Exercise-based fall prevention in the elderly: What about agility?

Donath, L.; van Dieen, J.H.; Faude, O.

published in
Sports Medicine
2016

DOI (link to publisher)
10.1007/s40279-015-0389-5

Exercise-Based Fall Prevention in the Elderly: What About Agility?

Lars Donath, Jaap van Dieën & Oliver Faude

Sports Medicine

ISSN 0112-1642
Volume 46
Number 2

Sports Med (2016) 46:143-149
DOI 10.1007/s40279-015-0389-5

Springer

Sports Med (2016) 46:143–149
DOI 10.1007/s40279-015-0389-5

CURRENT OPINION

Exercise-Based Fall Prevention in the Elderly: What About Agility?

Lars Donath[1] · Jaap van Dieën[2] · Oliver Faude[1]

Published online: 22 September 2015

Abstract Annually, one in three seniors aged over 65 years fall. Balance and strength training can reduce neuromuscular fall risk factors and fall rates. Besides conventional balance and strength training, explosive or high-velocity strength training, eccentric exercises, perturbation-based balance training, trunk strength, and trunk control have also been emphasized. In contrast, aerobic exercise has to date not been included in fall-prevention studies. However, well-developed endurance capacity might attenuate fatigue-induced declines in postural control in sports-related or general activities of daily living. Physical performance indices, such as balance, strength, and endurance, are generally addressed independently in exercise guidelines. This approach seems time consuming and may impede integrative training of sensorimotor, neuromuscular, and cardiocirculatory functions required to deal with balance-threatening situations in the elderly. An agility-based conceptual training framework comprising perception and decision making (e.g., visual scanning, pattern recognition, anticipation) and changes of direction (e.g., sudden starts, stops and turns; reactive control; concentric and eccentric contractions) might enable an integrative neuromuscular, cardiocirculatory, and cognitive training. The present paper aims to provide a scientific sketch of how to build such an integrated modular training approach, allowing adaptation of intensity, complexity, and cognitive challenge of the agility tasks to the participant's capacity. Subsequent research should address the (1) link between agility and fall risk factors as well as fall rates, (2) benefit–risk ratios of the proposed approach, (3) psychosocial aspects of agility training (e.g., motivation), and (4) logistical requirements (e.g., equipment needed).

Key Points

Agility-based training may integratively improve cardiovascular, neuromuscular, and cognitive function.

This framework considers complex functional tasks, including perception, decision making, reaction, and changes of direction.

Future research should investigate this framework in terms of fall prevention in seniors.

1 Background

Seniors aged >65 years will account for approximately 30 % of the population in Western societies at the end of the twenty-first century [1]. Each year, one-third of those seniors fall and half of those fallers will fall again within the subsequent year [2]. Falls are defined as "unexpected events in which the participant unintentionally comes to rest on the ground, floor, or lower level" [3]. Fall-related injuries are the leading cause of hospitalizations due to injuries [4], lead to increasing healthcare expenditures [5]

✉ Lars Donath
lars.donath@unibas.ch

[1] Department of Sport, Exercise and Health, University of Basel, Birsstrasse 320 B, 4052 Basel, Switzerland

[2] MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, Amsterdam, The Netherlands

and form a major contribution to years of life lost due to disability [6]. The rate of fall-related injuries increases with age [7].

Numerous personal fall risk factors (e.g., asymmetric and deteriorated maximal and explosive lower extremity strength [8], or impaired postural control [9, 10]) have been identified in the past. Regular strength and balance training has the potential to attenuate aging-induced declines of neuromuscular function [10]. For instance, seniors with well-developed plantar flexion strength, maximal limb muscle strength, and adequate static and dynamic postural control can reduce their fall risk up to 50 % [11]. Such training schemes should be conducted on a regular basis, be embedded into appealing training regimes [12], and use a multicomponent approach [13]. These findings have led to promising best practice recommendations for training interventions targeting fall prevention [14].

2 Exercise-Based Fall Prevention: Available Best Practice Guidelines

Although daily moderate to vigorous physical activity is regarded as a primary preventive strategy to prevent falls in elderly women [15], simply 'being active' is not per se an appropriate fall-prevention policy [16]. In 2007, the American College of Sports Medicine (ACSM) and the American Heart Association (AHA) recommended that "to reduce risk of injury from falls, community-dwelling older adults with substantial risk of falls should perform exercises that maintain balance" [17]. Chodzko-Zajko et al. [18] elaborated further on these recommendations 2 years later, emphasizing that "multimodal exercises, including strength and balance training, and Tai-Chi have been shown to be effective in reducing the risk of falls in populations who are at an elevated risk of falling". At this time, the underlying studies only met evidence level C, pointing to "generally positive or suggestive evidence from a smaller number of observational studies and/or uncontrolled or nonrandomized trials".

Meanwhile, a Cochrane meta-analysis computed fall rates and risks obtained from 159 studies on fall-prevention interventions in nearly 80,000 community-dwelling elderly [11]. Results showed that multiple-component exercise reduced fall risk by 15 %, irrespective of whether it was completed as home- or group-based exercise. A systematic review by Sherrington et al. [14] corroborated these findings: an overall average fall rate reduction of 16 % [95 % confidence intervals (CI) 9–23] was found after pooling 54 randomized controlled trials (RCTs). A follow-up meta-regression analysis revealed that the highest reductions in fall rates were found when excluding walking (possibly because it causes exposure to fall risk or occurs at the expense of specific balance training) and including challenging balance exercises on a regular basis for more than 50 h [16]. Interestingly, a more restrictive meta-analysis of 44 trials including exercises (1) with highly challenging balance exercises, (2) with a high dosage, and (3) without walking revealed a reduction of fall rate of 42 % [16].

To translate these findings into specific best practice recommendations for balance training, practitioners should employ exercises that (1) include standing exercises with a gradually reduced base of support (e.g., two-legged stand, semi-tandem stand, tandem stand, one-legged stand), (2) include dynamic movements that perturb the center of gravity (e.g., tandem walk, circle turns), (3) stress postural muscle groups (e.g., heel stands, toe stands), and (4) modify sensory inputs (e.g., standing with eyes closed) [18, 19]. Although less extensively studied, it appears useful to combine gait and balance training with cognitive and/or motor interference tasks [20, 21]. Such dual or multitask paradigms are suitable for both testing and training purposes. Seniors' static and dynamic balance performance (e.g., spatio-temporal gait characteristics, static balance performance) can be negatively affected by such interference tasks [20, 22]. A withdrawal of cognitive resources for managing the interference task at the expense of postural control seems to account for a higher fall risk in dual-task situations [23]. These current best practice balance training recommendations are summarized in Fig. 1.

Additional resistance exercises have been proposed along with these recommendations for balance training [10]. Resistance training in the elderly has been mostly conducted either as high-intensity training at moderate movement velocity [with 70–80 % of the one-repetition maximum (1RM)] or high-velocity training (i.e., power training) at maximal speed during the concentric phase with 20–80 % of the 1RM (for review, see Granacher et al. [10]). 'Negative' resistance training programs, which focus on eccentric work, in view of the possibility to impose high mechanical loads at low energy costs [24], have also been successfully conducted [25]. However, the latter should be implemented very cautiously (e.g., qualified personnel, strong concentrated guidance, specific devices) in terms of minimizing the risk of harmful effects (avoiding incorrect movements and shear forces). Available evidence obtained from randomized controlled trials (RCTs) on traditional resistance training led to the following training prescriptions: strength training performed at least two times per week can yield notable muscle hypertrophy, strength, and power improvements. The training should be performed at moderate to high intensity (i.e., 60–80 % 1RM) and moderate volume (i.e., two to three sets per exercise) [26]. Thereby, six to eight exercises with 8–12 repetitions for each set should be completed. Transfer effects of such resistance training to balance performance seems limited

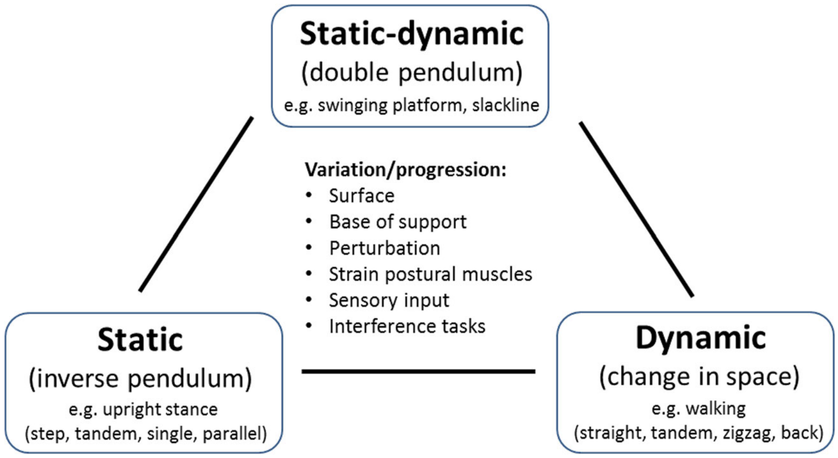

Fig. 1 Aspects and principles of balance training based on Chodzko-Zajko et al. [18], Sherrington et al. [14], Granacher et al. [20], and Muehlbauer et al. [19]. In static situations, balance can be regarded as an inverse pendulum where ankle moments control the center of mass position relative to the base of support, whereas in static–dynamic exercises the body moves as a double pendulum and changes in angular momentum contribute relative to the base of support, and in dynamic exercises changes in location of the center of mass require changes of the base of support. These exercise types should (1) be applied in both general and high-risk populations, (2) provide at least a moderate challenge to balance, (3) be regularly conducted for 2 h per week in total. Exercise progression can be achieved by varying the (1) surface (e.g., foam, firm, mats), (2) base of support (step stance, tandem stance, single limb stance), (3) perturbations (e.g., at the trunk, leg, shoulder, tripping) (4) loading of postural muscles (e.g., heel stance), (5) sensory input (e.g., deprived vision, acoustic), and (6) interfering tasks (motor and/or cognitive dual or triple tasks)

[27]. However, seniors with higher muscle strength are more likely to regain balance after external perturbations [28]. Consequently, traditional resistance training programs can reduce fall risk and may attenuate the consequences of falls [28]. Therefore, traditional strength training should probably be embedded into multifactorial neuromuscular training approaches but should not serve as the only form of exercise training [10]. The impact of traditional resistance training regimens on rapid force production (explosive power) has been debated in the past. Explosive power is of particular relevance since situations in which balance is threatened require a rapid force production [29], which may not be sufficiently trained within traditional strength training regimens. In response, power and high-velocity training regimes have been introduced and established. Power training had larger effects on force development and physical functional capacity (e.g., floor rise to stand test, 6-min walking test, repeated chair rise test) than traditional resistance training [30]. Power training also beneficially affects maximal strength and can induce transfer effects to balance performance with a lower total training load [10]. As a consequence, the ACSM recommends high-velocity training for the elderly applying one to three sets using light to moderate intensity (40–60 % of 1RM) for six to ten repetitions with high-movement velocity [18]. Recommendations for both maximal strength and power training according to Granacher et al. [10] are shown in Table 1.

3 Agility-Based Exercise for Fall Prevention

Falls in community-dwelling elderly have been reported to be due to a wide range of causes (e.g., tripping, slipping, losing consciousness [hypotension], ‘frozen leg’, loss of support, misstep, pain, and syncope [33]). Among these causes, tripping appears to account for the largest proportion of falls [34–36]. Among seniors residing in long-term care institutions, more than 80 % of falls are attributed to incorrect weight shifting (41 %) or tripping, bumping, and losing support (totaling 43 %) [37]. The effects of strength and balance training on fall risk and rates and the underlying evidence level can be regarded as acceptable (level A or B). The role of adequate endurance in fall prevention has not been sufficiently addressed at present. Inactive seniors might have an elevated relative fall risk when starting to become active. Acute effects of aerobic activities during daily life might also adversely affect postural control, particularly in subjects with less aerobic capacity. There is evidence that fatigue resulting from moderate and heavy bicycle and walking exercise reduces balance performance in seniors [38–40]. Higher aerobic capacity, in turn, may attenuate acute exercise-induced declines of balance performance. Therefore, aerobic training may need to be integrated in fall prevention training programs.

Based on the above, fall prevention likely requires a successful interplay between perception, cognitive function

Table 1 Overview of maximal and explosive strength training recommendations according to Granacher and colleagues [10] and Donath et al. [31]

	Maximal strength training	Explosive strength or power training
Volume	8–12 weeks, approximately 45–60 min per session	6–12 weeks, approximately 45–60 min per session
	6–8 exercises per session	6–8 exercises per session
	3 sets of 8–12 repetitions	3 sets of 8–10 repetitions
Set break	2–3 min	1–2 min
Frequency	2–3 sessions per week	2–3 sessions per week
Intensity	70–80 % of 1RM	20–70 % (maximal 80 %) of 1RM
		70 % beneficial for explosive strength
	1RM: determined maximal or submaximal[a] based on ratings of RPE between 12 and 16 (Borg scale 6–20)	20 % for transfer effects to balance based on ratings of RPE between 10 and 13 (Borg scale 6–20)
Velocity	Slow to moderate contraction velocity during eccentric and concentric work	Fast and explosive during concentric work and moderate during eccentric phase

RPE rate of perceived exertion, *1RM* one repetition maximum

[a] Submaximal 1RM estimations according to Baechle and Earle [32]

(e.g., attention, planning, decision making), neuromuscular performance (trunk, legs), and cardiovascular capacity. Although recent balance and strength training recommendations increasingly emphasize these aspects (e.g., higher velocity and explosive strength training for the legs and the trunk with and without perturbations) [10, 41], best practice guidelines do not completely mirror such considerations. Moreover, current recommendations still tackle balance, strength, and endurance performance separately. Integrative multicomponent exercise training frameworks on fall prevention that address all aspects have not been applied. Recent studies have focused on cognitive aspects concerning decision making employing computer games and tablets, or functional mobility using stepping and obstacle tasks [42–45]. Although these approaches are of a more functional nature and cognitive domains are included, strength and endurance aspects are not sufficiently addressed within these training concepts. Other studies have addressed muscle strength specifically and shown that, for example, explosive strength training with relatively low weights yielded larger effects on force development than traditional strength training [10]. Yet another class of studies addressed balance training programs and demonstrated that balance training can alter spinal reflex circuits, facilitating the neuronal drive to generate higher muscle power [46–48]. In all of these studies, training was one dimensional (e.g., machine training, standing balance training) and stationary, while challenging, functional, comprehensive, and integrative training approaches appeared to be lacking.

Agility-based training approaches comprising accelerations, decelerations, stop-and-go patterns, changes of direction (cutting manoeuvres), and eccentric loads, combined with demanding spatial orientation tasks, may serve as an integrative motor competency training approach for seniors. Such agility-based training regimens can comprise aspects of perception and decision making (e.g., visual scanning, situational awareness, pattern recognition, and anticipation), movement direction changes (involving reactive motor control and fast concentric as well as eccentric muscle contractions), and cardiovascular training stimuli. A multidimensional exercise profile reflecting the participants' physical performance state can be developed [49]. Physical, perceptual, and cognitive demands of the training modules should become progressively more complex and demanding, and cardiocirculatory demands can also be varied through task choice, circuit length, and number of circuit repetitions. Such an integrative neuromuscular training strategy might serve as a promising, appealing, and time-efficient training regimen within fall-prevention programs in the elderly and may be adaptable to real-life settings. While traditional balance and strength training protocols are frequently considered less specific to situations where balance is threatened (e.g., recovering from sudden perturbations and rapidly producing the required joint moments) [10], and yield task specific training adaptations [50–52] with marginal transfer effects, such an integrative training regimen might bypass these limitations.

Cognitive, physical, vestibular, and proprioceptive functions are necessary prerequisites for ensuring spatial orientation, and these functions decline with aging [53]. Probably, these functions can be integratively trained in such agility-based training approaches. Varying and complex agility patterns including a variety of changes of direction, starts, and stops, are likely to induce slight vestibular perturbations, and challenge proprioceptive and visual control of movement.

An agility circuit can emphasize different motor components at varying levels of difficulty, both physically and

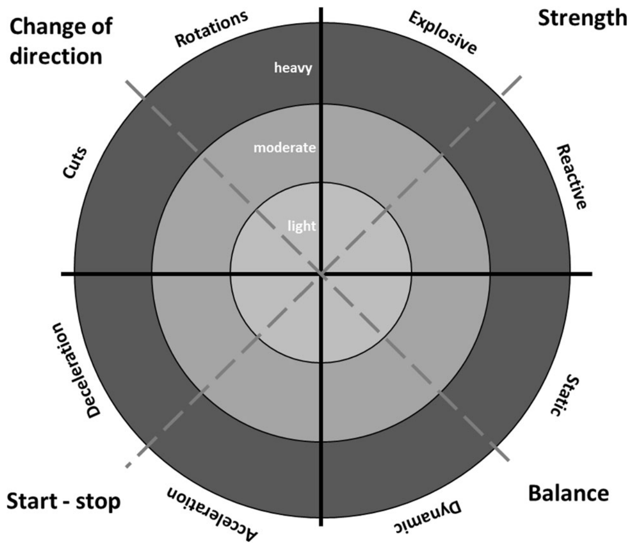

Fig. 2 Modular agility framework including changes of direction, starts and stops, strength, and balance requirements. An example of an agility circuit can accentuate different motor components at varying difficulty levels, physically or cognitively, ranging from light (*light grey*), moderate (*grey*) to heavy (*dark grey*)

cognitively (Fig. 2). The difficulty of the modules can be progressively adapted by (1) surface (e.g., firm, foam, mats), (2) movement velocity (e.g., slow, moderate, fast), (3) movement direction (e.g., forward, backwards, sideways, zig-zag), (4) repetitions (e.g., 5–25), (5) duration (number of agility modules), (6) sets (rounds of the entire agility circuit), (7) type of exercise (easy, complex, stationary, moving, e.g., jumps, skipping, lunges, squats, etc.), (8) interference task (motor, cognitive).

An example of an agility circuit comprising (1) cutting manoeuvres, (2) spatial rotation drills, (3) accelerations and decelerations, and (4) hopping and skipping movements is depicted in Fig. 3. The choice and focus of the respective modules and underlying exercise severity can be made depending on individual capacities and motor deficiencies.

4 Conclusion and Outlook

Falls are a serious health issue in increasingly aging societies. Balance and strength training can successfully reduce fall risk factors and fall rates. Endurance aspects have been rarely considered in these training programs, while an adequate aerobic capacity not only improves cardiovascular health but may also be instrumental in fall prevention, as it may attenuate fatigue-related declines of postural control during activities of daily living. Within recent years, high-velocity strength training, eccentric exercises, perturbation-based balance training, and trunk muscle strength and control training have been emphasized. Addressing these issues independently would be very time consuming, and RCTs on these aspects are scarce to date. Thus, it seems reasonable to stimulate agility-based training regimens that aim at improving relevant neuromuscular and cardiocirculatory health parameters in an integrated manner. Such a training concept will enhance aspects of agility, strength, and balance by challenging muscle power, reactive control, and cognitive demands. Trunk and leg muscles would then be challenged in varying movement directions. Modules can be progressively adapted from an easy and short circuit to a challenging and long circuit emphasizing different neuromuscular and cardiocirculatory demands to appropriately address the individual performance abilities.

The proposed conceptual framework should be further examined regarding (1) validity relative to traditional fall risk parameters, (2) benefit–risk ratios of potential

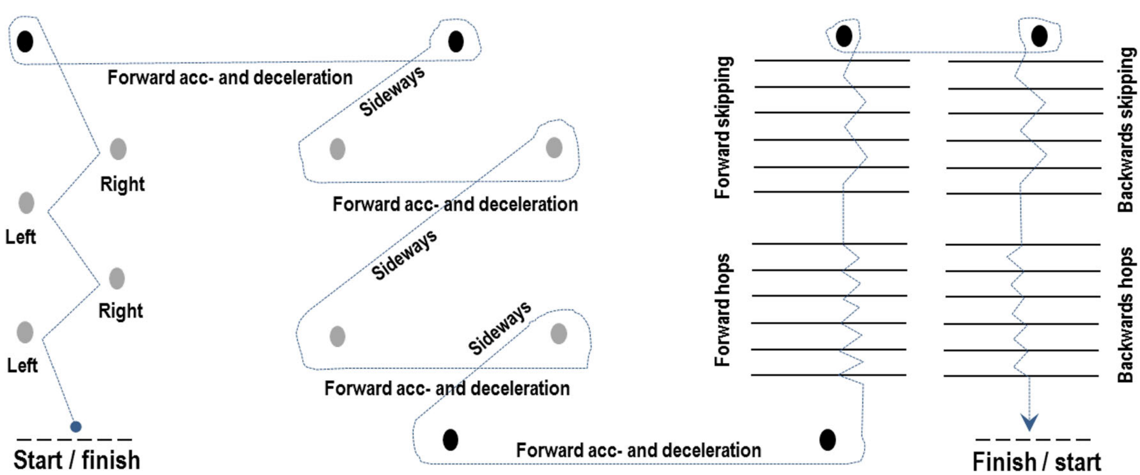

Fig. 3 An example of an agility circuit comprising cutting maneuvers, spatial rotation drills, accelerations and decelerations, and hopping and skipping tasks in different directions

interventional effects in relation to safety issues, (3) psychosocial aspects (motivation, enjoyability, adherence, social interaction) and (4) space and equipment requirements (sports hall, gymnasium).

Compliance with Ethical Standards

This article was written according to the ethical standards of scientific writing and publishing.

Funding No sources of funding were used to assist in the preparation of this article.

Conflict of interest Lars Donath, Jaap van Dieën, and Oliver Faude declare that they have no conflicts of interest relevant to the contents of this review.

References

1. Lutz W, Sanderson W, Scherbov S. The coming acceleration of global population ageing. Nature. 2008;451(7179):716–9.
2. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age Ageing. 2006;35(Suppl 2):ii37–41.
3. Lamb SE, Jorstad-Stein EC, Hauer K, et al. Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. J Am Geriatr Soc. 2005;53(9):1618–22.
4. Jones TS, Ghosh TS, Horn K, et al. Primary care physicians perceptions and practices regarding fall prevention in adult's 65 years and over. Accid Anal Prev. 2011;43(5):1605–9.
5. 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.
6. Murray CJ, Lopez AD. Global mortality, disability, and the contribution of risk factors: Global Burden of Disease Study. Lancet. 1997;349(9063):1436–42.
7. Peel NM, Kassulke DJ, McClure RJ. Population based study of hospitalised fall related injuries in older people. Inj Prev. 2002;8(4):280–3.
8. Skelton DA, Kennedy J, Rutherford OM. Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. Age Ageing. 2002;31(2):119–25.
9. Hytonen M, Pyykko I, Aalto H, et al. Postural control and age. Acta Otolaryngol. 1993;113(2):119–22.
10. Granacher U, Muehlbauer T, Zahner L, et al. Comparison of traditional and recent approaches in the promotion of balance and strength in older adults. Sports Med. 2011;41(5):377–400.
11. Gillespie LD, Robertson MC, Gillespie WJ, et al. Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev. 2012;9:CD007146.
12. Donath L, Faude O, Bridenbaugh SA, et al. Transfer effects of fall training on balance performance and spatiotemporal gait parameters in healthy community-dwelling older adults: a pilot study. J Aging Phys Act. 2014;22(3):324–33.
13. Karlsson MK, Vonschewelov T, Karlsson C, et al. Prevention of falls in the elderly: a review. Scand J Public Health. 2013;41(5):442–54.
14. Sherrington C, Tiedemann A, Fairhall N, et al. Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations. N S W Public Health Bull. 2011;22(3–4):78–83.
15. Heesch KC, Byles JE, Brown WJ. Prospective association between physical activity and falls in community-dwelling older women. J Epidemiol Community Health. 2008;62(5):421–6.
16. Tiedemann A, Sherrington C, Close JC, Exercise, Sports Science Australia, et al. Exercise and Sports Science Australia position statement on exercise and falls prevention in older people. J Sci Med Sport. 2011;14(6):489–95.
17. Nelson ME, Rejeski WJ, Blair SN, et al. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. Med Sci Sports Exerc. 2007;39(8):1435–45.
18. 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.
19. Muehlbauer T, Roth R, Bopp M, et al. An exercise sequence for progression in balance training. J Strength Cond Res. 2012;26(2):568–74.
20. Granacher U, Muehlbauer T, Gruber M. A qualitative review of balance and strength performance in healthy older adults: impact for testing and training. J Aging Res. 2012;2012:708905.
21. Dorfman M, Herman T, Brozgol M, et al. Dual-task training on a treadmill to improve gait and cognitive function in elderly idiopathic fallers. J Neurol Phys Ther. 2014;38(4):246–53.
22. Beauchet O, Kressig RW, Najafi B, et al. Age-related decline of gait control under a dual-task condition. J Am Geriatr Soc. 2003;51(8):1187–8.
23. 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.
24. 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 Pt 2):R611–5.
25. 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):M419–24.
26. Cadore EL, Pinto RS, Bottaro M, et al. Strength and endurance training prescription in healthy and frail elderly. Aging Dis. 2014;5(3):183–95.
27. 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.
28. Pijnappels M, van der Burg PJ, Reeves ND, et al. Identification of elderly fallers by muscle strength measures. Eur J Appl Physiol. 2008;102(5):585–92.
29. Pijnappels M, Bobbert MF, van Dieen JH. Push-off reactions in recovery after tripping discriminate young subjects, older non-fallers and older fallers. Gait Posture. 2005;21(4):388–94.
30. 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.
31. Donath L, Faude O, Bopp M, et al. Health-related strength and power training in seniors: Purpose and recommendations. Ther Umsch. 2015;72(5):335–42.
32. Baechle TR, Earle RW. Essentials of strength training and conditioning. 3rd ed. Champaign: Human Kinetics; 2008.
33. Zecevic AA, Salmoni AW, Lewko JH, et al. Utilization of the seniors falls investigation methodology to identify system-wide causes of falls in community-dwelling seniors. Gerontologist. 2009;49(5):685–96.
34. 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.

35. Berg WP, Alessio HM, Mills EM, et al. Circumstances and consequences of falls in independent community-dwelling older adults. Age Ageing. 1997;26(4):261–8.
36. Nevitt MC, Cummings SR, Hudes ES. Risk factors for injurious falls: a prospective study. J Gerontol. 1991;46(5):M164–70.
37. Robinovitch SN, Feldman F, Yang Y, et al. Video capture of the circumstances of falls in elderly people residing in long-term care: an observational study. Lancet. 2013;381(9860):47–54.
38. Donath L, Kurz E, Roth R, et al. Does a single session of high-intensity interval training provoke a transient elevated risk of falling in seniors and adults? Gerontology. 2015;61(1):15–23.
39. Donath L, Zahner L, Roth R, et al. Balance and gait performance after maximal and submaximal endurance exercise in seniors: is there a higher fall-risk? Eur J Appl Physiol. 2013;113(3):661–9.
40. Stemplewski R, Maciaszek J, Salamon A, et al. Effect of moderate physical exercise on postural control among 65–74-years-old men. Arch Gerontol Geriatr. 2012;54(3):e279–83.
41. Granacher U, Gollhofer A, Hortobagyi T, et al. The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: a systematic review. Sports Med. 2013;43(7):627–41.
42. Close JC, Lord SL, Menz HB, et al. What is the role of falls? Best Pract Res Clin Rheumatol. 2005;19(6):913–35.
43. van het Reve E, de Bruin ED. Strength-balance supplemented with computerized cognitive training to improve dual task gait and divided attention in older adults: a multicenter randomized-controlled trial. BMC Geriatr. 2014;14:134.
44. Bridenbaugh SA, Kressig RW. Laboratory review: the role of gait analysis in seniors' mobility and fall prevention. Gerontology. 2011;57(3):256–64.
45. Granacher U, Bridenbaugh SA, Muehlbauer T, et al. Age-related effects on postural control under multi-task conditions. Gerontology. 2011;57(3):247–55.
46. Gruber M, Taube W, Gollhofer A, et al. Training-specific adaptations of H- and stretch reflexes in human soleus muscle. J Mot Behav. 2007;39(1):68–78.
47. 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 (Oxf). 2007;189(4):347–58.
48. Taube W, Kullmann N, Leukel C, et al. Differential reflex adaptations following sensorimotor and strength training in young elite athletes. Int J Sports Med. 2007;28(12):999–1005.
49. Young WB, James R, Montgomery I. Is muscle power related to running speed with changes of direction? J Sports Med Phys Fitness. 2002;42(3):282–8.
50. Granacher U, Iten N, Roth R, et al. Slackline training for balance and strength promotion. Int J Sports Med. 2010;31(10):717–23.
51. Donath L, Roth R, Rueegge A, et al. Effects of slackline training on balance, jump performance and muscle activity in young children. Int J Sports Med. 2013;34(12):1093–8.
52. Donath L, Roth R, Zahner L, et al. Slackline training and neuromuscular performance in seniors: a randomized controlled trial. Scand J Med Sci Sports. 2015. doi:10.1111/sms.12423.
53. Lackner JR, DiZio P. Vestibular, proprioceptive, and haptic contributions to spatial orientation. Ann Rev Psychol. 2005;56:115–47.