REVIEW ARTICLE

Sports Med 2011; 41 (5): 377-400
0112-1642/11/0005-0377/$49.95/0

Comparison of Traditional and Recent Approaches in the Promotion of Balance and Strength in Older Adults

Urs Granacher,[1] *Thomas Muehlbauer,*[1] *Lukas Zahner,*[2] *Albert Gollhofer*[3] and *Reto W. Kressig*[4]

1 Institute of Sport Science, Friedrich-Schiller University, Jena, Germany
2 Institute of Exercise and Health Science, University of Basel, Basel, Switzerland
3 Institute of Sport and Sport Science, University of Freiburg, Freiburg, Germany
4 Basel University Hospital, Division of Acute Geriatrics, Basel, Switzerland

Contents

Abstract

Demographic change in industrialized countries produced an increase in the proportion of elderly people in our society, resulting in specific healthcare challenges. One such challenge is how to effectively deal with the increased risk of sustaining a fall and fall-related injuries in old age. Deficits in postural control and muscle strength represent important intrinsic fall risk factors. Thus, adequate training regimens need to be designed and applied that have the potential to reduce the rate of falling in older adults by countering these factors. Therefore, the purpose of this review is to compare traditional and recent approaches in the promotion of balance and strength in older adults. Traditionally, balance and resistance training programmes proved to be effective in improving balance and strength, and in reducing the number of falls. Yet, it was argued that these training protocols are not specific enough to induce adaptations in neuromuscular capacities that are specifically needed in actual balance-threatening situations (e.g. abilities to recover balance and to produce force explosively). Recent studies indicated that perturbation-based or multitask balance training and power/high-velocity resistance training have the potential to improve these specific capacities because they comply with the principle of training specificity. In fact, there is evidence that these specifically tailored training programmes are more effective in improving balance recovery mechanisms and muscle power than traditional training protocols. A few pilot studies have even shown that these recently designed training protocols have an impact on the reduction of fall incidence rate in older adults. Further research is needed to confirm these results and to elucidate the underlying mechanisms responsible for the adaptive processes.

1. Introduction

The world population is increasingly becoming 'old'. According to the United Nations, the proportion of older people aged ≥60 years in the world has grown from 8% to 10% between 1950 and 2000, and by 2050 the proportion of this population worldwide is expected to be as high as 22%.[1] A serious concern, particularly of developed countries, is that an older age structure would undermine the sustainability of the public healthcare system, since per capita health expenditures are five times higher for people older than 75 years of age than for those aged 25–34 years.[2] One reason for high medical treatment costs in the elderly seems to be an increased prevalence of sustaining falls and fall-related injuries:[3,4] 28–35% of individuals over the age of 65 years suffer at least one fall over a 1-year period,[5,6] and the occurrence increases to 32–42% in adults over the age of 75 years and to 56% of adults between the ages of 90 and 99 years.[7,8] About 20% of falls need medical attention; 15% of those result in severe injuries like joint dislocations, soft tissue bruises and contusions. The remaining 5% cause fractures, with femoral neck fractures occurring at a rate of 1–2% in community-dwelling older adults.[9]

The aetiology of falls is generally considered to be multifactorial, involving extrinsic (environmental) and intrinsic (patient-related) circumstances.[10] Numerous epidemiological studies have identified a multitude of extrinsic and intrinsic risk factors for falling in older adults.[11-15] Extrinsic factors include loose rugs, obstructed walkways, inadequate handrails, etc.[16] In terms of intrinsic fall risk factors, impaired postural control under single (e.g. walking/standing) and particularly multitask conditions (e.g. walking/standing while talking), and deficits in maximal and particularly explosive force production of lower extremity muscles, have most frequently been reported to increase the risk of falling in the elderly population.[17,18] Age-related changes in postural control can be attributed mainly to cognitive impairment,[19] visual, vestibular and proprioceptive dysfunctions[20] and muscle weakness.[21] The decline in maximal and explosive force production is primarily caused by a reduced excitability of efferent corticospinal pathways[22] resulting in lower levels of central muscle activation,[23] a gradual loss of spinal motoneurons due to apoptosis,[24] a subsequent decline in muscle fibre number and size (sarcopenia),[25] changes in muscle architecture[26] and decreases in tendon stiffness.[27]

Given these detrimental effects of ageing, it is important to design and apply adequate intervention programmes that are able, for example, to delay or even reverse age-related constraints within the neuromuscular system. Recently, it was reported that postural control and strength are two independent neuromuscular capacities.[28] Thus, the authors suggested that the abilities to control posture and to produce force should be trained complementarily. This finding is reinforced by a recent meta-analysis, which provides evidence that, in particular, the combination of balance- and strength-promoting exercises has an impact on both intrinsic fall risk factors, such as deficits in postural control and muscle weakness, and on fall rate (up to 50% reduction).[29] In recent years, a trend towards more specifically designed balance and resistance training programmes has been noted in the literature. It is argued that perturbation-based or multitask balance training programmes as well as power or high-velocity strength training programmes are more effective than traditional balance or resistance training programmes in attenuating or even reversing intrinsic fall risk factors in old age.[30-38] Thus, the objective of this review is to describe and discuss traditional and particularly recent approaches in balance and resistance training regarding the effects of these training regimens on intrinsic fall risk factors, i.e. postural control and strength in older adults.

2. Literature Search

2.1 Search Strategy

Two reviewers performed systematic electronic searches on MEDLINE, PubMed, SportDiscus® and Web of Science. The last search was performed on 25 June 2010. A search filter containing medical subject headings (MeSH) terms was applied. The primary search included permutations of keyword combinations for the following PICO (Patient/population and/or problem, Intervention, Comparison/control intervention and Outcome or effects)[39] categories:

1. Patient/population and/or problem: ‘aged’, ‘ageing’, ‘aging’, ‘elderly’, ‘geriatric’, ‘older adults’, ‘senior’.
2. Intervention: ‘balance training’, ‘sensorimotor training’, ‘perturbation exercise’, ‘step training’, ‘dual-task training’, ‘resistance training’, ‘strength training’, ‘high-velocity strength training’, ‘power training’, ‘weight training’.
3. Comparison/control intervention: ‘intervention versus no treatment’, ‘intervention versus usual care programme’, ‘traditional intervention versus recent intervention’.
4. Outcome: ‘balance’, ‘gait’, ‘walking’, ‘stance’, ‘standing’, ‘postural stability’, ‘postural control’, ‘body sway’, ‘strength’, ‘power’, ‘physical function’.

The MeSH terms for each PICO category were connected using the ‘AND’ operator. Furthermore, we set limits on the types of article (i.e. randomized or clinical controlled trial, peer-reviewed journal article), ages (i.e. ≥60 years), species (i.e. humans), text options (i.e. full text) and languages (i.e. English). Results of the initial search are summarized in figure 1. In a secondary search, articles from the reference list of included articles were screened using the same criteria as applied to the initial citation search.

2.2 Selection Criteria

Studies were included in the review if they (i) were randomized or clinical controlled trials published in peer-reviewed journals; (ii) had study participants who were aged ≥60 years (except otherwise stated due to a limited amount of studies available); and (iii) had incorporated at least one balance or strength outcome measure. Studies were excluded if they (i) did not meet the minimum requirements of an experimental study design (e.g. case reports); (ii) did not meet the minimum requirements regarding training design (e.g. volume, frequency or intensity statements); and (iii) were not written in English. Based on the inclusion and exclusion criteria, two independent reviewers screened citations of potentially relevant publications. If the citation showed any potential relevance, it was screened at the abstract level. When abstracts indicated potential inclusion, full text articles were reviewed for inclusion. A third-party consensus meeting was held if two reviewers were not able to reach agreement on inclusion of an article.

2.3 Quality Assessment

Two reviewers independently performed quality assessments of included studies, and disagreements were resolved during a consensus meeting or rating by a third assessor. Initially, methodological quality was assessed using the Physiotherapy Evidence Database (PEDro) scale[40] because it had previously shown good reliability.[41,42] This scale rates randomized controlled trials from 0 to 10. The PEDro scores are presented in tables I and II for the respective studies. Given that only a few but highly relevant perturbation-based and dual-task balance training studies are available, we decided to include articles in this review that

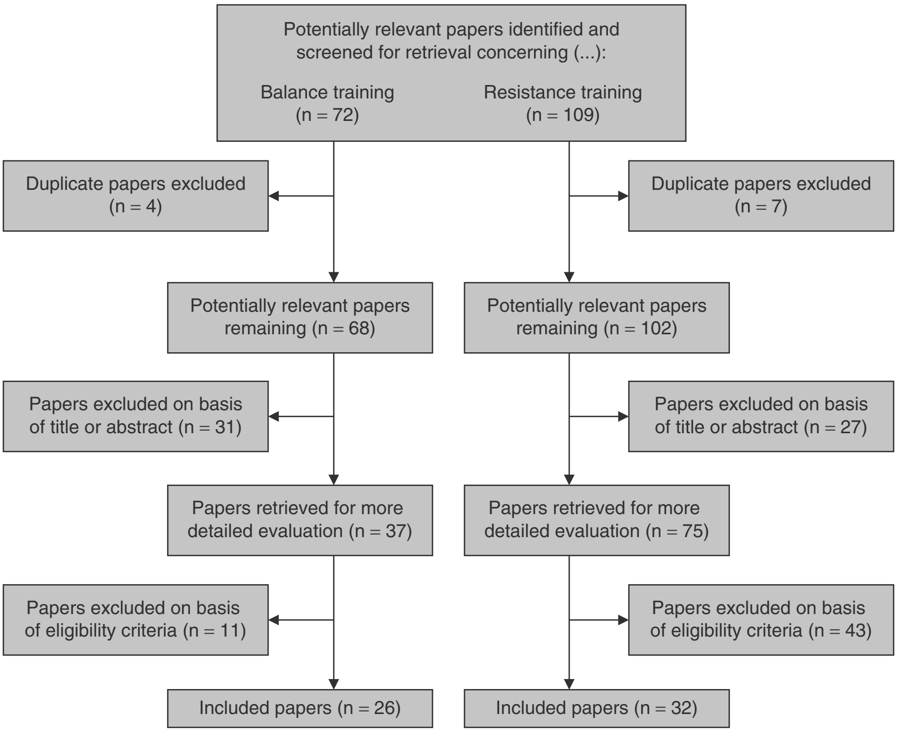

Fig. 1. Flowchart illustrating the different phases of the search and selection of the balance/resistance training studies.

do not fully meet the high standards of the PEDro scale.

3. Balance Training in Older Adults

3.1 Traditional Balance Training

Traditionally, balance training has been used to rehabilitate ankle and knee joint injuries. More recently, the application area of balance training was expanded to the geriatric population with the purpose of fall prevention. However, in contrast to resistance training, there are hardly any scientific guidelines concerning contents, optimal duration and intensity in balance training. Thus, there is a large variation in these parameters. With regard to content, even Tai Chi can be classified as balance training in the broadest sense. Yet, primarily static and dynamic exercises on stable and unstable surfaces during bipedal or monopedal stance with eyes open or closed represent the core of traditional balance training. Regarding optimal duration of balance training, reported training periods range from 2 days,[34] over 4 and 13 weeks[36,74] to 1 year.[75] A recent systematic review on balance training in healthy individuals clarifies this issue by indicating that balance training programmes performed at least 10 minutes per day, 3 days per week for 4 weeks have the potential to improve balance ability.[76] Training intensity often varies in balance training in terms of diverse conditions regarding the base of support (e.g. bipedal vs monopedal stance), the sensory input (e.g. eyes open vs eyes closed) and task complexity (e.g. single task balance training vs multitask balance training). In a recent position stand on exercise and physical activity for older adults, the American College of Sports Medicine[77] provided preliminary exercise prescription guidelines that included the following:

1. Progressively difficult postures that gradually reduce the base of support (e.g. two-legged stand, semi-tandem stand, tandem stand, one-legged stand).

Table I. Studies examining the impact of perturbation-based and multitask balance training on balance performance in older adults

Study (y)	No. of subjects; sex; exercise group; age (y)	Training regimen; volume	Frequency	Intensity	Balance gain	PEDro score
Mynark and Koceja[34] (2002)	10; F (5), M (5); EG; ≥65	PBBT; 2 d	1 ×/d	NA	Improvements in regulation of the Hoffman reflex (↑ 19–21%; $p<0.05$) and in static sway area (↑ 10%; $p<0.05$)	3
Rogers et al.[43] (2003)	8; F (4), M (4); EG; ≥63	PBBT; 3 wk	2 ×/wk	53 trials each session	Improvements in step initiation time (↑ 7–19%; $p<0.01$), and in step completion time (↑ 17–28%; $p\leq 0.05$). No significant improvements in step length	2
Jöbges et al.[44] (2004)	14; F (8), M (6); EG; ≥41[a]	PBBT; 2 wk	2 ×/d	20 min each session	Improvements in length of compensatory steps (↑ 88%; $p<0.001$), step initiation time (↑ 30%; $p<0.001$), step length (↑ 11%; $p=0.026$), cadence (↑ 9%; $p=0.03$), gait velocity (↑ 20%; $p=0.007$) and in double support time (↑ 48%; $p=0.046$). No significant improvements in measures of static postural control	0
Shimadaet al.[45] (2004)	32; F (11), M (3); EG; F (14), M (4); TEG; ≥66	PBBT; 6 mo	1–3 ×/wk	600 min total sessions	Improvements in reaction time during unperturbed (↑ 32%; $p=0.015$) and perturbed walking (↑ 34%; $p=0.007$), in one-leg standing time (↑ 60%; $p=0.017$) and in FRT (↑ 42%; $p<0.001$)	3
Marigold et al.[46] (2005)	30; F (7), M (23); AG; 31; F (10), M (21); SWG; ≥50[b]	PBBT; 10 wk	3 ×/wk	60 min each session	Improvements in postural reflex onset latency (↑ 4–17%; $p\leq 0.05$), step reaction time (↑ 16%; $p=0.005$), BBS (↑ 10%; $p<0.001$) and in TUG (↑ 17%; $p<0.001$)	8
Silsupadol et al.[47] (2006)	3; F (2), M (1); EG; ≥82	MTBT; 4 wk	3 ×/wk	45 min each session	Improvements in BBS (↑ 6–45%) in DGI (↑ 10–17%) and in TUG (↑ 8–25%)	1
Yang et al.[48] (2007)	25; F (5), M (7); CG; F (6), M (7); EG; range 45–80[b]	DTWT; 4 wk	3 ×/wk	30 min each session	Improvements in gait speed (↑ 30%; $p<0.001$), cadence (↑ 15%; $p<0.001$), stride time (↑ 0.2%; $p=0.007$) and stride length (↑ 18%; $p=0.003$)	6

Continued next page

Table I. Contd

Study (y)	No. of subjects; sex; exercise group; age (y)	Training regimen; volume	Frequency	Intensity	Balance gain	PEDro score
Sakai et al.[32] (2008)	43; F (26), M (19); EG; ≥68	PBBT; 1 d	1 ×/d	5 min	Improvements in the degree of body sway (↑ 7%; $p < 0.01$), stride time (↑ 3%; $p < 0.01$) and integral EMG (↑ 5–13%; $p < 0.01$) of muscles compensating for the perturbation impulse. No significant improvements in the latency EMG of muscles compensating for the perturbation impulse	1
Silsupadol et al.[49] (2009)	21; F (7); ST; F (10), M (4); DT; ≥65	MTBT; 4 wk	3 ×/wk	45 min each session	No significant improvements in gait speed and stride length. Improvements in ankle joint inclination angle (↑ 30–56%; $p = 0.04$)	5
Silsupadol et al.[36] (2009)	21; F (7); ST; F (10), M (4); DT; ≥65	MTBT; 4 wk	3 ×/wk	45 min each session	Improvements in single-task gait speed (↑ 3–14%; $p = 0.02$) for ST and DT, in dual-task gait speed (↑ 17–18%; $p < 0.001$) for DT, and in BBS (↑ 10–15%; $p < 0.001$) for ST and DT	7
Brauer and Morris[50] (2010)	20; F (8), M (12); EG; ≥39[b]	MTBT; 1 d	1 ×/d	20 min	Improvements in single- (↑ 13%; $p < 0.001$) and dual-task (↑ 4–12%; $p < 0.05$) gait speed and in single- (↑ 12%; $p < 0.001$) and dual-task (↑ 5–16%; $p < 0.01$) step length	1
Granacher et al.[51] (2010)	11; F (7), M (4); EG; ≥67	MTBT; 6 wk	3 ×/wk	60 min each session	Improvements in stride time variability during single- (↑ 35%; $p = 0.02$) but not dual- and triple-task walking	6
Mansfield et al.[52] (2010)	30; F (7), M (7); CG; 16; F (8), M (8); EG; 64–80	PBBT; 6 wk	3 ×/wk	30 min each session	Improvements in frequency of multi-step reactions (↑ 31%; $p = 0.034$) and foot collisions (↑ 67%; $p = 0.005$) following surface translation and in grasping reactions (↑ 19%; $p = 0.004$) following cable pull	7
Schwenk et al.[53] (2010)	49; F (18), M (11); CG; F (13), M (7); EG; ≥67[c]	DT; 12 wk	2 ×/wk	60 min each session	Changes in dual-task cost in gait speed (↑ 38%; $p = 0.086$), cadence (↑ 27%; $p = 0.846$), stride length (↑ 98%; $p = 0.074$), stride time (↑ 30%; $p = 0.750$) and single support (↑ 32%; $p = 0.459$)	5

a Patients with PD.

b Patients with CS.

c Patients with dementia.

×/d = times per day; **×/wk** = times per week; **AG** = agility exercise group; **BBS** = Berg balance scale; **CG** = control group; **CS** = chronic stroke; **DGI** = dynamic gait index; **DP** = dementia patients; **DT** = dual-task balance training group; **DTWT** = dual-task walking training; **EG** = exercise group containing physical therapy, stretching and gait training; **EMG** = electromyogram; **F** = female; **FRT** = functional reach test; **M** = males; **MTBT** = multitask balance training; **NA** = not available; **PBBT** = perturbation-based balance training; **PD** = Parkinson's disease; **PEDro** = Physiotherapy Evidence Database; **ST** = single-task balance training group; **SWG** = stretching/weight-shifting exercise group; **TEG** = treadmill exercise group containing perturbed walking on a treadmill; **TUG** = timed up-and-go test; ↑ indicates an increase in percentage change (e.g. from pre- to post-testing).

Table II. Studies examining the impact of power or high-velocity resistance training on balance and strength performance in older adults

Study (y)	No. of subjects; sex; age	Training regimen; volume (wk)	Frequency (×/wk)	Intensity (%)[a]	Sets; reps	Balance gain	Strength gain	PEDro score
Häkkinen et al.[54] (1998)	21; F (10), M (11); ≥64	PT; 24	2	50–80	3–4; 10–15	ND	Improvements in maximal isometric (M: ↑36%; $p<0.001$; F: ↑57%; $p<0.001$) and dynamic (M: ↑21%; $p<0.001$; F: ↑30%; $p<0.001$) leg extensor strength	2
Häkkinen et al.[55] (2000)	10; F (5), M (5); ≥62	PT; 24	2	50–80	3–4; 10–15	ND	Improvements in maximal isometric leg extension values (↑23–29%; $p<0.001$)	1
Earles et al.[56] (2001)	18; F (11), M (7); ≥70	HVRT; 12	3	50–70	3; 10	Improvements in gait velocity (↑5%; $p<0.001$). No significant improvements in 6-m walk distance and in single-leg stance time	Improvements in maximal leg press power (↑22%; $p=0.004$) and strength (↑22%; $p<0.001$)	5
Izquierdo et al.[57] (2001)	11; M; ≥62	PT; 16	2	50–80	3–4; 10–15	ND	Improvements in maximal isometric force (↑26%; $p<0.001$)	2
Fielding et al.[58] (2002)	30; F; ≥72	HVRT; 16	3	70	3; 8–10	ND	Improvements in leg press (↑35%; $p<0.001$) and knee extensor (↑25%; $p<0.001$) strength and leg press (↑97%; $p<0.002$) and knee extensor (↑33%; $p<0.001$) power	4
Miszko et al.[59] (2003)	39; F (9), M (6); CG; F (7), M (6); PG; F (6), M (5); SG; ≥65	PT; 16	3	50–80	3; 6–8	Improvements on the CS-PFP (↑15%; $p<0.05$)	No significant improvements in strength parameters	3
Sayers et al.[60] (2003)	15; F; ≥65	HVRT; 16	3	70	3; 8	Improvements in tandem walk (↑8%; $p=0.03$) and stair climb time (↑9%; $p<0.001$). No significant improvements in chair-rise time and gait velocity	ND	3

Continued next page

Table II. Contd

Study (y)	No. of subjects; sex; age	Training regimen; volume (wk)	Frequency (×/wk)	Intensity (%)[a]	Sets; reps	Balance gain	Strength gain	PEDro score
Bean et al.[61] (2004)	10; F; ≥70	HVRT; 12	3	NA	3; 10	Improvements chair rise time ($\uparrow$ 8%; $p<0.05$). No significant improvements in gait speed and single-leg stance time	Improvements in leg press power ($\uparrow$ 12–36%; $p<0.05$)	5
Kongsgaard et al.[62] (2004)	6; M; ≥65[b]	HVRT;12	2	80	4; 8	Improvements in maximal gait time ($\uparrow$ 14%; $p<0.01$) and stair climbing time ($\uparrow$ 17%; $p<0.05$)	Improvements in lower extremity strength ($\uparrow$ 15–37%; $p<0.01$) and peak power ($\uparrow$ 19%; $p<0.01$)	3
De Vos et al.[63] (2005)	112; F (68), M (44); ≥60	PT; 8–12	2	20, 50, 80	3; 8	ND	Improvements in muscle strength ($\uparrow$ 13–20%; $p\leq 0.001$) and muscle power ($\uparrow$ 14–15%; $p\leq 0.05$) performance	6
Henwood and Taaffe[64] (2005)	25; F (17), M (8); ≥60	HVRT; 8	2	33, 55, 75	3; 6–8	Improvements in 6-m backward walk ($\uparrow$ 7%; $p<0.01$), floor rise to standing ($\uparrow$ 10%; $p<0.05$) and chair rise ($\uparrow$ 10%; $p<0.05$) times	Improvements in upper ($\uparrow$ 29%; $p\leq 0.01$) and lower ($\uparrow$ 43%; $p\leq 0.01$) extremity strength and lower knee extensor power ($\uparrow$ 17%; $p\leq 0.002$)	4
Henwood and Taaffe[65] (2006)	23; F (14), M (9); ≥65	HVRT; 8	2	45, 60, 75	3; 8	Improvements in 6-m walk ($\uparrow$ 7%; $p<0.01$) and chair rise ($\uparrow$ 12%; $p<0.05$) times	Improvements in upper ($\uparrow$ 10–25%; $p\leq 0.05$) and lower ($\uparrow$ 10–43%; $p<0.01$) extremity strength	5
Holviala et al.[66] (2006)	22; W; ≥60	HVRT; 21	2	40–80	2–5; 8–15	Improvements in 6-m walk ($\uparrow$ 3%; $p<0.05$)	Improvements in maximal isometric force ($\uparrow$ 20%; $p<0.001$) and rate of force development ($\uparrow$ 18–31%; $p<0.01$)	3
Orr et al.[67] (2006)	12; F (68), M (44); ≥60	PT; 8–12	2	20, 50, 80	3; 8	Improvements in balance performance ($\uparrow$ 1–11%; $p=0.006$)	Improvements in muscle strength ($\uparrow$ 13–20%; $p<0.004$) and in muscle power ($\uparrow$ 14–15%; $p<0.004$) performance	7
Bottaro et al.[68] (2007)	11; M; ≥60	HVRT; 10	2	60	3; 8–10	Improvements in 8-ft (2.4-m) up-and-go test ($\uparrow$ 15%; $p<0.05$) and in 30-sec chair stand test ($\uparrow$ 43%; $p<0.05$)	Improvements in dynamic upper ($\uparrow$ 28%; $p<0.05$) and lower ($\uparrow$ 27%; $p<0.05$) body strength and upper ($\uparrow$ 37%; $p<0.05$) and lower ($\uparrow$ 31%; $p<0.05$) body power	3

Continued next page

Table II. Contd

Study (y)	No. of subjects; sex; age	Training regimen; volume (wk)	Frequency (×/wk)	Intensity (%)[a]	Sets; reps	Balance gain	Strength gain	PEDro score
Caserotti et al.[69] (2008)	65; W; 60–65 (old community-dwelling women [$n=40$]); 80–89 (very-old community-dwelling women [$n=25$])	HVRT; 12	2	75–80	4; 8–10	ND	60–65 y: improvements in peak force (↑ 22%; $p<0.001$), rate of force development (↑ 18%; $p=0.003$), and jumping height (↑ 10%; $p=0.002$); 80–89 y: improvements in peak force (↑ 28%; $p=0.005$), rate of force development (↑ 51%; $p=0.005$), and jumping height (↑ 18%; $p=0.05$)	2
Henwood et al.[70] (2008)	19; F (12), M (7); ≥65	PT; 24	2	40–75	3; ≥8	Improvements in the 6-m backwards walk (↑ 16%; $p\leq 0.001$), chair rise time (↑ 13%; $p=0.004$) and FRT (↑ 9%; $p<0.05$)	Improvements in upper (↑ 19–21%; $p\leq 0.05$) and lower (↑ 35–125%; $p\leq 0.05$) maximal strength and upper (↑ 70–78%; $p\leq 0.05$) and lower (↑ 55–65%; $p\leq 0.005$) peak power	4
Reid et al.[37] (2008)	23; F (12), M (11); ≥65	PT; 12	3	70	3; 8	ND	Improvements in maximal muscle knee extensor strength (↑ 49%; $p<0.01$) and power (↑ 55%; $p<0.01$)	5
Marsh et al.[71] (2009)	15; F (9), M (6); ≥65	PT; 12	3	40–70	3; 8–10	ND	Improvements in maximal knee extension (↑ 34%; $p=0.003$) and leg press (↑ 41%; $p<0.001$) power, and knee extension (↑ 20%; $p=0.02$) and leg press (↑ 22%; $p=0.03$) strength	3
Nogueira et al.[72] (2009)	20; M; 60–76	PT + TRT; 10	3	40–60	3; 8–10	ND	Improvements in leg extensor strength (PT: ↑ 27%; $p<0.05$; TRT: ↑ 27%; $p<0.05$) and leg extensor power (PT: ↑ 31%; $p<0.05$; TRT: ↑ 8%; $p<0.05$)	3
Webber and Porter[73] (2010)	50; W; 70–88	PT; 12	2	80	3; 8–10	Changes in reaction time (↑ 2%; $p<0.51$) and movement time (↑ 8%; $p<0.20$)	Changes in dorsi flexor peak power (↑ 27%; $p<0.89$) and plantar flexor peak power (↑ 17%; $p<0.84$)	5

a Intensity is with 1RM unless otherwise stated.

b Patients with chronic obstructive pulmonary disease.

×/wk = times per week; **1RM** = one-repetition maximum; **BW** = bodyweight; **CG** = control group; **CS-PFP** = Continuous Scale Physical Functional Performance; **F** = female; **FRT** = functional reach test; **HVRT** = high-velocity resistance training; **M** = males; **NA** = not available; **ND** = no data; **PEDro** = Physiotherapy Evidence Database; **PEG** = power exercise group; **PT** = power training; **reps** = repetitions; **SEG** = strength exercise group; **TRT** = traditional resistance training; ↑ indicates an increase in percentage change (e.g. from pre- to post-testing).

2. Dynamic movements that perturb the centre of gravity (e.g. tandem walk, circle turns).
3. Stressing postural muscle groups (e.g. heel stands, toe stands).
4. Reducing sensory input (e.g. standing with eyes closed).

Despite the wide variety of contents, training duration and intensity in balance training, convincing results were obtained over recent years regarding the effects of balance training on both intrinsic fall risk factors (e.g. deficits in postural control and muscle strength) and the reduction of fall incidence rate.[74,75,78] In this regard, Steadman et al.[79] reported that 6 weeks of balance training with two training sessions per week improved the performance in clinical balance and mobility tests in elderly subjects aged ≥60 years. Granacher et al.[80] examined the effects of a 13-week balance training programme (three training sessions per week) for men between the ages of 60 and 80 years and its effects on performance in clinical balance tests (functional reach test, tandem walk test) and on the ability to compensate for medio-lateral perturbation impulses while standing on a two-dimensional balance platform. After training, performance in the clinical balance tests was significantly improved and summed oscillations of the balance platform were significantly reduced together with an improved activation of muscles compensating for the perturbation impulse. In a more functional approach, Granacher et al.[74] investigated the impact of a 13-week balance training programme (three training sessions per week) in elderly men on the ability to compensate for decelerating gait perturbations while walking on a treadmill. Balance training resulted in a decrease in onset latency and an enhanced reflex activity in the prime mover compensating for the decelerating perturbation impulse. Furthermore, Rochat et al.[81] reported that 10 weeks of low-intensity balance training (one training session per week) produced significant improvements in gait speed, stride length and falls efficacy in older adults who were fearful of falling (figure 2). In another study, Granacher et al.[78] were able to show that 13 weeks of balance training (three training sessions per week) improved maximal and explosive force production capacity of the leg extensors in a cohort of healthy elderly men between the ages of 60 and 80 years. Recently, the effects of a 16-week Tai Chi programme (one training session per week) on measures of postural control and walking ability were investigated in older community-dwelling older adults with a mean age of 69 years.[82] Postural sway under different task conditions (e.g. standing on the floor or on a foam mat) and choice stepping reaction time, i.e. the ability to step as quickly as possible on one of four randomly illuminated rectangular panels, were significantly improved in the Tai Chi group after training but not in the control group.

Given the potential of balance training and Tai Chi in old age to counteract a large number of intrinsic fall risk factors, it can be expected that these training regimens have a significant effect on fall incidence rate in older adults. In fact, Madureira et al.[75] investigated the impact of a 1-year balance training programme (static and dynamic exercise) with one session per week on their performance in different functional mobility

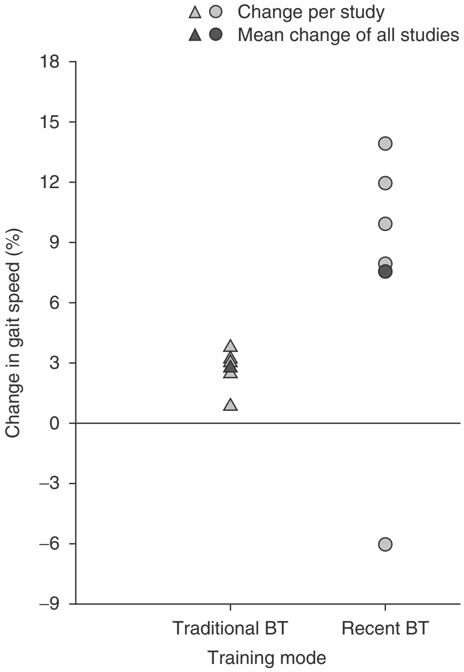

Fig. 2. Percentage of change in gait speed following traditional or recent approaches in balance training (BT). For clarity, more circles and triangles are plotted than there are studies in which gait speed was measured because a number of studies involved the assessment of more than one intervention (see table I).

tests (e.g. Berg balance scale [BBS], timed up-and-go test [TUG]) as well as on the rate of falling in women aged ≥65 years. After training, the intervention group showed improvements in functional mobility in terms of a significantly higher BBS score and a reduced time to complete the TUG. Notably, this enhancement was paralleled by a significant reduction in the number of falls in the intervention compared with the control group. In terms of Tai Chi, Li et al.[83] reported that a 6-month Tai Chi programme performed three times per week, is effective in decreasing the number of falls, risk for falling and fear of falling in physically inactive persons aged ≥70 years.

Only scarce information is available regarding adaptive mechanisms following balance training in old age, which is why results from different age groups have to be consulted. In his 2003 publication, Gollhofer[84] assumed that adaptive processes following balance training take place mainly at a spinal level due to the high intermuscular activation frequencies observed during stabilization tasks on unstable platforms. Recently, Taube et al.[85] investigated cortical and spinal adaptations in young adults following 4 weeks of balance training (three training sessions per week) by means of Hoffmann reflex stimulation, transcranial magnetic stimulation, and conditioning of the Hoffmann reflex by transcranial magnetic stimulation. After training, the authors observed an improved postural stability accompanied by a decrease in motor-evoked potentials during stance perturbation on a treadmill. At the same time, Hoffmann reflexes were decreased despite an unchanged background EMG during the performance of a balance task. This could imply that balance training induced changes in the regulation of human erect posture in terms of a shift from cortical to subcortical areas. Thus, supraspinal rather than spinal mechanisms seem to be responsible for the training-induced postural improvement.[85] In other words, after balance training, less neural effort might be required for the regulation of posture due to increased task automatization. However, further research is necessary to clarify whether the training-induced adaptive processes responsible for improvements in postural control observed in young adults can be transferred to elderly adults.

3.2 Perturbation-Based Balance Training

Recently, more specifically designed balance training programmes – so-called 'perturbation-based training regimens' – have begun to receive attention.[33] This approach is based on the fact that slips and trips account for 30–50% of falls in community-dwelling older adults.[86,87] Thus, compensatory strategies for recovery of equilibrium play a vital functional role in preventing falls. The successful recovery of balance demands the centre of mass to remain within the boundaries of the base of support. This compensatory mechanism can be achieved by different movement strategies (ankle, hip and step strategy).[88] In an actual fall situation, in-place strategies such as the ankle and hip strategy could be insufficient to recover balance, which is why a step is used to bring the support base back into alignment under the centre of mass. These change-in-support reactions (step strategy) can provide a much larger degree of stabilization, compared with in-place reactions where the base of support does not change.[89] It has been reported that neural control of change-in-support reactions evoked by postural perturbation differ in some fundamental way from volitional limb movements.[89] Given that recovery strategies are not under direct volitional control, it is not possible to train this specific capacity through voluntary exercises alone. However, since most balance training programmes include voluntarily controlled exercises only, it was suggested that adequate training regimens should comply with the principle of training specificity and involve the use of perturbation-based exercises.[31] The principle of training specificity requires that a person should experience training conditions (e.g. perturbation exercises) that match real-life conditions (e.g. balance recovery situations) as closely as possible. This fundamental principle of successful exercise prescription applies to anyone regardless of sex, level of physical activity or health status.[90]

Recently, Sakai et al.[32] were able to show that a short-term perturbation-based training programme (one session with 20 perturbation impulses) on a treadmill produced acute adaptations in terms of significant decreases in postural sway during slip-perturbed gait in a cohort of community-dwelling elderly subjects with a mean age of 71 years. This finding was paralleled by an improved activation of muscles compensating for the perturbation impulse. In an earlier study, Mynark and Koceja[34] investigated whether subjects older than 65 years of age show acute adaptations in the soleus muscle Hoffman reflex following short-term (2 days) perturbation-based balance training. After the first day of training, a significant down-regulation of the Hoffman reflex was observed (19%). On day 2, the Hoffman reflex was decreased by 21% in elderly subjects, indicating that the potential to functionally modulate reflex output persists despite the effects of ageing. In addition to the changes observed in Hoffman-reflex amplitude, the down-training of the Hoffman reflex also seemed to have a functional impact on the static balance of elderly subjects resulting in a significant 10% decrease in the area of static sway from pre- to post-test.

Perturbation-based balance training programmes were not only applied in short-term exercise regimens but also in long-term training programmes. Marigold et al.[46] determined the effect of two different community-based group exercise programmes on functional balance (e.g. BBS), mobility (e.g. TUG), postural reflexes (e.g. step reaction time, onset latency following platform translations), and falls in older adults (mean age 68 years) with chronic stroke. Participants were randomly assigned to an agility exercise group (e.g. standing in various postures, walking with various challenges, standing perturbations, etc.) or a stretching/weight-shifting exercise group (e.g. low-impact stretching, Tai Chi-like movements). Both groups exercised three times a week for 10 weeks. For both types of exercise programmes, training improved functional balance and mobility, and led to shorter latencies in postural reflexes and to faster step reaction time. Notably, the agility group demonstrated greater improvement in step reaction time and postural reflex onset latency, as well as a trend toward greater improvement in the TUG. In addition, the total number of falls experienced during platform translations was reduced to a larger extent in the agility than the stretching/weight-shifting group after the interventions.

Jöbges et al.[44] scrutinized the impact of compensatory step training in outpatients with Parkinson's disease (mean age 61 years) on the ability to compensate for unexpected perturbation impulses while standing, as well as on various gait parameters. Training was conducted for 2 weeks with two training sessions per day (weekends were excluded), and consisted of repetitive pulls to the patient's back and pushes to the person's right and left side applied by a physiotherapist. The strength of the pulls and pushes was adapted to the degree of the patient's individual postural instability. After training, a significant increase in length of compensatory steps was observed, which was accompanied by a significantly shorter step initiation time. In addition, significant training-induced increases in gait velocity and step length, as well as decreases in double support time, i.e. time in which both feet contact the floor during walking, were found during normal walking.

In another study with healthy older adults (mean age 70 years), Rogers et al.[43] showed that a 3-week period (two training session per week) of either voluntary or waist-pull-induced step training significantly reduced step initiation time, i.e. the time interval from the onset of a reaction stimulus cue until the vertical ground reaction force under the stepping limb equals zero at foot lift-off. Moreover, compared with voluntary step practice, the waist-pull-induced step training resulted in a significantly greater improvement in reaction time stepping.

In a comparative approach, Shimada et al.[45] investigated the effects of two types of exercise programmes (perturbed walking on a treadmill and exercise containing physical therapy, stretching and gait training) on the ability to compensate for gait perturbations, on functional reach performance and on fall rate in long-term care facility residents and outpatients aged 66–98 years. After 6 months of training (one to three training sessions per week), significant improvements in reaction time during perturbed walking and in functional reach performance were seen in the perturbed walking group but not in the exercise group with physical therapy, stretching and gait training. The number of falls occurring in the treadmill exercise group was 21% lower than that in the multi-component exercise group (odds ratio for falls 0.4). However, this difference was not significant, possibly due to the small sample size utilized in this study (n = 18 treadmill group vs 14 multi-component group). Recently, it was suggested to conduct a water-based balance training programme that includes perturbation exercises to improve stepping responses.[91] Water seems to provide a safe environment for perturbation exercises and may thus reduce the occurrence of exercise-induced fear of falling, which could be present during exercising on land. For therapists and practitioners, a schematic illustration of progression in perturbation-based balance training is presented in figure 3.

3.3 Multitask Balance Training

In accordance with the principle of training specificity, effective fall-prevention programmes should not only include balance-recovery reactions but also multitask balance exercises, because gait instability, and thus risk of falling, increases even when shared attention or dual-tasks (e.g. walking while talking) are performed.[18] In this regard, Brauer and Morris[50] investigated the impact of a 20-minute dual-task walking training session on acute adaptations in gait characteristics of people with Parkinson's disease. Participants performed a series of 10-m walking trials under seven conditions: gait only, and with six different added tasks varying by task type (e.g. motor, cognitive), domain (e.g. postural, manual manipulation, language, calculation, auditory, visuospatial) and difficulty level. Following training, step length increased when performing five of the six added tasks, indicating that transfer of dual-task training when walking occurred across task types and domains. Improvements in gait speed were present in three of the six added tasks (figure 2). When other gait variables were examined, such as step length variability, few improvements with training were found. Thus, dual-task training has the potential to induce acute improvements in specific gait characteristics of people with Parkinson's disease.

Regarding long-term training effects, Granacher et al.[51] investigated the impact of a 6-week balance training programme in healthy older adults with an age range of 65–80 years on the variability of their walking pattern both with and without dual and triple tasking, while concurrently performing a cognitive (backward

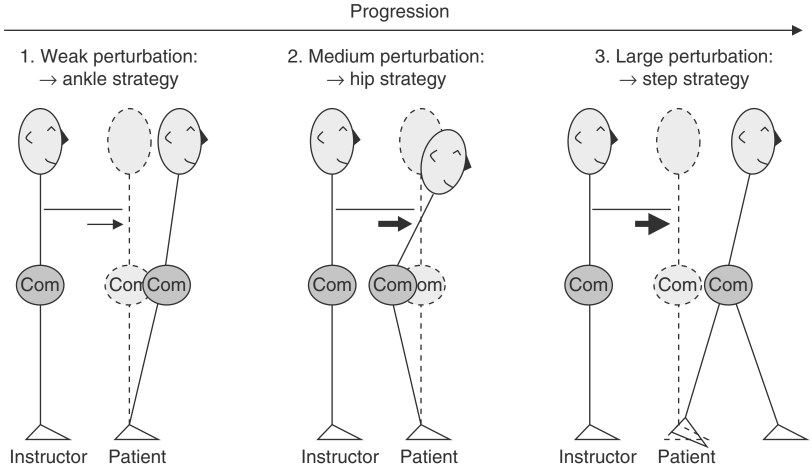

Fig. 3. Schematic illustration of progression in perturbation-based balance training. **Com** = centre of mass (the three different arrow thicknesses indicate an increase in the applied severity of the perturbation).

counting) and/or motor interference task (holding two interlocked sticks in front of the body). Balance training was conducted three times a week and training intensity was intensified by including additional motor interference tasks (e.g. catching and throwing a ball while performing a balance exercise) and by increasing the number of sets and/or the duration of single exercise sets. Balance training resulted in statistically significant reductions in stride time variability under single- (only walking) but not dual- (walking + cognitive/motor interference) or triple-task walking (walking + cognitive + motor interference). In addition, significant improvements in the motor interference task, but not in the cognitive interference task, were found while walking. Findings showed that improved performance during single-task walking did not transfer to walking under dual- or triple-task conditions, suggesting multiple-task balance training as an alternative training modality. Improvement of the secondary motor but not cognitive task may indicate the need for the involvement of motor, and particularly cognitive, tasks during balance training.

Silsupadol et al.[36] investigated the effects of single-task versus dual-task balance training with fixed-priority instructions and dual-task balance training with variable-priority instructions on gait speed under single- (only walking) and dual-task conditions (walking while concurrently performing an arithmetical task) in elderly adults. Single-task balance training involved the performance of balance exercises only (e.g. standing with eyes closed, tandem standing). The participants receiving dual-task balance training with fixed-priority instructions practiced balance tasks while simultaneously performing cognitive tasks (e.g. naming objects), and were instructed to maintain attention on both postural and cognitive tasks at all times. Participants in the dual-task balance training with variable-priority instructions performed the same exercises as the fixed instruction dual-task balance training group, but spent half the session focused on balance and half focused on cognitive task performance. Training lasted for 4 weeks with three training sessions a week. Gait speed was obtained at baseline, in the second week, at the end of training and in the twelfth week after the end of training. Following training, participants in all exercise groups significantly improved performance on single-task gait speed (figure 2). However, dual-task training (fixed and variable-priority instruction) was superior to single-task training in improving walking under dual-task conditions. In fact, only participants who received dual-task training walked significantly faster after the training when simultaneously performing a cognitive task. In addition, only dual-task balance training with variable-priority instructions resulted in a dual-task training effect in the second week and maintained the training effect at the 12-week follow-up. These findings suggest that older adults are able to improve their walking performance under dual-task conditions only when specific types of training, i.e. dual-task training, are performed. Furthermore, it seems that training balance under single-task conditions may not generalize to balance control in dual-task contexts.[36] This finding further strengthens the principle of training specificity when designing fall-preventive interventions. In fact, Oddsson et al.[92] followed this principle when introducing a concept for balance training that incorporates voluntary exercises as well as perturbation and dual-task exercises to improve balance control. The programme is performed on five different levels where levels 1–4 focus on the skill to maintain balance (voluntary control) and level 5 adds perturbation exercises that focus on the skill to recover balance (automatic postural corrections), as well as dual-task exercises providing a cognitive load during the execution of a balance task. The feasibility of the concept has been demonstrated in elderly fallers.[93] For therapists and practitioners, a schematic illustration of progression in multitask balance training is presented in figure 4. A detailed list of studies that conducted perturbation-based or multitask balance training is given in table I.

In summary, our outlines indicate that studies following the traditional or recent approach in balance training are heterogeneous in terms of training volume, training frequency and training intensity. Nevertheless, most of these studies were

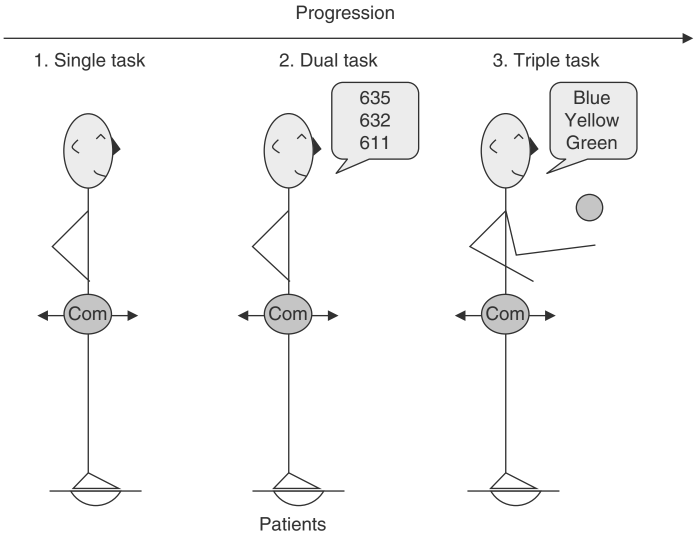

Fig. 4. Schematic illustration of progression in multitask balance training. **Com** = centre of mass (arrows indicate displacements of the Com).

effective in inducing acute or long-term adaptations in the postural control system. However, there is evidence that perturbation-based balance training is even more effective than traditional balance training in improving balance recovery mechanisms following perturbation impulses. Furthermore, it seems plausible to argue that multitask conditions should be applied in balance training because only multitask and not single-task balance training improves performance in multitask walking. Since training volume, frequency and intensity were rather heterogeneous in both traditional and recent approaches in balance training, it appears that training specificity in particular could be the major determinant responsible for the enhanced effectiveness of perturbation-based and multitask balance training over traditional balance training.

4. Resistance Training in Older Adults

Currently, resistance training programmes in the geriatric context mainly comprise three major methodological approaches: (i) high-intensity resistance training conducted at moderate movement speed, with loads corresponding to 70–80% of one-repetition maximum (1RM)[94,95] – the 1RM is defined as the load that can be lifted only once; (ii) high-velocity or power training conducted at maximum speed during the concentric phase and released at moderate speed during the eccentric phase of the exercise, with loads of 20–80% of 1RM;[37,58] and (iii) eccentric resistance training (also called negative resistance training) conducted at moderate movement speed with high mechanical loads.[96,97] It has been argued that negative work intervention programmes are particularly suited for elderly people because high mechanical loads can be produced at low energetic costs. In fact, LaStayo et al.[98] reported that the energy cost of eccentric work is approximately four times less than that of concentric work at a comparable external load. For a review on this topic see Roig et al.[99] However, the implementation of eccentric resistance training as an intervention programme for elderly people is hard to realize because the performance of resistance training in isolated eccentric contraction mode requires special training equipment (e.g. an isokinetic device). Further, intense guidance during training is mandatory and demands highly qualified personnel as well as a personnel-intense therapist-to-participant ratio. This is why eccentric resistance training was mainly applied in a scientific context and to a lesser extent in large-scale intervention programmes.

Due to these exercise-specific limitations of eccentric resistance training, we decided to focus our review on high-intensity resistance training and high-velocity or power training, which can be applied in large-scale intervention programmes and group exercises.

4.1 Traditional Resistance Training

The specific effects of resistance training in the elderly have been explored scientifically for many years. Early research from the 1970s and the 1980s was methodologically limited and quite conservative in terms of the intensity of the exercise prescription. At that time, it was assumed that resistance training for older adults could only induce neural adaptations but not muscle hypertrophy (for a review see Porter and Vandervoort[100]). However, in the late 1980s and early 1990s, new insights were gained regarding the real potential of resistance training for older adults, partly due to improved testing equipment, but also because of a better understanding of dose-response relations. Frontera et al.[101] and Fiatarone et al.[94] were among the first to prove that high-intensity resistance training conducted at 80% of 1RM is a feasible, safe and effective means to induce large increases in muscle strength (up to 227% increase in lower extremity strength)[101] and function (48% higher tandem gait speed).[94] CT scans indicated significant increases in muscle mass of the quadriceps (9.3%) following 12 weeks of training with three training sessions a week.[101] Today, it is well known that resistance training using heavy loads (>70% of 1RM) is more effective than low-intensity training in terms of strength gains and increases in muscle mass.[102] It was reported that heavy-resistance strength training leads to gains in muscle cross-sectional area ranging between 5–12% in elderly individuals as evaluated by MRI or CT scanning.[103] In addition, neural factors – such as an increased activation of the prime movers (improved recruitment pattern, discharge rate and synchronization of motor units), an improved coactivation of the synergists and a reduced coactivation of the antagonist muscles – have been discussed as potential adaptive mechanisms following resistance training in older adults.[104] Changes in muscle architecture in terms of an increased fascicle length and pennation angle[105] as well as increased tendon stiffness[106] may also account for an enhanced strength performance following resistance training in older adults. Yet, it seems that resistance training increases strength but has less-clear effects on balance abilities. Recently, it was shown that 13 weeks of heavy-resistance strength training with three training sessions per week had an impact on maximal and explosive force production[95] in elderly men but not on the ability to compensate for platform[95] or gait perturbation impulses.[74] A recent systematic review of randomized controlled trials on the efficacy of resistance training on balance performance in older adults found similar results.[107] In addition, Latham et al.[102] could not find a clear effect of resistance training on various measures of standing balance among 789 participants (effect size = 0.11). This rather limited adaptive potential of traditional resistance training restricted to variables of strength could be the reason why, to the authors' knowledge, no clear fall-preventive effect could be shown for resistance training alone.[108] Due to the well documented impact of resistance training on bone mineral content in the elderly,[109-112] it could be speculated that resistance training does not influence the risk of sustaining a fall in old age but does influence the risk of sustaining a fall-related fracture. Further research is necessary to prove this hypothesis.

4.2 Power or High-Velocity Resistance Training

The ability to generate force rapidly in advancing age declines more precipitously than maximal strength[113] and is, in a fall-threatening situation, more relevant for preventing a fall than the capacity to produce maximal strength.[114] In an actual fall risk situation (e.g. unexpected stop during standing in a driving bus/train), the time taken to produce maximal strength is too long to recover successfully from the balance threat. In fact, there is evidence that lower extremity muscle strength and power are predictors of the risk of falling.[115,116] Therefore, it is of paramount importance to apply resistance training programmes that have the potential to specifically enhance explosive force production capacity. It has been suggested that high-velocity and power training have a greater impact on explosive force production in the elderly than heavy-resistance strength training.[38]

Fielding et al.[58] were among the first to investigate the impact of a 16-week high- versus low-velocity resistance training regimen on variables of muscle strength (1RM) and power (force × velocity) of the knee and leg extensors in elderly women with self-reported disability. Both training groups exercised three times per week at an intensity of 70% of 1RM. After training, both groups improved their leg extensor 1RM strength (high velocity 35%; low velocity 33%) and knee extensor 1RM strength (high velocity 45%; low velocity 41%) to a similar extent. However, those in the high-velocity strength training group experienced significantly greater improvements in leg press peak muscle power than those participants in the low-velocity training group (high velocity 97%; low velocity 45%). Improvements in knee extensor peak power were not significantly different between the high- (33%) and low-intensity (25%) groups.

In a similar study design, Henwood et al.[70] investigated the impact of a 24-week high-velocity or constant-velocity resistance training regimen conducted twice a week on measures of dynamic and isometric muscle strength and peak muscle power. Participants in the high-velocity strength training group performed three sets with eight repetitions using maximal movement velocity. The first set was conducted at 45% of 1RM, the second set at 60% of 1RM, and the third set at 75% of 1RM. The constant-velocity resistance training group performed three sets with eight repetitions at 75% of 1RM using moderate movement velocity. Following training, the average change in dynamic muscle strength (across six exercises) amounted to 51% for the high-velocity, and 48% for the constant-velocity resistance training group. Maximal isometric strength significantly increased in the high-velocity group (30%) and in the constant-velocity group (24%). Significant training-induced increases in peak muscle power were observed for both exercise groups (high velocity 51%; constant velocity 34%). Overall, no significant differences between exercise groups emerged following training. Yet, it is important to note that these gains in muscle strength and power occurred for the high-velocity group using a reduced total workload per exercise session compared with the constant-velocity group. Thus, these findings support the efficiency of using high-velocity varied resistance training protocols in older adults as a means to enhance muscle strength and power. Recently, it was shown that older adults aged 60–65 years, and particularly those aged 80–89 years, benefit from 12 weeks of power training (two training sessions per week) in terms of large increases in the rate of force development (21% and 51%, respectively) and muscle power of the leg extensors (12% and 28%, respectively).[69]

Miszko et al.[59] scrutinized the effects of a 16-week power or strength training programme with three training sessions a week on maximal strength and peak anaerobic power of the leg extensors as well as physical function in community-dwelling older adults (mean age 73 years). Intensity in strength training progressed from 50% to 70% of 1RM by week 8, and then remained at 80% of 1RM for weeks 9–16. Intensity in power training was the same as in strength training for the first 8 weeks. After 8 weeks, the programme was altered to increase muscle power. Each subject performed three sets of 6–8 repetitions at 40% of 1RM value as fast as possible. Miszko et al.[59] found that power training was more effective than strength training for improving whole-body physical function on the continuous scale physical functional performance test, which assesses 16 everyday tasks with components for the lower body, the upper body, balance, coordination and endurance. In addition, results indicated that both programmes were equally effective for improving maximal strength. The strength training group were significantly stronger than the control group following training; however, there were no significant differences between the exercise groups. In a recently conducted study,[37] high-velocity power training and traditional slow-velocity progressive resistance training yielded similar increases of lower extremity power in older adults with mobility limitations. It is of interest to note that after 12 weeks of training (three training sessions a week), no significant changes in total leg lean mass assessed by dual-energy x-ray absorptiometry occurred over the course of the intervention in any group. Thus, the authors hypothesized that neuromuscular adaptations rather than muscle hypertrophy may account for the investigated gains in muscle strength and power.[37] Similarly, Fielding et al.[58] suggested that changes in motor unit recruitment and activation seem to be primarily responsible for increased peak power following 16 weeks of high-velocity resistance training (three training sessions per week).

Returning to the results of Miszko et al.[59] regarding the impact of power or resistance training on measures of physical function, Henwood and Taafe[64] confirmed these results by demonstrating that 8 weeks of high-velocity resistance training (two training sessions per week) produced larger improvements in tests of physical performance, i.e. the floor rise to standing test, the 6-m walk test, the repeated chair rise test, and the lift and reach test than traditional strength training. In a later study, however, Henwood et al.[70] reported that 24 weeks of high-velocity or constant resistance training (two training sessions per week) resulted in similar improvements in the 6-m fast walk, chair rise, stair climbing and functional reach task.

From a functional point of view, it is of interest to know whether power training has an impact on balance in older adults, since balance control is an important component of physical performance. In this regard, Orr et al.[67] investigated the effects of a 10-week power training (two sessions per week) programme at one of three intensities (20%, 50% and 80% of 1RM) on balance performance in sedentary healthy older adults. Irrespective of training intensity, significant improvements were observed in peak power, strength and endurance of lower extremity muscles. Notably, in the low-intensity group (20% of 1RM) training-induced improvements in balance were significantly higher than in the high (80% of 1RM) and medium (50% of 1RM) exercise groups, indicating that a low-load high-velocity regimen might be particularly well suited for the promotion of balance in older adults.

However, the question regarding the most effective training intensity in power training with older adults is still under debate. The American College of Sports Medicine, for instance, recommended that healthy older adults should perform one to three sets using light to moderate resistance (40–60% of 1RM) for six to ten repetitions with high-movement velocity. In contrast to these recommendations, it was reported that 8–12 weeks of power training with high loads (80% of 1RM) induced larger gains in muscle power, strength and endurance than power training with medium (50% of 1RM) and low loads (20% of 1RM).[63] It has to be mentioned that the risk of sustaining an injury during training was greater in the high-intensity group than that of the medium- and low-intensity groups. This has to be put into perspective though, since the rate of adverse

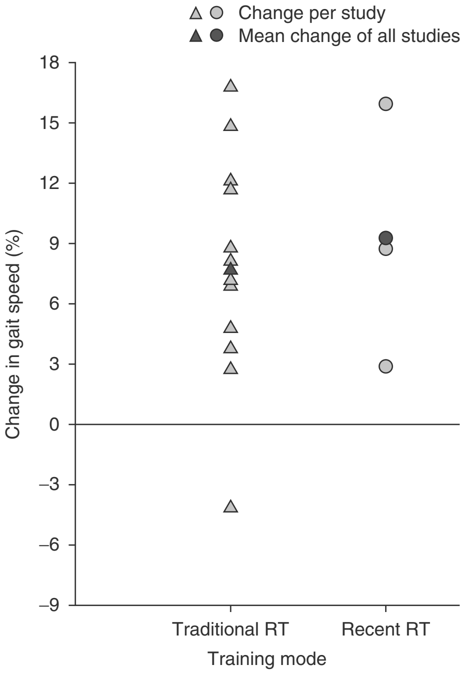

Fig. 5. Percentage of change in gait speed following traditional or recent approaches in resistance training (RT). For clarity, more circles and triangles are plotted than there are studies in which gait speed was measured because a number of studies involved the assessment of more than one intervention (see table II).[117-127]

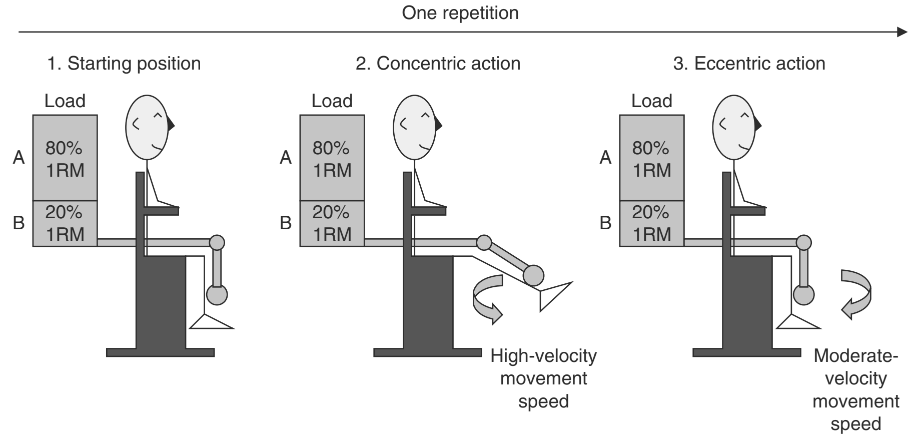

Fig. 6. Schematic description of power or high-velocity resistance training. **1RM** = one-repetition maximum.

events for strength testing (16 events, 4711 strength tests [0.34%]) and power training (four events, 1633 training sessions [0.25%]) was rather low.[63] In another study, the effects of a heavy-resistance training with explosive concentric contractions in elderly men with chronic obstructive pulmonary disease was investigated on muscle strength, power and physical performance.[62] Following 12 weeks of training (two training sessions per week), significant improvements in isometric (14%) and isokinetic (18%) knee extension strength, leg extension power (19%), quadriceps cross-sectional area (4%), maximal gait speed (14%) and stair climbing time (17%) were observed (figure 5). Notably, no training-related injuries were reported in this cohort of elderly men suffering from chronic disease. For therapists and practitioners, a schematic illustration of training load and contraction mode in power/high-velocity resistance training is presented in figure 6. A detailed list of studies that conducted power/high-velocity resistance training is given in table II.

In summary, our review indicates that high-intensity resistance training and power or high-velocity resistance training are effective in improving muscle strength/power and functional capacity even though major determinants of the respective study designs (e.g. training volume, frequency, intensity) were rather heterogeneous across the traditional and recent approaches. Yet, there is preliminary evidence that power training with particularly high loads is more effective/efficient in increasing power than traditional resistance training. Further, it seems that power training compared with resistance training is more beneficial in improving measures of physical function. More specifically, there is evidence that especially low-intensity power training is well suited to enhance balance in older adults. Given the heterogeneity in study designs across traditional and recent approaches in resistance training, it appears that the specificity of the contraction mode (moderate vs high velocity) may represent an important determinant for producing substantial gains in muscle power and functional capacity. This result complies with the principle of training specificity and suggests that ballistic contractions should be incorporated in resistance training for older adults.

5. Conclusions

During the last 30 years, intense research efforts have been undertaken regarding the effects of balance and resistance training on measures of postural control and strength in older adults. In general, these training regimens appear to be feasible, safe and effective. There is evidence that traditional balance training has an impact on postural control, physical function, and strength and fall rate in older adults. Based on preliminary data, it seems plausible to argue that specific types of balance training (perturbation-based and multitask) are particularly effective in promoting balance recovery mechanisms and variables of postural control under single and multitask conditions. This could indirectly imply that these training regimens may have a larger impact on fall rate than traditional balance training programmes. However, this important issue needs to be confirmed in future studies.

Traditional approaches have proven that resistance training particularly enhances strength performance but has limited effect on physical function. Thus, recent studies focused on the impact of power or high-velocity strength training and found that this training regimen seems to have larger effects on explosive force production and physical function than traditional resistance training. However, clear dose-response relations need to be established for power training.

Additional verification is needed regarding the underlying neuromuscular mechanisms responsible for training-induced adaptive processes following perturbation-based/multitask balance training and power/high-velocity resistance training.

Acknowledgements

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

References

1. United Nations. World population prospects: the 2004 revision. New York: United Nations, 2005
2. Reinhardt UE. Does the aging of the population really drive the demand for health care? Health Affairs 2003; 22 (6): 27-39
3. Stevens JA, Corso PS, Finkelstein EA, et al. The costs of fatal and non-fatal falls among older adults. Inj Prev 2006; 12 (5): 290-5
4. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing 2006; 35 Suppl. 2: 37-41
5. Campbell AJ, Reinken J, Allan BC, et al. Falls in old age: a study of frequency and related clinical factors. Age Ageing 1981; 10 (4): 264-70
6. Blake AJ, Morgan K, Bendall MJ, et al. Falls by elderly people at home: prevalence and associated factors. Age Ageing 1988; 17 (6): 365-72
7. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988; 319 (26): 1701-7
8. Downton JH, Andrews K. Prevalence, characteristics and factors associated with falls among the elderly living at home. Aging 1991; 3 (3): 219-28
9. Kannus P, Parkkari J, Koskinen S, et al. Fall-induced injuries and deaths among older adults. JAMA 1999; 281 (20): 1895-9
10. Bueno-Cavanillas A, Padilla-Ruiz F, Jimenez-Moleon JJ, et al. Risk factors in falls among the elderly according to extrinsic and intrinsic precipitating causes. Eur J Epidemiol 2000; 16 (9): 849-59
11. Alexander NB, Goldberg A. Gait disorders: search for multiple causes. Cleve Clin J Med 2005; 72 (7): 586-600
12. Jensen J, Nyberg L, Gustafson Y, et al. Fall and injury prevention in residential care: effects in residents with higher and lower levels of cognition. J Am Geriatr Soc 2003; 51 (5): 627-35
13. Lord SR, Dayhew J. Visual risk factors for falls in older people. J Am Geriatr Soc 2001; 49 (5): 508-15
14. Moreland JD, Richardson JA, Goldsmith CH, et al. Muscle weakness and falls in older adults: a systematic review and meta-analysis. J Am Geriatr Soc 2004; 52 (7): 1121-9
15. Nnodim JO, Alexander NB. Assessing falls in older adults: a comprehensive fall evaluation to reduce fall risk in older adults. Geriatrics 2005; 60 (10): 24-8
16. Carter SE, Campbell EM, SansonFisher RW, et al. Environmental hazards in the homes of older people. Age Ageing 1997; 26 (3): 195-202
17. 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 (6): 325-40
18. Beauchet O, Annweiler C, Dubost V, et al. Stops walking when talking: a predictor of falls in older adults? Eur J Neurol 2009; 16 (7): 786-95
19. Whitman GT, Tang Y, Lin A, et al. A prospective study of cerebral white matter abnormalities in older people with gait dysfunction. Neurology 2001; 57 (6): 990-4
20. Shaffer SW, Harrison AL. Aging of the somatosensory system: a translational perspective. Phys Ther 2007; 87 (2): 193-207
21. Hurley MV, Rees J, Newham DJ. Quadriceps function, proprioceptive acuity and functional performance in healthy young, middle-aged and elderly subjects. Age Ageing 1998; 27 (1): 55-62
22. Sale MV, Semmler JG. Age-related differences in corticospinal control during functional isometric contractions in left and right hands. J Appl Physiol 2005; 99 (4): 1483-93
23. Macaluso A, Nimmo MA, Foster JE, et al. Contractile muscle volume and agonist-antagonist coactivation account for differences in torque between young and older women. Muscle Nerve 2002; 25 (6): 858-63
24. Terao S, Sobue G, Hashizume Y, et al. Age-related changes in human spinal ventral horn cells with special reference to the loss of small neurons in the intermediate zone: a quantitative analysis. Acta Neuropathol 1996; 92 (2): 109-14

25. Lexell J, Taylor CC, Sjostrom M. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. J Neurol Sci 1988; 84 (2-3): 275-94
26. Narici MV, Maganaris CN, Reeves ND, et al. Effect of aging on human muscle architecture. J Appl Physiol 2003; 95 (6): 2229-34
27. Narici MV, Maganaris CN, Reeves N. Muscle and tendon adaptations to ageing and spaceflight. J Gravit Physiol 2002; 9 (1): 137-8
28. Granacher U, Gruber M, Gollhofer A. Force production capacity and functional reflex activity in young and elderly men. Aging Clin Exp Res. Epub 2009 Nov 27
29. Gillespie LD, Robertson MC, Gillespie WJ, et al. Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev 2009; (2): CD007146
30. Mansfield A, Peters AL, Liu BA, et al. A perturbation-based balance training program for older adults: study protocol for a randomised controlled trial. BMC Geriatr 2007; 7: 12
31. Maki BE, Cheng KC, Mansfield A, et al. Preventing falls in older adults: new interventions to promote more effective change-in-support balance reactions. J Electromyogr Kinesiol 2008; 18 (2): 243-54
32. Sakai M, Shiba Y, Sato H, et al. Motor adaptations during slip-perturbed gait in older adults. J Phys Ther Sci 2008; 20 (2): 109-15
33. Maki BE, McIlroy WE. Change-in-support balance reactions in older persons: an emerging research area of clinical importance. Neurol Clin 2005; 23 (3): 751-83
34. Mynark RG, Koceja DM. Down training of the elderly soleus H reflex with the use of a spinally induced balance perturbation. J Appl Physiol 2002; 93 (1): 127-33
35. Sayers SP. High-speed power training: a novel approach to resistance training in older men and women: a brief review and pilot study. J Strength Cond Res 2007; 21 (2): 518-26
36. Silsupadol P, Shumway-Cook A, Lugade V, et al. 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 (3): 381-7
37. Reid KF, Callahan DM, Carabello RJ, et al. Lower extremity power training in elderly subjects with mobility limitations: a randomized controlled trial. Aging Clin Exp Res 2008; 20 (4): 337-43
38. Porter MM. Power training for older adults. Appl Physiol Nutr Metab 2006; 31 (2): 87-94
39. Richardson W, Wilson M, Nishikawa J, et al. The well-built clinical question: a key to evidence-based decisions. ACP J Club 1995; 123: 12-3
40. Physiotherapy Evidence Database. PEDro scale, 2010 [online]. Available from URL: http://www.pedro.org au/english/downloads/pedro-scale/ [Accessed 2010 Jun 25]
41. Tooth L, Bennett S, McCluskey A, et al. Appraising the quality of randomized controlled trials: inter-rater reliability for the OTseeker evidence database. J Eval Clin Pract 2005; 11 (6): 547-55
42. Maher CG, Sherrington C, Herbert RD, et al. Reliability of the PEDro scale for rating quality of randomized controlled trials. Phys Ther 2003; 83 (8): 713-21
43. Rogers MW, Johnson ME, Martinez KM, et al. Step training improves the speed of voluntary step initiation in aging. J Gerontol A Biol Sci Med Sci 2003; 58 (1): 46-51
44. Jöbges M, Heuschkel G, Pretzel C, et al. Repetitive training of compensatory steps: a therapeutic approach for postural instability in Parkinson's disease. J Neurol Neurosurg Psychiatry 2004; 75 (12): 1682-7
45. Shimada H, Obuchi S, Furuna T, et al. New intervention program for preventing falls among frail elderly people: the effects of perturbed walking exercise using a bilateral separated treadmill. Am J Phys Med Rehabil 2004; 83 (7): 493-9
46. Marigold DS, Eng JJ, Dawson AS, et al. Exercise leads to faster postural reflexes, improved balance and mobility, and fewer falls in older persons with chronic stroke. J Am Geriatr Soc 2005; 53 (3): 416-23
47. Silsupadol P, Siu KC, Shumway-Cook A, et al. Training of balance under single- and dual-task conditions in older adults with balance impairment. Phys Ther 2006; 86 (2): 269-81
48. Yang YR, Wang RY, Chen YC, et al. Dual-task exercise improves walking ability in chronic stroke: a randomized controlled trial. Arch Phys Med Rehabil 2007; 88 (10): 1236-40
49. Silsupadol P, Lugade V, Shumway-Cook A, et al. Training-related changes in dual-task walking performance of elderly persons with balance impairment: a double-blind, randomized controlled trial. Gait Posture 2009; 29 (4): 634-9
50. Brauer SG, Morris ME. Can people with Parkinson's disease improve dual tasking when walking? Gait Posture 2010; 31 (2): 229-33
51. Granacher U, Muehlbauer T, Bridenbaugh S, et al. Balance training and multi-task performance in seniors. Int J Sports Med 2010; 31 (5): 353-8
52. Mansfield A, Peters AL, Liu BA, et al. Effect of a perturbation-based balance training program on compensatory stepping and grasping reactions in older adults: a randomized controlled trial. Phys Ther 2010; 90 (4): 476-91
53. Schwenk M, Zieschang T, Oster P, et al. Dual-task performances can be improved in patients with dementia: a randomized controlled trial. Neurology 2010; 74 (24): 1961-8
54. Häkkinen K, Kallinen M, Izquierdo M, et al. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. J Appl Physiol 1998; 84 (4): 1341-9
55. Häkkinen K, Alen M, Kallinen M, et al. Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. Eur J Appl Physiol 2000; 83 (1): 51-62
56. Earles DR, Judge JO, Gunnarsson OT. Velocity training induces power-specific adaptations in highly functioning older adults. Arch Phys Med Rehabil 2001; 82 (7): 872-8
57. Izquierdo M, Häkkinen K, Ibanez J, et al. Effects of strength training on muscle power and serum hormones in

middle-aged and older men. J Appl Physiol 2001; 90 (4): 1497-507

58. Fielding RA, LeBrasseur NK, Cuoco A, et al. High-velocity resistance training increases skeletal muscle peak power in older women. J Am Geriatr Soc 2002; 50 (4): 655-62
59. Miszko TA, Cress ME, Slade JM, et al. Effect of strength and power training on physical function in community-dwelling older adults. J Gerontol A Biol Sci Med Sci 2003; 58 (2): 171-5
60. Sayers SP, Bean J, Cuoco A, et al. Changes in function and disability after resistance training: does velocity matter? A pilot study. Am J Phys Med Rehabil 2003; 82 (8): 605-13
61. Bean JF, Herman S, Kiely DK, et al. Increased Velocity Exercise Specific to Task (InVEST) training: a pilot study exploring effects on leg power, balance, and mobility in community-dwelling older women. J Am Geriatr Soc 2004; 52 (5): 799-804
62. Kongsgaard M, Backer V, Jorgensen K, et al. Heavy resistance training increases muscle size, strength and physical function in elderly male COPD-patients: a pilot study. Respir Med 2004; 98 (10): 1000-7
63. de Vos NJ, Singh NA, Ross DA, et al. Optimal load for increasing muscle power during explosive resistance training in older adults. J Gerontol A Biol Sci Med Sci 2005; 60 (5): 638-47
64. Henwood TR, Taaffe DR. Improved physical performance in older adults undertaking a short-term programme of high-velocity resistance training. Gerontology 2005; 51 (2): 108-15
65. Henwood TR, Taaffe DR. Short-term resistance training and the older adult: the effect of varied programmes for the enhancement of muscle strength and functional performance. Clin Physiol Funct Imaging 2006; 26 (5): 305-13
66. Holviala JH, Sallinen JM, Kraemer WJ, et al. Effects of strength training on muscle strength characteristics, functional capabilities, and balance in middle-aged and older women. J Strength Cond Res 2006; 20 (2): 336-44
67. Orr R, de Vos NJ, Singh NA, et al. Power training improves balance in healthy older adults. J Gerontol A Biol Sci Med Sci 2006; 61 (1): 78-85
68. Bottaro M, Machado SN, Nogueira W, et al. Effect of high versus low-velocity resistance training on muscular fitness and functional performance in older men. Eur J Appl Physiol 2007; 99 (3): 257-64
69. Caserotti P, Aagaard P, Buttrup LJ, et al. Explosive heavy-resistance training in old and very old adults: changes in rapid muscle force, strength and power. Scand J Med Sci Sports 2008; 18 (6): 773-82
70. Henwood TR, Riek S, Taaffe DR. Strength versus muscle power-specific resistance training in community-dwelling older adults. J Gerontol A Biol Sci Med Sci 2008; 63 (1): 83-91
71. Marsh AP, Miller ME, Rejeski WJ, et al. Lower extremity muscle function after strength or power training in older adults. J Aging Phys Act 2009; 17 (4): 416-43
72. Nogueira W, Gentil P, Mello SN, et al. Effects of power training on muscle thickness of older men. Int J Sports Med 2009; 30 (3): 200-4
73. Webber SC, Porter MM. Effects of ankle power training on movement time in mobility-impaired older women. Med Sci Sports Exerc 2010; 42 (7): 1233-40
74. Granacher U, Gollhofer A, Strass D. Training induced adaptations in characteristics of postural reflexes in elderly men. Gait Posture 2006; 24 (4): 459-66
75. Madureira MM, Takayama L, Gallinaro AL, et al. Balance training program is highly effective in improving functional status and reducing the risk of falls in elderly women with osteoporosis: a randomized controlled trial. Osteoporos Int 2007; 18 (4): 419-25
76. DiStefano LJ, Clark MA, Padua DA. Evidence supporting balance training in healthy individuals: a systemic review. J Strength Cond Res 2009; 23 (9): 2718-31
77. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, et al. American College of Sports Medicine position stand: exercise and physical activity for older adults. Med Sci Sports Exerc 2009; 41 (7): 1510-30
78. Granacher U, Gruber M, Strass D, et al. The impact of sensorimotor training in elderly men on maximal and explosive force production capacity. Deut Z Sportmed 2007; 58 (12): 446-51
79. Steadman J, Donaldson N, Kalra L. A randomized controlled trial of an enhanced balance training program to improve mobility and reduce falls in elderly patients. J Am Geriatr Soc 2003; 51 (6): 847-52
80. Granacher U, Gruber M, Gollhofer A. The impact of sensorimotor training on postural control in elderly men. Deut Z Sportmed 2009; 60 (12): 387-93
81. Rochat S, Martin E, Piot-Ziegler C, et al. Falls self-efficacy and gait performance after gait and balance training in older people. J Am Geriatr Soc 2008; 56 (6): 1154-6
82. Voukelatos A, Cumming RG, Lord SR, et al. A randomized, controlled trial of tai chi for the prevention of falls: the Central Sydney tai chi trial. J Am Geriatr Soc 2007; 55 (8): 1185-91
83. Li F, Harmer P, Fisher KJ, et al. Tai Chi and fall reductions in older adults: a randomized controlled trial. J Gerontol A Biol Sci Med Sci 2005; 60 (2): 187-94
84. Gollhofer A. Proprioceptive training: considerations for strength and power production. In: Komi PV, editor. Strength and power in sport. Oxford: Blackwell Publishing, 2003: 331-42
85. Taube W, Gruber M, Beck S, et al. Cortical and spinal adaptations induced by balance training: correlation between stance stability and corticospinal activation. Acta Physiol 2007; 189 (4): 347-58
86. Gabell A, Simons MA, Nayak US. Falls in the healthy elderly: predisposing causes. Ergonomics 1985; 28 (7): 965-75
87. Lord SR, Ward JA, Williams P, et al. An epidemiological study of falls in older community-dwelling women: the Randwick falls and fractures study. Aust J Public Health 1993; 17 (3): 240-5
88. Woollacott MH, Shumway-Cook A, Nashner LM. Aging and posture control: changes in sensory organization and muscular coordination. Int J Aging Hum Dev 1986; 23 (2): 97-114

89. Maki BE, McIlroy WE. The role of limb movements in maintaining upright stance: the "change-in-support" strategy. Phys Ther 1997; 77 (5): 488-507

90. Reilly T, Morris T, Whyte G. The specificity of training prescription and physiological assessment: a review. J Sports Sci 2009; 27 (6): 575-89

91. Melzer I, Elbar O, Tsedek I, et al. A water-based training program that include perturbation exercises to improve stepping responses in older adults: study protocol for a randomized controlled cross-over trial. BMC Geriatr 2008; 8: 19

92. Oddsson LIE, Boissy P, Melzer I. How to improve gait and balance function in elderly individuals: compliance with principles of training. Eur Rev Aging Phys Act 2007; 4 (1): 15-23

93. Boissy P, Yurkow J, Chopra A, et al. Balance training in the elderly using Swiss ball: a pilot study [abstract]. Arch Phys Med Rehabil 2000; 81 (10): 1463

94. Fiatarone MA, Marks EC, Ryan ND, et al. High-intensity strength training in nonagenarians: effects on skeletal muscle. JAMA 1990; 263 (22): 3029-34

95. Granacher U, Gruber M, Gollhofer A. Resistance training and neuromuscular performance in seniors. Int J Sports Med 2009; 30 (9): 652-7

96. LaStayo PC, Ewy GA, Pierotti DD, et al. The positive effects of negative work: increased muscle strength and decreased fall risk in a frail elderly population. J Gerontol A Biol Sci Med Sci 2003; 58 (5): 419-24

97. Mueller M, Breil FA, Vogt M, et al. Different response to eccentric and concentric training in older men and women. Eur J Appl Physiol 2009; 107 (2): 145-53

98. LaStayo PC, Reich TE, Urquhart M, et al. Chronic eccentric exercise: improvements in muscle strength can occur with little demand for oxygen. Am J Physiol 1999; 276 (2): 611-5

99. Roig M, O'Brien K, Kirk G, et al. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. Br J Sports Med 2009; 43 (8): 556-68

100. Porter MM, Vandervoort AA. High-intensity strength training for the older adult: a review. Topics Geriatr Rehabil 1995; 10 (3): 61-74

101. Frontera WR, Meredith CN, O'Reilly KP, et al. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J Appl Physiol 1988; 64 (3): 1038-44

102. Latham NK, Bennett DA, Stretton CM, et al. Systematic review of progressive resistance strength training in older adults. J Gerontol A Biol Sci Med Sci 2004; 59 (1): 48-61

103. Aagaard P, Suetta C, Caserotti P, et al. Role of the nervous system in sarcopenia and muscle atrophy with aging: strength training as a countermeasure. Scand J Med Sci Sports 2010; 20 (1): 49-64

104. Häkkinen K. Ageing and neuromuscular adaptation to strength training. In: Komi PV, editor. Strength and power in sport. Oxford: Blackwell Publishing, 2003: 409-25

105. Seynnes OR, de Boer M, Narici MV. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. J Appl Physiol 2007; 102 (1): 368-73

106. Reeves ND, Narici MV, Maganaris CN. Strength training alters the viscoelastic properties of tendons in elderly humans. Muscle Nerve 2003; 28 (1): 74-81

107. Orr R, Raymond J, Fiatarone SM. Efficacy of progressive resistance training on balance performance in older adults: a systematic review of randomized controlled trials. Sports Med 2008; 38 (4): 317-43

108. Latham NK, Anderson CS, Lee A, et al. A randomized, controlled trial of quadriceps resistance exercise and vitamin D in frail older people: the Frailty Interventions Trial in Elderly Subjects (FITNESS). J Am Geriatr Soc 2003; 51 (3): 291-9

109. McMurdo ME, Mole PA, Paterson CR. Controlled trial of weight bearing exercise in older women in relation to bone density and falls. BMJ 1997; 314 (7080): 569

110. Wolff I, van Croonenborg JJ, Kemper HC, et al. The effect of exercise training programs on bone mass: a meta-analysis of published controlled trials in pre- and postmenopausal women. Osteoporos Int 1999; 9 (1): 1-12

111. Liu-Ambrose TY, Khan KM, Eng JJ, et al. Both resistance and agility training increase cortical bone density in 75- to 85-year-old women with low bone mass: a 6-month randomized controlled trial. J Clin Densitom 2004; 7 (4): 390-8

112. Suominen H. Muscle training for bone strength. Aging Clin Exp Res 2006; 18 (2): 85-93

113. Skelton DA, Greig CA, Davies JM, et al. Strength, power and related functional ability of healthy people aged 65-89 years. Age Ageing 1994; 23 (5): 371-7

114. Suetta C, Magnusson SP, Beyer N, et al. Effect of strength training on muscle function in elderly hospitalized patients. Scand J Med Sci Sports 2007; 17 (5): 464-72

115. Perry MC, Carville SF, Smith IC, et al. Strength, power output and symmetry of leg muscles: effect of age and history of falling. Eur J Appl Physiol 2007; 100 (5): 553-61

116. Shigematsu R, Rantanen T, Saari P, et al. Motor speed and lower extremity strength as predictors of fall-related bone fractures in elderly individuals. Aging Clin Exp Res 2006; 18 (4): 320-4

117. Judge JO, Underwood M, Gennosa T. Exercise to improve gait velocity in older persons. Arch Phys Med Rehabil 1993; 74 (4): 400-6

118. Judge JO, Lindsey C, Underwood M, et al. Balance improvements in older women: effects of exercise training. Phys Ther 1993; 73 (4): 254-62

119. Sipila S, Multanen J, Kallinen M, et al. Effects of strength and endurance training on isometric muscle strength and walking speed in elderly women. Acta Physiol Scand 1996; 156 (4): 457-64

120. Buchner DM, Cress ME, de Lateur BJ, et al. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. J Gerontol A Biol Sci Med Sci 1997; 52 (4): 218-24

121. Singh NA, Clements KM, Fiatarone MA. A randomized controlled trial of progressive resistance training in depressed elders. J Gerontol A Biol Sci Med Sci 1997; 52 (1): 27-35

122. Schlicht J, Camaione DN, Owen SV. Effect of intense strength training on standing balance, walking speed, and sit-to-stand performance in older adults. J Gerontol A Biol Sci Med Sci 2001; 56 (5): 281-6
123. Tyni-Lenne R, Gordon A, Jensen-Urstad M, et al. Aerobic training involving a minor muscle mass shows greater efficiency than training involving a major muscle mass in chronic heart failure patients. J Card Fail 1999; 5 (4): 300-7
124. Englund U, Littbrand H, Sondell A, et al. A 1-year combined weight-bearing training program is beneficial for bone mineral density and neuromuscular function in older women. Osteoporos Int 2005; 16 (9): 1117-23
125. Judge JO, Whipple RH, Wolfson LI. Effects of resistive and balance exercises on isokinetic strength in older persons. J Am Geriatr Soc 1994; 42 (9): 937-46
126. Topp R, Mikesky A, Wigglesworth J, et al. The effect of a 12-week dynamic resistance strength training program on gait velocity and balance of older adults. Gerontologist 1993; 33 (4): 501-6
127. Topp R, Mikesky A, Dayhoff NE, et al. Effect of resistance training on strength, postural control, and gait velocity among older adults. Clin Nurs Res 1996; 5 (4): 407-27

Correspondence: Prof. Dr *Urs Granacher*, Institute of Sport Science, Friedrich-Schiller-University, Seidelstr. 20, 07749 Jena, Germany.
E-mail: urs.granacher@uni-jena-de
Dr *Thomas Muehlbauer*, Institute of Sport Science, Friedrich-Schiller-University, Seidelstr. 20, 07749 Jena, Germany.
E-mail: t.muehlbauer@uni-jena.de