Gain in Strength and Muscular Balance After Balance Training

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The isolated effect of balance training on muscle strength of the flexors and extensors of the knee, without accompanying strength training, has not been addressed in the past. Effects of a balance training program alone were compared to a strength training program. Balance and strength training were performed by 15 persons each for 6 weeks including 12 training units of 25 min. Balance training was performed on instability training devices such as rolling board, mini trampoline and large rubber ball. The 15 persons of the strength training group trained on machines for leg curls and on leg presses for 25 min per unit. Measurements for balance were performed with one-leg balance on a narrow edge and a tilting stabilometer for 30 s; maximum isometric strength was measured using an isokinetic device for each leg separately. The muscular balance between dominant and non-dominant leg was calculated. Strength gain was similar for the flexors and extensors in both groups. One-leg balance improved after balance training ($P < 0.01$) with a 100% increase over the strength training group ($P < 0.05$) and the stabilometer test for each person in the balance ($P < 0.01$), but not in the strength training group. In the balance group the initial difference between right and left diminished. The results indicate balance training to be effective for gain in muscular strength, and secondly, in contrast to strength training, equalisation of muscular imbalances may be achieved after balance training.

■ Key words: Strength training, balance, knee flexors, knee extensors.

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Introduction

Regular strength training is usually some form of cross training. After injuries or immobilization the restrengthening process in rehabilitation is approached applying a combination of cross training and muscle balance improvement in physical therapy. The initial gain in strength during strength training is based on improved neuromuscular function [9]; morphologic or metabolic adaptations develop later. New training exercises are initially associated with some inefficient accompanying movements, which are controlled by impulses from the motor cortex of the gyrus praecentralis. These effects are suppressed by fascilitations, and movement patterns become more efficient through neural adaptation expressed by improvement in intramuscular and intermuscular coordination. Not only power and strength, but also muscle endurance improve at the same level of energy expenditure. While strength training is part of almost all sport training programs as well as in fitness training, coordination training alone as balance training is usually only found in technique training specific for a particular sport. Thus its typical effects can hardly be separated from those of the concomitant strength training.

Investigations on the effects of a coordination training as balance training on strength gain have rarely been performed. When done, it was usually in connection with complicated injuries, during which coordination training was normally coupled with a strength training program [6] and in very old persons for research on prevention of falls [8].

Based on the premise that the gain in strength at the beginning of a strength program originates from neural adaptations, the question considered by the present work was whether and to what extent neuromuscular function improvements, including strength gain, can be achieved without strength training, with only coordination training as balance training. However, it must be considered that balance training may include strengthening effects and strength training balance effects in a closed kinematic chain.

The aim of the study was to quantify the possible gain in strength by balance training in comparison to strength training. The directly related question of how muscle imbalance between the strength of the right and left leg disappears through balance training was also considered.

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Method

A total of 30 persons agreed to participate in this study after being informed about possible risks. They had all engaged in some physical training on fitness machines for 1.5–3.0 years to compensate for their sedentary life style and had not suffered a serious leg injury before. None had engaged in maximum strength training or competitive strength training. Cross training leads to strength gain in part by increase in intramuscular and intermuscular coordination. Therefore, 15 persons were assigned randomly except for gender to a strength training program group, and the other 15 were assigned to a balance training program group. In the first group 7 of 15 persons were female, in the second 8. The average age was 31.7 ± 5.7 and 31.2 ± 4.7 years, the height 177 ± 8.0 and 177 ± 7.7 cm and the weight 74.2 ± 12.5 and 72.3 ± 12.2 kg, respectively. The differences were not significant. Former sport activities included jogging, dancing, handball, badminton, volleyball, table tennis, tennis and were distributed equally in both groups.

The sense of balance was quantified and assessed with 2 self-constructed apparatuses. The first was designed for the one-leg balance capacity test, which was developed according to preliminary work by Fleishman [2]. It makes use of a base plate (60 × 35 cm) on which a rectangular 60 × 10 × 2.5 cm board was fixed with its 2.5 cm side attached to the midline of the plate, parallel to the long sides. The persons being tested placed one foot on the small 2.5 cm edge while the other rested on the base plate. After an equilibrium was found, the person lifted the leg from the base plate and balanced on the small edge. At the same time an electronic time measurement started by a light contact. The participants began the test balancing on the right leg holding their hands behind their back and looking at a point on the wall in front of them. The test was repeated 4 times. Before the first test everyone had practised the balance technique 8 times to get acquainted with the test device.

The second apparatus applied was a stabilometer, which was constructed according to modified original plans of Singer [12]. It consists of a rectangular base board with 2 guiding ridges attached to the long sides and connected with a common axis of rotation to which a board is attached, its plane parallel to the base plate. On the board two 28 x 23 cm areas surfaced with roughened rubber 20 cm apart were mounted for rough positioning and to prevent the standing persons slipping (Fig. 1). The ideal distance between the feet for each participant was documented by a scale. The plate tilted a maximum of 13°, and if the left or right side touched the base plate, it was registered by an electronic device and recorded as an error. The test person held his or her hands fixed behind the back. The knees and hips were slightly bent while the upper body leaned forward. After stabilisation the test person attempted to hold a relatively stable balanced position for 30 s. The test was performed 4 times with a break of 90 s between each test.

For the measurements of force an isokinetic device (Cybex Norm) with special software (Lumex) was applied. The device enabled exact positioning and fixation of the test person for measurement of maximum knee extension and flexion. The isometric maximum strength measurements for both legs were made first at a 60° angle for extension, and then after 2 min rest at 30° for flexion measured from full extension. The isometric tension was measured for 5 s and was repeated twice

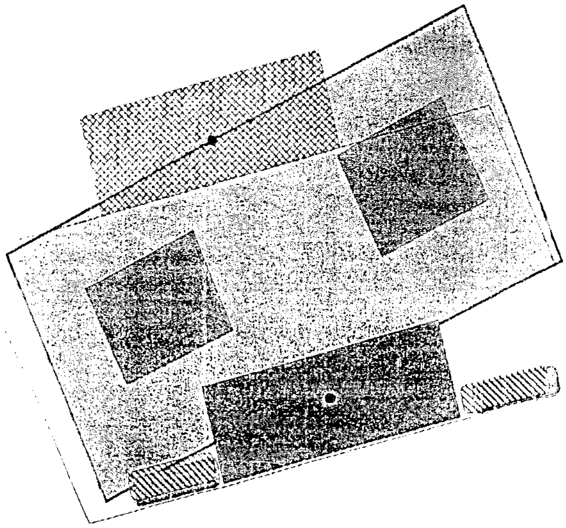

Fig. 1 Schematic presentation of the stabilometer with marked areas for foot positioning. Maximum turn 13°.

after 2 min rest intervals. The maximum torque was calculated in Newtonmeters (Nm). Before measurement the test persons warmed up for 2 min at an angular velocity of 150°/s.

Because of the exact positioning required, measurements took 20 min for extension and flexion. The balance measurements for one-leg balancing and with the stabilometer took 10 min each. The total testing time amounted to 60 min, not taking in account the individual time warming up on a bicycle ergometer before the isokinetic measurements.

Training programs

Both groups trained 2–3 times/week for 4–6 weeks until 12 training units were completed. Final testing took place on the following day. The strength training group worked out on two exercise devices with 2 sets of 5 repetitions at 80% of maximum strength. The workload remained unchanged throughout the training. The device for leg press was individually adjusted in a recumbent position, and leg curls were individually performed in a standardized manner with lumbar spine not stressed in a sitting position. Each training unit lasted 25 min.

The balance training group stressed the hamstrings with a rubber ball with a diameter of 0.90 m during each unit (Table 1). Balance exercise on the swinging plate (Posteromed, Haider Bioswing), unstable plate (stabilometer) (Fig. 1) and mini trampoline mainly stressed the quadriceps muscles, and on the rolling board (Rola) both quadriceps muscles and hamstrings. For dynamic balance improvement the 'Pedalo' and the stepper were alternated. One unit lasted 25 min with 5–8 sets for each exercise. Preliminary tests had shown that more than 8 units led to stiffening of the thigh muscles. The balance training devices were different from the balance measurement systems.

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Analysis

The shortest of the 4 one-leg balancing trials was eliminated and the average of the 3 remaining trials calculated. The percentage of change in balancing time achieved was recorded for each individual. The results of right and left were added to indicate the combined balance capacity. The number of contacts made by the right and left sides of the stabilometer were added and the trial with the most contacts eliminated. The percentage of change in the number of contacts was recorded.

The isometric maximal force was calculated as the mean of 3 measurements, thus lower than single peak force measurements were found during short jerk-like movements. For better comparison the percentage of change after training was recorded. The right-left relationships for each person were standardised and expressed as percentage by subtracting the results of the right from the left leg and dividing by the mean of the two numbers.

After training all measurements were repeated with the same exercise devices in the same order on the same day of the week at the same time.

Statistics

The test for normal distribution according to Kolmogorov Smirnow was negative, thus the Wilcoxon paired t-test was applied for changes within groups after descriptive presentation of the results ($P < 0.05$). Group results from one-leg balance tests and two-leg stabilometer tests as well as from gain in total strength of both extensors and flexors were compared by the nonparametric Wilcoxon signed rank test and adjusted according to Bonferroni. The data were calculated by Excel 5.0. The level of significance for the median of the group results before and after training was $P < 0.05$.

Table 1 Device and mode of exercise for balance training

Apparatus	Type of Exercise	Option	Load
Pezzi-Ball 	Isometric exercise: Both legs; knees slightly bent, optional slow bending and stretching of the legs	one leg	5×20 s each
Bioswing, Mini-trampolin	Isometric exercise: always start with both legs, 40 s max on one leg – change side	throw ball in the air, catch it, repeat; try to close the eyes	5×20 s each
ROLA 	Balance	throw ball in the air; catch it, repeat; try to close the eyes	as long as possible
Pedalo Stepper	forward and backward with the back towards the apparatus, stand on the front of the foot	throw ball in the air, catch it, repeat; try to close the eyes	at least 5×20 s each

Table 2 Changes in balance measured by the number of touchdowns right and left (n) and the time standing on one leg (s) right and left before and after balance and strength training

		Touchdown (n)		One leg standing (s)	
		Right	Left	Right	Left
Balance training	Pre	12.7±2.53	13.0±2.36	6.81±4.61	6.90±4.17
	Post	10.4±2.13	10.4±2.42	14.2±6.75	14.4±7.19
Strength training	Pre	13.0±1.79	12.7±1.94	6.72±4.05	6.99±3.67
	Post	12.3±1.60	12.8±2.23	8.05±3.97	8.57±3.84

Results

For one-leg stand the mean increase in the balance training group was 146% and 34% in the strength training group ($P < 0.01$ and $P < 0.05$). The mean time and the large variability are shown in Table 2. The best single result (+328%) was achieved by one participant from the balance training group, in which all reached a better result ($P < 0.01$); in contrast, some persons from the strength training group showed a small decrease (Fig. 2) although the group together showed an increase ($P < 0.05$). Greater individual training responses were remarkable, especially in the balance training group.

As for the stabilometer the balance training group showed a positive but individually variable response after training ($P < 0.01$) while the strength training group again showed de-

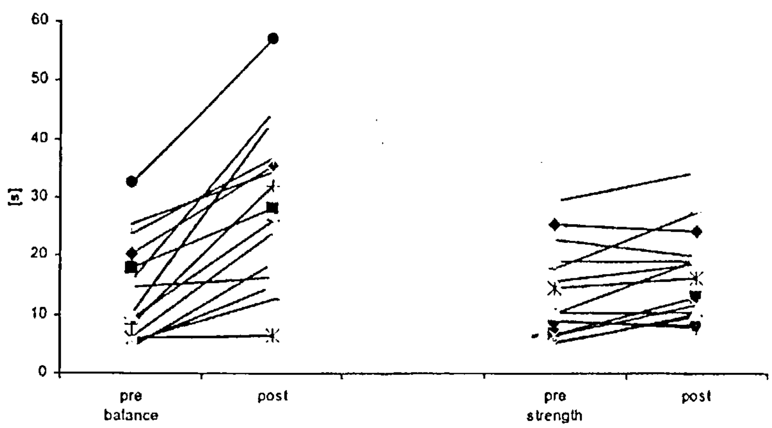

Fig. 2 Changes of the time of one-leg left and right standing; balance training left side, strength training right side, pre and post: before and after training.

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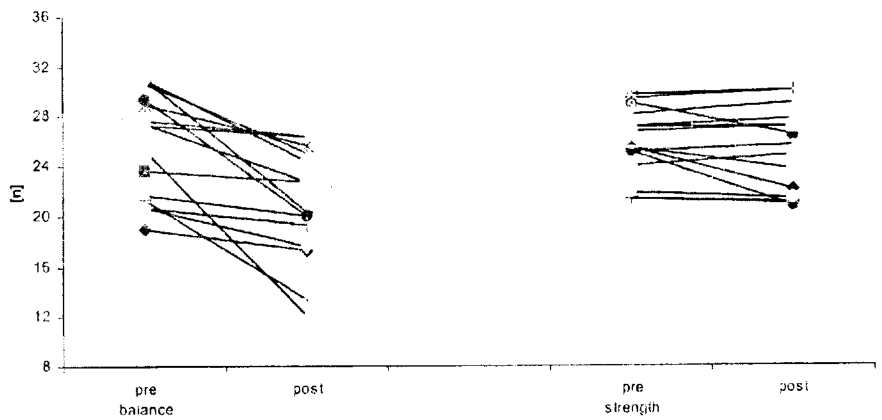

Fig. 3 Changes in the number of touchdowns on the stabilometer within 30 s, taken the results of both legs together. Measurements before (pre) and after (post) 12 training units of balance (left) and strength training (right).

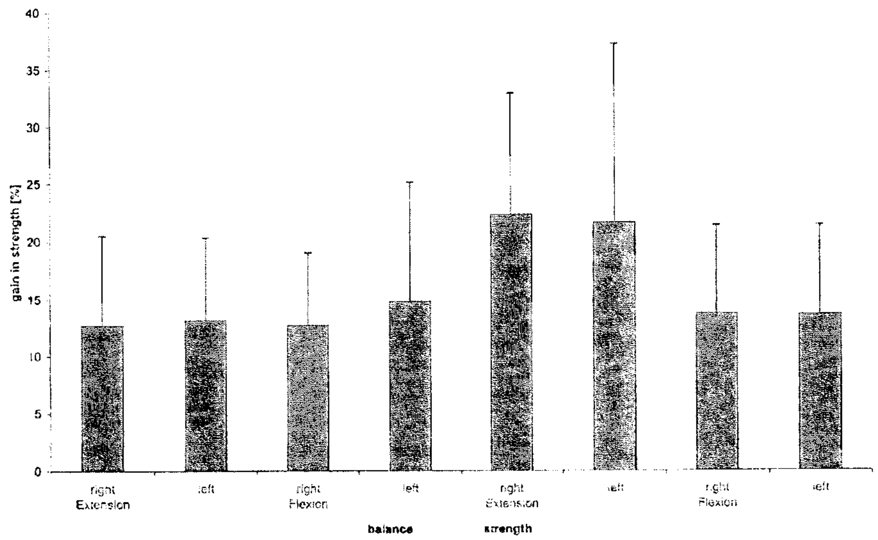

Fig. 4 Percentage and standard deviation of the gain in isometric maximum strength of the extensors and the flexors, displayed for the right and left limb separately. Balance training: columns 1–4; strength training: columns 5–8.

Table 3 Changes in strength (Nm) of the extensors and flexors, data before and after balance training (n = 15, 8 men, 7 women) and after strength training (n = 15, 7 men, 8 women)

		Extensors (Nm)		Flexors (Nm)	
		Right	Left	Right	Left
Balance training	Pre	179 ± 63	177 ± 59	100 ± 36	99 ± 36
	Post	200 ± 65	199 ± 65	112 ± 36	111 ± 35
Strength training	Pre	181 ± 60	181 ± 56	105 ± 36	105 ± 37
	Post	220 ± 72	220 ± 66	120 ± 44	118 ± 41

creases in some persons and only a small increase as a group (Fig. **3**). The number of touchdowns is shown for right and left leg in Table **2**. The maximal single performance was 52% by one person in the balance training group and 17% in the strength training group.

The maximal strength enabled us to compare the ratio of the extensors to the flexors at each side before and after the different kinds of training. The strength of the flexors increased in all persons in both groups ($P < 0.01$), and of the extensors in all participants except for one in the balance training group ($P < 0.01$). The gain in strength of the extensors was 22% on both sides after strength training, and in tendency higher than after balance training (12%); the results of each side are presented in Table **3**, the gain in strength of the flexors was only slightly higher after strength training (Fig. **4**). The gain in strength of the extensors showed a maximum of 55% in one case in the strength training group and a maximum of 27% for someone in the balance training group, and for the flexors 33% and 34%, respectively.

When the results of right and left were compared (Fig. **5**), there were very clear differences in strength gain for the extensors, which increased in all but one person (participant number 2) of the strength training group ($P < 0.01$), and to an even higher extent in the balance training group in which almost all persons reached similar strength of the extensors right and left (Fig. **5**). Person 10 demonstrated a remarkable loss of strength on the left side, showing at the same time the highest effect on the balance training group, in which persons 2, 4, 7, and 8 also reached a relative balance in spite of an initial imbalance up to 19% but without a loss of strength in the dominant extremity.

As for the flexors (Fig. **6**) the strength training led to an increase in muscular imbalance in 4 cases, while all persons of the balance training group showed an improvement in balance, in 3 equilibration.

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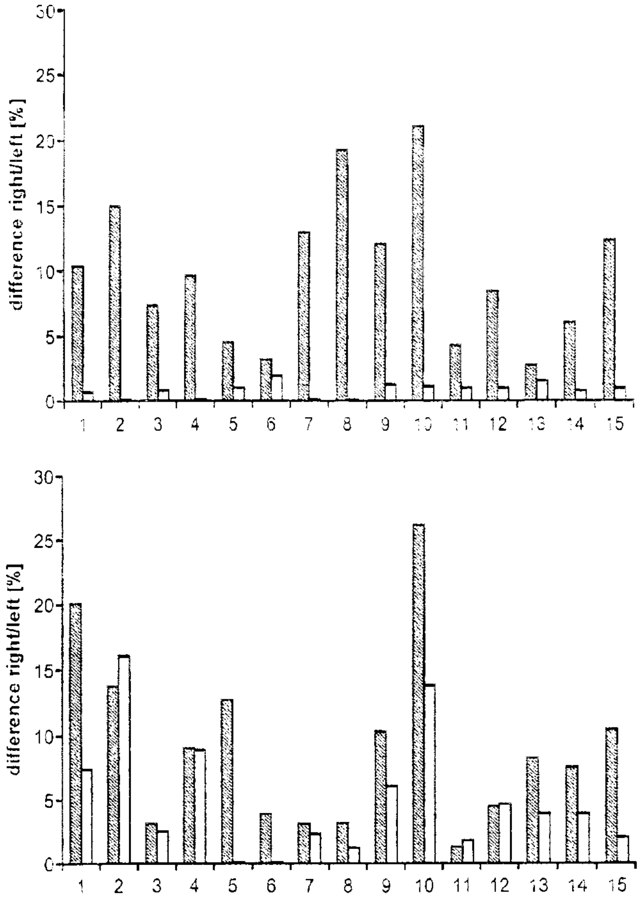

Fig. 5 Difference in maximum isometric strength of the extensors right versus left before and after training for each person, given as percent. Balance training group above (1–8 women, 9–15 men), strength training group below (1–7 women, 8–15 men); shaded columns before, unshaded columns after training.

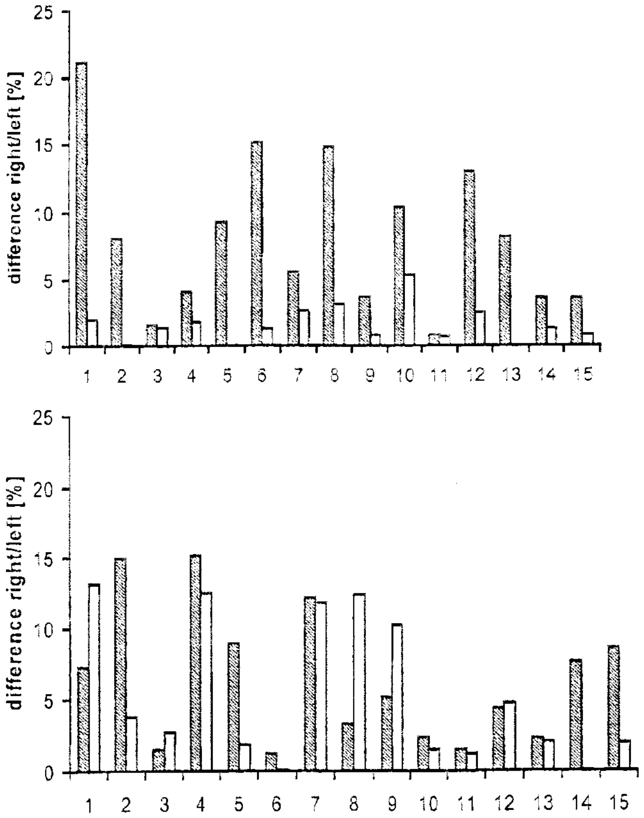

Fig. 6 Difference in maximum isometric strength of the flexors right versus left before and after training for each person, given as percent. Balance training group above (1–8 women, 9–15 men), strength training group below (1–7 women, 8 – 15 men); shaded columns before, unshaded columns after training.

Discussion

The quantification of the gain in femoral muscle strength after balance training showed a comparable gain in flexors and extensors. The strength training lacked a strict periodisation and severity and encompassed a relatively small amount of training time exactly matched to the balance training. Nevertheless the strength of the flexors and extensors of the balance training group could be increased by a similar percentage which may partly be due to an adaptation to the testing device.

The gain in flexor and extensor strength in the balance training group was similar to that in the strength training group. Improved sympathetic transmission of motor neurons might be an explanation [1]. In earlier studies electrophysiological traces of reinforcement were shown when certain movements were performed [13]. The effects might be called learning effects.

Exercising in a closed kinematic chain like the leg press and measuring with an open chain might have influenced the results so that the one-leg balance showed a gain after strength training. On the other hand, exercising on a rubber ball might have induced a gain in strength of the hamstrings. Cross training effects seem possible. The important aim of the study, however, was that balance training induces gain in strength, possible cross training effects being small.

For the extensors a certain strengthening effect by the one-leg standing exercise must be discussed because of the one-sided stress. Compared to strength training, this stress appears to be almost negligible, nevertheless similar effects were found. The gain in strength does not seem to be due to changes in contractile pattern of the muscles since no change in maximal twitch force, maximal torque development and rate of relaxation were seen in strength training [7]. The different gain in strength after maximum strength training cannot be attributed to the better trainability of muscles less stressed during every day life: the quadriceps muscles were relatively better trained than the hamstrings.

After balance training an increase in balance performance could be expected and was shown on the stabilometer, this increase was missing after strength training. For the one-leg balance the performance increased, however, also after strength training, presumably based on a training effect on the reflex control of muscle activity induced by exercising in the closed kinematic chain with known proprioceptive effects. The gain in strength may be explained by an improved intramuscular and intermuscular coordination, as well as by a more econom-

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ic activation of agonists, thus achieving a stabilisation of the extremities [11].

The related question of how muscular imbalance improves from balance training could be explained in part by the changing but equally intensive stress on both sides. Neither the extent of the clear strength increase of the weaker muscles for improving the balance nor the case of decreased strength of the previously dominant limb have been described previously. The lack of improvement in muscular balance during flexion after strength training is difficult to explain in view of the muscular balance improvement of the extensors in both groups.

Improved muscular balance is an important part of injury prevention. Some of the participants spontaneously described a feeling of increased stability, but it is not possible to judge whether this is due to the gain in strength or the improvement in muscular balance. Most persons show a muscular imbalance to some extent which may vary greatly, analogous to the present group. For the extensors maximal isometric strength tests showed a clinically non-relevant difference of 1.1% between right and left leg for younger, and 3.4% for older persons [5,10]. On the other hand, in accordance with the present results differences up to 10% were considered to be normal for isokinetic measurements [10,16]. Some authors claimed higher injury rates when imbalances exceeded 10% [4]. To date, muscular imbalances have not been recognised as important enough to be treated unless immobilisation or injuries caused obvious one-sided atrophy. In these cases strengthening of the atrophic region has been supplemented by balance training increasingly during the last several years. This addition has led to earlier improvement in and recovery of function.

Based on positive results of short-term exposure to destabilizing platform movements leading to an inhibition of inappropriate motor response and improved balance, balance training was applied to frail persons over 75 years of age [15]. Resistive training with simple machines and balance exercises to improve postural control, a combined training and a control group were compared after 3 months [8]. Resistive training or the combination with balance training yielded an improvement in strength, but contrary to the present results, balance training yielded no improvement in strength. Balance exercise was conducted in a much lower intensity than in the present investigation.

The application of the present results seems to be important not only for younger active persons but also for older ones since balance and strength decrease with age [14]. Only in older persons a relationship was found between muscle performance and balance. Strength training resulted in a smaller gain in balance than proprioceptive training in a group of older subjects [3].

The effectiveness of strength training has been well documented and is widely accepted. Now significant gains in strength could also be shown from balance training. Applications in rehabilitative and preventive medicine as well as for geriatric patients need further investigations.

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