BRIEF REVIEW

Prevention of Falling Risk in Elderly People: The Relevance of Muscular Strength and Symmetry of Lower Limbs in Postural Stability

Luisa Pizzigalli,[1,2] Alberto Filippini,[1,2] Said Ahmaidi,[2] Hugues Jullien,[2] and Alberto Rainoldi[1]

[1]*Motor Science Research Center, University School of Motor and Sport Science, University of Turin, Turin, Italy ; and* [2]*Exercise Physiological Adaptations and Strain Rehabilitation, University School of Motor and Sport Science, University of Picardie Jules Verne, Amiens, France*

Abstract

Pizzigalli, L, Filippini, A, Ahmaidi, S, Jullien, H, and Rainoldi, A. Prevention of falling risk in elderly people: the relevance of muscular strength and symmetry of lower limbs in postural stability. *J Strength Cond Res* 25(2): 567–574, 2011—Falls are one of the major health problems affecting the quality of life among older adults. The aging process is associated with decreasing muscle strength and an increasing risk of falling. The variables and techniques adopted to quantify muscular strength and postural stability were different in each protocol; a great number of reports analyzed the risk factors and predictors of falls, but the results appear still uncertain. To date, there is no clear, definitive statement or review that has examined the effect of the quadriceps strength on static balance performances in different sensory conditions. This contribution aims to provide an overview of experimental works to increase the comprehension and prevention of falls and fall-related injuries in the elderly. Based on a review of the literature, this work was designed to explore the relationship among risk of falls, postural stability, and muscular strength of lower limbs in older adults.

Key Words aging, balance, muscle weakness, power

Introduction

The aims of this review are (a) to discuss the role of muscular strength in prevention of falling risk in elderly people; (b) to show neuromuscular differences such as muscular strength, stiffness, and symmetry of the lower limbs between older "fallers" and "older nonfallers," and exercise-based intervention programs to prevent falls; (c) to examine the evidence supporting decreased balance and lower limbs muscular weakness as a risk factors and how to counteract these factors as a strategy for fall prevention.

The literature analysis was conducted on Pubmed using the following keywords: strength, power of leg muscles, fallers nonfallers comparisons, lower leg symmetry, asymmetry in fallers, stiffness in middle-aged people, static and dynamic balance, elderly, risk of falling, postural control.

The language was limited to English. The search was terminated in March 2008 and was limited to the works published between 1980 and 2008. Subjects included were healthy and older than 65 years.

Background

The preservation of muscle strength during aging is essential because in healthy elderly people a reduction in muscle mass and muscle strength is usually observed (1,41). Lower extremity muscle weakness and power and balance impairment are major independent intrinsic contributors to falls and susceptible to intervention. Falls are a serious health problem for older adults (83). The association between postural stability and muscular strength of the lower limbs received little attention in the literature although the gradual loss of muscle strength results in functional impairment and in an increased risk of falling (90).

A great number of falls in elderly people are caused by wrong responses to the perturbations in the vertical and horizontal planes (52); the quantification of the lateral translations to such perturbation can predict falls. Falling risk has been related to a lot of factors such as history of falls, muscle weakness, gait deficit, balance deficit, use of walking device, visual impairment, mobility impairment, fear of falling, cognitive impairment, depression sedentary behavior, age, number of medications, psychotropic, cardiovascular medications, nutritional deficits, urinary incontinence, arthritis, home hazards, and footwear (23,63). Further, this phenomenon is often associated with fitness decline, negative impact on quality of life, and reduced survival (5). Falls and

Address correspondence to Dr. Alberto Rainoldi, alberto.rainoldi@unito.it.

25(2)/567–574

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problems of mobility, in fact, reduce the autonomy of elders and are one of the major causes of mortality and morbidity; they often anticipate the recovery in rest homes. The 30–40% of healthy elderly people (>65 years old) who live at home fall in a year (9) (4); this percentage increases with age. Although the major part of falls do not have serious consequences, approximately 5% of seniors falling at home, suffer from fractures or necessitate hospital intervention. When the incidence of this kind of episodes with serious complications is in the range 10–25%, older people are institutionalized with much more severe consequences. The percentage of falls causing death is higher in men than in women (4).

Psychological consequences of falls are not less important than physical consequences. The fear of fall and the anxiety after fall produce a loss of self-confidence and cause functional limitations in people at both home and rest homes (6).

Thus, supervising and preventing the phenomenon of falls is a priority challenge; in fact, the number of the elderly at risk is actually growing. Reduction of functional capacities becomes much more frequent during old age. This degradation is generally associated with an increase of falling risk.

In Europe, 30% of people older than 65 years fall every year and, in people older than 80 years, more than 50% fall at least once during the year (33).

Muscular Strength and Balance

Falls occur during various daily activities, which are constrained by limits of stability (LOS). Limits of stability can be described as the maximum *distance that* a person can intentionally displace his or her center of gravity, and lean his or her body in a given direction without losing balance, grasping, or stepping. Clark and Rose (12) and Holbein-Jenny et al. (26) showed that aging is associated with decrease in LOS. Reduced foot sensation may contribute to increase risk of falls (51), because elderly people might not properly detect when the center of gravity approaches the LOSs.

Recent studies have shown that postural sway does not correlate with clinical functional balance measurements suggesting that those tests measure different aspects of balance. The results of the review of Rydwik et al. (75) indicate that strength training alone is not enough to improve balance. A combination of both strength and balance training is most likely to be useful in fall incidence reduction (20). However, the relationship between lower limb muscle strength and falls is unclear. Perry (68) proved that elderly "fallers" have a reduction of muscular strength (−15%) and of power (−21%) with respect to elderly "nonfallers". Many studies show minimal or no differences in strength between fallers and nonfallers (14,79).

Muscle weakness, gait, and balance deficits increase fall risk by 440, 290, and 290%, respectively (74). These risk factors are often targeted in multifactorial fall prevention programs. However, there is uncertainty about the extent to which these factors may be a direct cause of falls or alternatively are effects of other underlying causes. In addition, these risk factors appear to provide only inconsistent fall predictions (21).

Pijnappels at al. showed that after an induced trip, the diminished lower extremity muscle strength in elderly people, measured by a leg-press exercise, correctly discriminated 100% of those older adults who fell and 90% of those who did not fall (69).

In contrast, Pavol et al., in a similar study, showed that older adults with both higher and lower than average levels of isokinetic and isometric lower extremity strength were unable to avoid falling after an induced trip (66).

It could be questioned whether older people fall more often than young people because they trip and stumble more often or because they are less able to recover balance after a trip or a stumble.

In the first hypothesis, they need to increase muscular strength and reaction times and to counteract visual and cognitive impairments that are typical of aging and necessary to detect and avoid an obstacle. In the second hypothesis, elderly people have to train their successful balance recovery after a stumble or a trip. The probability to recover successfully after a trip or a stumble has been experimentally shown to be clearly lower in older adults than in young adults (86).

Given the finding that muscle weakness is a risk factor for falls, the important clinical question is whether strengthening exercises prevent falls. A search of the literature for randomized, controlled trials on the effectiveness of muscle strengthening for preventing falls was conducted by Moreland et al. (60). They concluded that muscle strength (especially lower extremity) should be one of the factors that is assessed and treated in older adults at risk of falls.

Muscular strength and power of lower limbs are necessary to maintain essential parameters of gait. Grabiner et al. (21) induced in a group of young and elderly healthy adults trips and slips. This experiment required rapid compensatory responses to avoid falling, during locomotion. It was shown that power is more important to recover after a fall in elderly than in young people.

Other authors found useful for independent or community dwelling older adults weeks of endurance, power strength exercises, and balance training (54,58,64,72,75).

In conclusion, it is important to ensure which types of physical exercises are effective and avoid musculoskeletal injuries; caution needs to be exercised in the prescription of muscle-strengthening exercises. Balance training needs to be more individualized to be effective for frail elderly people. Further studies are needed, with larger sample sizes, to investigate the effects of these types of interventions before to provide any further conclusions.

Many studies investigated eccentric and concentric force of different muscular lower limbs in older people and with respect to young people. Eccentric muscular strength of lower limb decreases with age but concentric decreases more than eccentric muscular force (27,71).

Porter (70) claimed that no differences can be observed between young and elderly people in eccentric strength during dorsiflexion.

In quadriceps muscle, Lord et al. (49) and Takazawa et al. (81) found force differences, between young and older people in the MVC values; in contrast to the studies of Daubney and Culham, (14); Skelton et al. (79); and Melzer et al. (55) who found no differences.

Similarly, no differences were reported between strength of plantar-flexors in "fallers " and "nonfallers," but the former showed deficits in quadriceps's strength (15,80). On the contrary, Schwender et al. (76) and Skelton et al. (79) showed no differences in quadriceps of this kind of subjects.

Asymmetry or Symmetry of Lower Limbs

In his work of 2007, Valderrabano et al. (85) bilaterally analyzed the biomechanical variables, including maximal voluntary isometric ankle joint torque and surface electromyography (mean EMG frequency and intensity) of 4 lower leg muscles: tibialis anterior, medial gastrocnemius, soleus, and peroneus longus in healthy middle-aged subjects. Results showed that in nondominant muscles were found more slow fibers (and in dominant muscles more fast fibers), because the dominant leg is used during the propulsive step phase.

Skelton et al. (79) demonstrates that asymmetry and explosive power of lower leg are more predictive than strength in detecting "fallers." During the age, concentric muscular force decreases more than eccentric muscular force (24,43,70,73). On the contrary, it was also shown that "fallers" increased their power and strength asymmetry in leg muscles. Similarly, in the study of Benjuya et al. (3) was found no significant difference in lower limb muscle strength between fallers and nonfallers. Arampatzis et al. (2) examined by ultrasonography the elongation of the gastrocnemius medialis and the vastus lateralis tendon and aponeuroses during isometric contraction. They found that there were no differences in leg extensor muscle strength or tendon stiffness between older adults who are able to recover stability and others who failed to regain stability with a single step after a forward fall.

In contrast, Ghulyan and Paolino (19) compared dynamic postural control in patients with balance disorders with and without a history of falling. They used a platform to induce destabilizing perturbations confirming the evidences of a previous study of Skelton et al. (79), who observed that, in elderly people, asymmetric loss of muscle strength in lower limbs is more marked in fallers than in nonfallers, thus providing an explanation for the loss of later postural control, a typical sign to predict future falls (82).

The ability to rapidly develop high force contributes to successful performances in activities such as rising from a chair, climbing stairs, or regaining balance after tripping to avoid an impending fall. In this direction, Whipple et al. (87) and Wolfson et al. (90) described that both knee and ankle strengths of fallers were significantly lower compared with nonfallers group (Pearson $R = -0.36$, $p < 0.001$). Recently, Karamanidis et al. (34) showed that compared to older adults, younger adults had higher muscle strength and tendon stiffness. Younger adults showed a higher margin of stability compared with older adults, independently by perturbation intensity. In 2008, the same authors (2) compared balance behavior of older adults who were able and others who failed to recover stability with a single step after a forward fall. No differences in leg extensor muscle strength or tendon stiffness were observed between the 2 groups, proving that muscle tendon characteristics may not be the factor for the observed differences in dynamic stability control.

Muscular Stiffness and Balance

Changing the support platform, applying sensory perturbations, sway referencing the support platform, are strategies commonly adopted to study the effect of altered sensory information on human balance. For the sway referencing trial, the platform rotates in the anterior–posterior (A–P) direction for an angle equal to the angular hip displacement as determined by the hip rod potentiometer signal. Hip displacements are measured using rigid rods attached to a fixed position on one end and attached to the subjects by a harness on the opposite end. The rods can rotate freely about the fixed end in the A–P plane. The amount of displacement is determined by the change in voltage of potentiometers located on the fixed ends of the hip rods (13)

It is generally recognized that during postural stance, there is an active muscular control system but whether or not this muscle activity is necessary is still under debate. During a trial on a foam support, or sway referencing the support surface, a degradation or a removal of the passive stiffness benefit is observed. Jeka et al. (30) consider that the observed increase in sway is a consequence of changing biomechanical system time constant in relation to human bandwidth of control rather than to a sensory phenomenon. For the same reason, more recently, Loram et al. (45) assessed that ignoring the dependence of passive stiffness on sway size could lead to misinterpretation of findings obtained with perturbations, sway referencing, and altered support surfaces.

Several investigations confirmed that the maintenance of upright stance is supported by the positive role of the calf muscles. The passive (no neural modulation) stiffness of the activated calf muscles is enough to allow dynamic human stability (62,88,89). In 1999, Morasso and Schieppati (59) reviewed the evidence of active mechanisms of sway stabilization highlighting the role of foot skin and muscle receptors. Somatosensory input from the lower limb has long been recognized as an important source of sensory information in controlling standing balance (36). Although the specific source of this essential input remains to be determined, there are several classes of receptors in the lower limb that may provide feedback related to stance and movement. Proprioceptive information from muscle spindles in muscles from around the knee and ankle may code for the change in joint angle relative to the trunk (29), whereas Golgi tendon organs may be responsible for force feedback about the loading of the body (67). Finally, skin receptors in the foot sole are sensitive to contact pressures (51) and may be sensitive to potential changes in the distribution of pressure (35). Together, the integration of all these somatosensory inputs appears to provide important information about body position with respect to the supporting surface.

Loram et al. (44) assessed that the passive stiffness was not sufficient for static stability, but it reduces the effect of gravity on the human inverted pendulum. Lark et al. (37) compared the joint torque pattern and the dynamic joint stiffness at the knee and ankle in elderly and young men during stepping down. They showed that maximum ankle torque values, recorded during stepping down phase, were significantly lower in the elderly and were achieved at greater dorsiflexion angles across all step heights. As a consequence, ankle stiffness was significantly ($p < 0.05$) lower in this group of people, indicating that an altered control strategy during stepping down is adopted by elderly subjects. For this reason, rehabilitation strategies and exercise intervention should focus on activities allowing the maintenance and development of foot function.

Exercise-Based Intervention Programs to Prevent Falls

To develop exercise-based intervention programs to prevent falls, it is necessary to understand what characteristics are essential for maintain balance during such events of daily activities. To effectively design such exercise programs, it is necessary to identify biomechanical and neuromuscular factors pivoting the ability to restore balance and prevent falls.

Positive effects of physical training on physical performance in elderly patients were shown in the systematic review of Rydwik et al. (75). According to that work, Ledin et al demonstrated the positive effect of physical training on balance in healthy elderly people (40).

Chandler et al. (11) reported that lower extremity strength gain is associated with gain in gait speed, in chair rise, and in mobility tasks but not with improved balance or endurance. In contrast, Lord et al. (48) found that physical exercises significantly improve coordinated stability and dynamic postural control in elderly subjects. They also reported that the improvement in coordinated stability is associated with improvements in hip flexion, hip extension, knee extension, and ankle dorsiflexion. Ryushi et al. (84) explained that these contradictory results between Chandler et al. and Lord et al. are because of the difference in home resistive exercise programs. The purpose of the study conducted by Ryushi et al., in fact, was to determine whether knee extension strength gain in middle-aged and elderly persons was associated with improvement in the LOSs leaning the body in different directions. They suggested that one set of resistive knee extension training was sufficient to increase knee extension strength in middle-aged and elderly subjects. Their findings showed that strength gain in the quadriceps femoris allows accurate movement of the COM far from the central position toward the rear, suggesting a positive influence on individual perception to avoid falls.

Granata and Lockhart, in their pilot study (22), showed the dynamic orbital stability of the anthropometric COM with respect to the COP in a group of fall-prone elderly individuals and healthy adults. Three-dimensional video-motion-analysis kinematic data were recorded for 35 contiguous steps while subjects walked on a treadmill at 3 different speeds. From these data, authors estimated the vector from COM to the COP at each foot strike. Dynamic stability of walking was computed by methods of Poincaré analyses of these vectors. The fall-prone group demonstrated poorer stability of dynamic walking than the other group.

Slow motion exercises such as Tai chi was studied as an example of possible training intervention in older people (42). In this study, authors analyzed researches between 1997 and 2007 to clarify the role of Tai Chi and its effectiveness in fall prevention programs. They concluded that an actual impact on fall-related outcomes is not yet available but that more large-scale and longitudinal studies with consistent intervention parameters are still needed.

This review aims to provide the reader evidence in exercise typology in the reduction of risk factors and the prevention of falls. The maintenance of physical performances is important not only to prevent a fall but, in the event of a fall, to also save functional capability to be able to get up from a floor and regain independence and confidence. Loss of strength is reduced in elderly people who participate in sports and is reversed by physical activity (7). When threats to balance (narrowed base of support, perturbation, loss of vision, or proprioception) occur, rapid responses must be engaged to maintain postural stability. With aging, slowed response initiation further reduces the possible time to produce remedial action. The velocity at which high muscular forces can be generated may be the critical determinants to prevent a fall (65). Muscle power (Force × Velocity of shortening) must be preferred to the strength during exercise-based intervention programs to prevent falls, because the ability to develop high force rapidly contributes to successful performance in everyday activities such as climbing stairs, regain balance after a trip or slip, rising from a chair... Skelton et al. demonstrated that muscular power in 65- to 84-year-old subjects showed a decline of approximately 3.5% per year, whereas the loss in isometric strength was approximately 1.5% per year (78). This decrease of velocity could be also explained by the loss of type II fibers in elderly people. The loss of maximum isometric force during aging varies among different muscle groups, being higher in the lower limb than in the upper limb (57). The reduction in size of muscular fibers type II b because of age, is more evident in vastus lateralis than in biceps muscle (1). Merletti et al. (56) confirmed, in a noninvasive way, the decrease in maximal voluntary contraction torque and in myoelectric manifestations of muscle fatigue in an elderly group. Changes in fiber type distribution and decrease in MU firing rate with aging may be factors determining the decrease in maximal voluntary contraction torque and in myoelectric manifestations of muscle fatigue.

In older people muscles are more uniformly composed by slow fibers, with motor units larger than younger people (25,39). Seniors have a decreased number and size of fast twitch fibers, during contraction, than do young people. Surface EMG analysis shows alteration in the spectral and amplitude characteristics of the signal and in muscle fiber conduction velocity (57). The main conclusions are that myoelectric manifestations of muscle fatigue are higher in young subjects than in elderly subjects. Those phenomena suggest that elderly subjects show a (paradoxically) higher resistance to fatigue and longer endurance time. In agreement with what is described above, continuous exercise was found to counteract these physiological effects slowing the aging of the muscle (10).

Sway and balance can be improved with gait and strength training (32,47) and computerized balance training (8,17,42,91). Through all the inconsistencies regarding frequency, mode, and intensity of training, it is proved that to improve health and modify certain risk factors for falling (such as strength and balance) moderate physical activity is appropriate (77).

Conclusion

A number of studies demonstrated a positive association between muscle strength of the lower extremities and mobility tasks such as rising from a chair and speed walking.

The relationship between lower limbs strength and postural stability in elderly people is less clear. Muscular strength in lower limbs can be measured by dynamometry, cable tensiometer, with free weights, or exercise machines using a 1 or 3 repetition maximum test. Cross-sectional studies indicate that isometric and concentric strength peak levels between the second and third decades remain unchanged until the fourth or fifth decade and start to decline from about the fifth decade at a rate of 12–15% per decade until the eighth decade in men (28).

A number of studies used motorized dynamometers such as isokinetic devices to distinguish fallers from nonfallers on the base of dorsal flexion, plantar flexion, or quadriceps strength (18,46). In general, works about the effects of age on muscular strength showed that older men required more time to reach peak torque in comparison to younger men (61). These data are supported by the observation of a close association between age-related losses in muscle power and functional abilities. These findings may be explained by a selective atrophy of type II b fibers with age (38); such a strength reduction occurs earlier in lower extremities than in upper extremities (16).

The association between eccentric strength and falling in older people did not receive enough attention in the literature. This fact is opposite to the fact that eccentric component of muscular strength is pivotal in many physical tasks such as descending stairs or sitting down. Moreover, eccentric strength is necessary for maintaining balance in static and in dynamic conditions (68). This is surprising when compared with the data from the study of Hortobagyi (27) who suggested a relative preservation of eccentric strength with aging in men and women that seems to be independent on muscle mass or muscle fiber type or size.

Therefore, conflicting reports exist about strength and falls in older adults, and there is still little uniformity in protocols. Unilateral measurements of lower limb strength of older people were collected in some other studies; forces generated by both legs were measured. No studies were found comparing asymmetry of lower limb strength in elderly fallers and nonfallers. This comparison could be important to understand one cause of falls and whether such an asymmetry of strength in fallers is because of an accelerated aging effect or some other reasons.

Studies of responses evoked by A-P perturbations showed that older adults tend to initiate stepping at lower levels of instability than do young adults (31,50). Older adults have a tendency to use multiple steps or arm reactions to regain equilibrium differently from young people. Moreover, decreased strength has been shown to be associated with the tendency to use multiple steps to recover balance; it seems that the torque demands in some muscles, as knee extensors during later phases of the step, can exceed the strength limits measured in older adults (53). These findings show that the strength loss in vastus lateralis muscle may contribute to the postural instability during the swing phase and landing in elderly persons. It was shown that leg muscle strength is a determinant in the capability to recover balance. Based on this review, it is possible to conclude that lower limb strength plays an important role in balance recovery. No data are available indicating if resistance training or power training in the elderly might improve such a recovery ability; moreover, no works were found aiming to verify if a correlation occurs between muscular fiber type and postural stability. The assessment of such a correlation is currently investigated also adopting biomechanical techniques and EMG analyses. Findings highlighted that submaximal levels of force, or rate of force generation, may be required in certain muscle groups of the lower limbs suggesting that strength training could be of benefit in feeble subjects, whereas balance training could potentially counteract sensorimotor deficits.

This review might contribute to the development of adequate exercise programs aiming to preventing or slowing down the age-related decline of physical functioning.

Eccentric component of muscular strength is a basilar component of many physical tasks; moreover, it provides the necessary deceleration forces necessary for maintaining balance in static and in dynamic conditions. Postural stability and, to a smaller extent, muscle strength seem to be important contributors to functional performance in elderly people. Findings collected in this work support the hypothesis that the maintenance of lower limbs muscular strength is useful for maintaining efficient postural stability during aging. Further researches should compare postural stability in different sensory conditions and strength of lower limbs in elderly people, to show if a correlation between these 2 functional aspects occurs, providing a further tool in decreasing risk of fall in the elderly.

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