomized controlled study design was used. Subjects in both training groups (ES and LP) were exposed to training for a period of nine weeks, while the subjects assigned to the CG continued with their normal life not being exposed to any systematic physical conditioning programme. Before and after the training period, the subjects underwent a set of clinical and laboratory tests, among other, also the assessment of static balance.

3. Measurements

On each of the two occasions (pre-training and post-training) the subject performed so called quiet stance task, with feet positioned parallel at hip width and vision restricted using a non-transparent mask. An introductory trial was performed and followed by tree 30-s repetitions; divided by 60-s rest intervals. The subject was standing on a force platform (Fitro Sway, Bratislava, Slovakia) while performing the balance task and the centre-of-pressure (CoP) signal was acquired at 100 Hz and stored on the PC for further analysis. The signal was pre-processed (low-pass 10 Hz Butterworth filter, second-order) and then quantified with average velocity, amplitude and frequency of CoP (total, medial-lateral and anterior-posterior direction) .

4. Training

Subjects in both the training groups (ES and LP) were exposed to regular training for a period of nine weeks. In the ES group the subjects received neuromuscular electrical stimulation of the anterior thigh muscles. In the LP group the subjects performed strength training on a computer-controlled leg press machine using the mode of combined slow movements and superponated vibrations.

ES training was performed with a custom-built battery-powered stimulator [12]. The subject was seated over the edge of the therapeutic table with the trunk upright and lower legs freely swinging. Two conductive rubber electrodes (9 × 14 cm) cowered by wet sponge were placed on the anterior thigh on each side of the body. The electrode pairs were connected to the independent channels of the stimulator and the left and the right thigh were stimulated in an alternative manner. Each repetition (i.e. ES evoked muscle contraction) was evoked by a 3.5 s train (60 Hz) of electrical pulses (rectangular, biphasic, width 0.6 ms). Consecutive contractions of the same thigh were separated by 4.5 s off intervals. During the first two weeks of the training period, two sessions per week were carried out and each session consisted of 45 contractions (3 sets × 15 repetitions) on each thigh. This was progressed during weeks 3 to 9 so that the total training volume per week came to 2.5-times of the initial (3 sessions/week, 75 contractions/thigh/session). Maximal tolerable intensity was used and monitored during the training sessions. In all the subjects in the ES group this induced a tetanic contraction of the stimulated muscles.

Subjects in the LP group trained on a custom built, computer controlled, linear electric motor powered leg press device [10]. The so called “swinging” vibrational-proprioceptive mode was used, which means that constant velocity of the pedals (0.3 m/s and 0.2 m/s for concentric and eccentric phase, respectively) was interrupted by short stops (every 8 mm), resulting in short force peaks appearing throughout the movement. Training load was progressively increased throughout the nine-week period as presented in Table 1.

4. Statistical Analysis

Statistical analysis was done using PASW Statistics 18 software (SPSS Inc., Quarry Bay, Hong Kong). Descriptive statistics, tests of normality and homoscedasticity were performed first. This was followed by testing the differences among the three groups (CG, ES, and LP) in the context of time (pre-intervention vs. post-intervention) using analysis of (co)variance and 2-tailed t-tests with Bonferroni corrections. Values are reported as mean (standard error). The level of statistical significance was set at 0.05.

Results and Discussion

As mentioned before, drop out of subjects from the study was ~15%. Additionally, four obvious outliers (> 3 SD from mean) were excluded from statistical analyses. Such a dataset was used for statistical comparisons. All the dependent variables were normally distributed. The three groups of subjects (CG, ES, and LP) showed statistically significant differences ($p < 0.05$) regarding the pre-training vs. post-training changes in CoP velocity, amplitude and frequency (Table 2). The differences were more pronounced for CoP velocity (F =4.9 – 9.6, p = 0.000 – 0.001) and amplitude (F = 5.6 – 8.5, p = 0.001 – 0.006), while they were less evident in case of mean frequency of the power spectrum (F = 1.6 – 3.6, p = 0.03 – 0.21). The mean improvements were higher in the LP group than in the ES group.

Results of this randomized controlled trial showed statistically significant effect of a nine-week strength training in elderly subjects on the body sway parameters during symmetrical bipedal stance with closed eyes. Specifically, the training effect was more evident in the subjects who performed voluntary activation of lower extremities` muscles (LP group) and less evident in subjects who received training with artificially evoked contractions of the anterior thigh muscles only (ES group).

Biological processes of neuromuscular aging lead to a decrease in physical and mental functions, which is more evident in people with a passive lifestyle [4, 6]. Impairments have been shown for cardio respiratory endurance, inter-joint and inter-muscle coordination, precision of movement, flexibility, balance, and strength [2, 8]. These aging related changes have some common origins encompassing sarcopenia, muscle fibre type transformation, loss of sensory functions, reduction in the number of neurons, and neuroplasticity changes [1, 11,24]. The latter has also been shown to be a reason for cognitive functions decay taking place through the aging process [25, 27]. However, several studies have shown that these negative trends can be effectively compensated using movement interventions of different kinds [7, 13]. Results of our study support such conclusions and advance knowledge about training specific effects in the context of balance.

Strength and balance (i.e. mechanical stability) represent ground stones for daily functional movements. Sustaining balance of an inherently unstable system such as human body is characterized by continuous automatic (reflexive and anticipatory) fine sensory-motor tuning of lower extremity muscles [29]. To the contrary, isometric muscle strength is defined as the ability to generate maximal force/torque,

Table 2: Results – training effects and differences among groups

CoP parameter	**Time**	**CG** (n = 19)		**ES** (n =27)		**LP** (n =28)		**ANCOVA** (p / effect size)
Velocity total [mm/s]	Before	14.0 (3.7)		16.8 (1.6)		17.6 (1.6)	*	0.001 / 0.198
	After	15.7 (4.5)		14.8 (1.1)		15.2 (1.2)		
Velocity A-P [mm/s]	Before	14.6 (1.7)	*	13.8 (1.4)		14.4 (1.5)	*	0.000 / 0.223
	After	16.1 (1.5)		12.4 (0.9)		11.4 (1.1)		
Velocity M-L [mm/s]	Before	6.8 (1.1)		6.9 (0.7)	*	7.5 (0.7)	*	0.010 / 0.128
	After	7.1 (1.6)		5.6 (0.4)		6.1 (0.5)		
Amplitude A-P [mm]	Before	5.2 (0.9)		5.4 (0.5)		5.6 (0.5)	*	0.001 / 0.200
	After	5.4 (1.1)		4.9 (0.4)		4.9 (0.5)		
Amplitude M-L [mm]	Before	3.0 (0.5)		2.8 (0.4)		2.8 (0.3)		0.006 / 0.143
	After	3.2 (0.3)		2.2 (0.2)		2.3 (0.2)		
Frequency A-P [Hz]	Before	0.32 (0.04)		0.33 (0.02)		0.33 (0.02)		0.033 / 0.096
	After	0.34 (0.05)		0.31 (0.02)		0.31 (0.02)		
Frequency A-P [Hz]	Before	0.37 (0.03)		0.33 (0.02)		0.33 (0.02)		0.241 / 0.043
	After	0.35 (0.05)		0.30 (0.02)		0.30 (0.02)		

Note: asterisks represent statistically significant before-after differences (pairwise t-test, $p < 0.05$).

the role of sensory information is less and it primarily relies on voluntary action. If only strength and balance are somehow different in their underlying mechanisms, several studies have shown that they do correlate at a small to medium level [3,21,22]. On the contrary, other studies have shown absence of correlation between strength and balance proposing the role of complementary diagnostics and training in their regard [17-19].

Our results are supportive to the above presented strength-balance relationship. Namely both experimental groups of subjects (LP and ES) showed improvements in the indexes of balance. These changes were more pronounced in subjects who performed maximal voluntary actions under proprioception facilitating conditions (i.e. dynamic movement with interpolated low-frequency vibrations). Subjects who trained with neuromuscular electrical stimulation showed lower improvements in static balance, potentially because of the specific characteristics of such training among which are (i) isolated training of knee extensors, (ii) submaximal activation of muscles, (iii) inverted order of motor units recruitment, (iv) absence of voluntary action and (v) less sensory-motor integration involved.

To summarize, our results provide supportive evidence to the existence of the strength:balance relationship. Some of the selected body sway parameters were namely improved after the training period in both experimental groups. The training effect on static balance was bigger in case of training with voluntary contractions and less when neuromuscular electrical stimulation was used. This might indicate the role of recruiting central (supraspinal and spinal) processes and activation of functional kinetic chains for the better end effect

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