

The Initial Effects of Low-Volume Strength Training on Balance in Untrained Older Men and Women

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ABSTRACT

Evidence indicates that leg weakness in older adults is associated with decreased control of balance. The gender-specific implications of strength training on control of balance in older men and women remains unknown. This study examined the initial adaptations to 12 weeks of low-volume, single-set-to-failure strength training and its effect on quadriceps strength and control of multidirectional balance in previously untrained older men ($n = 11$) and women ($n = 11$) 59–83 years of age. Leg strength increased 23–30% ($p < 0.001$) across genders; however, the effect on balance varied between genders. No significant changes were noted in the women, whereas 37% ($p < 0.014$) more sway in the medial-lateral direction was noted in the men, with no change in the anterior-posterior direction. These results demonstrate that this training protocol may not be effective for improving balance and may lead to worsening of balance in older men.

Key Words: strength, gender, aging, falls

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Introduction

Balance, or the ability to control postural sway, worsens with age, and this age-related decline has been associated with increased fall risk (10). The relationship between aging and decreasing control of balance has become a topic of much discourse as investigators have attempted to identify means of reducing the risk of falls and fall-related injuries in older adults. Decreased muscular strength has repeatedly been associated with increased risk of falling (2, 6, 13, 19, 27, 28). Pendergast et al. (19) reported that muscular weakness in older adults leads to a fourfold increase in the risk of falling. But Rubenstein and Josephson (21) reported that leg muscle weakness in-

creased the risk of falling fivefold, whereas gait and balance impairments resulted in only a threefold increase. This association between leg muscle strength and fall risk is in general agreement with the observations of other investigators who have presented data showing that the antigravity muscles of the lower extremity, specifically the quadriceps, show the effects of aging relatively early compared with the other muscles (12, 25).

The literature addressing the relationship between strength training and control of balance has not shown universal agreement regarding the efficacy of strength training in preservation of balance control or reduction of the frequency of falling in older adults. The use of strength training in older men and women has become widely accepted only in the last 2 decades because it was once thought to be too aggressive, or risky, for older individuals. To what extent strength training can improve control of balance in older men and women is not clearly known. Furthermore, the gender-specific effects of strength training on balance control are not known. Therefore, the intent of this study was to examine the initial, or early, adaptations to 12 weeks of low-volume strength training, with emphasis on quadriceps strength and control of balance in healthy, community-dwelling older men and women. The quadriceps was selected for 3 primary reasons: (a) data have shown the consequential effects of aging in the quadriceps sooner than in upper-extremity or other lower-extremity muscles, (b) the quadriceps is a major antigravity muscle of the lower extremity and is thus involved in maintenance of balance, and (c) training or measurement devices are widely available to the public and to training professionals.

Methods

Experimental Approach to the Problem

Data included measurements of quadriceps strength and balance in a group of older men and women.

Strength was measured as the maximal voluntary isometric strength (MVC) of the quadriceps and the 1 repetition maximum (1RM) strength of 2 leg exercise devices. Balance was examined under static and dynamic conditions with eyes opened and closed for a total of 4 conditions. Maximal voluntary isometric strength was measured at 0, 6, and 12 weeks, whereas 1RM and balance were measured at 0 and 12 weeks. Assessment of balance was conducted before, but during the same session as, testing of MVC, whereas 1RM strength was recorded 48 hours later. All subjects participated in a pretesting familiarization session 48 hours before baseline data collection to introduce the methods of testing MVC, 1RM, and balance. The same investigator (JWB) performed all measurements and conducted all training sessions. Before any testing or exercise session, subjects performed 5 minutes of warm-up activities consisting of calisthenics and marching in place.

Subjects

Eleven men and 11 women between 59 and 83 years of age (67.7 ± 5.5) volunteered. No subject had been involved in a strength-training program for a period of at least 5 years, and none were currently participating in any exercise apart from walking (1 male subject reported involvement in a "light" training program approximately 5 years earlier). The subjects were healthy, community dwelling, and self-ambulatory, with no history of falling. Exclusionary criteria included uncontrolled hypertension, diagnosed osteopenia or osteoporosis, transient ischemic attacks, stroke or congestive heart failure, visual or auditory compromise preventing driving, or ongoing anticoagulation therapy. Signed consent for participation was given by each volunteer after review of the consent form approved by the Institutional Review Board of the University of Kentucky. Before any exercise or testing, all subjects underwent a physical examination and a graded exercise stress test (modified Balke treadmill protocol) under the supervision of a physician (DRG).

Balance

Balance, measured as postural sway, was defined as the distance a subject deviated from his or her center of balance (COB). The Chattecx Dynamic Balance System (Chattanooga Group, Inc., Chattanooga, TN) was used to measure postural sway during a 2-legged stance with eyes opened and closed for a total of 4 conditions: eyes open stable (EOS), eyes closed stable (ECS), eyes open unstable (EOU), and eyes closed unstable (ECU). Figure 1 depicts the assessment of balance. The intertester and intratester reliability of this device has been reported previously, with correlation coefficients (ICCs) of 0.90 and 0.92, respectively (5). Our own reliability coefficients were calculated before testing (see Results). Balance was measured before

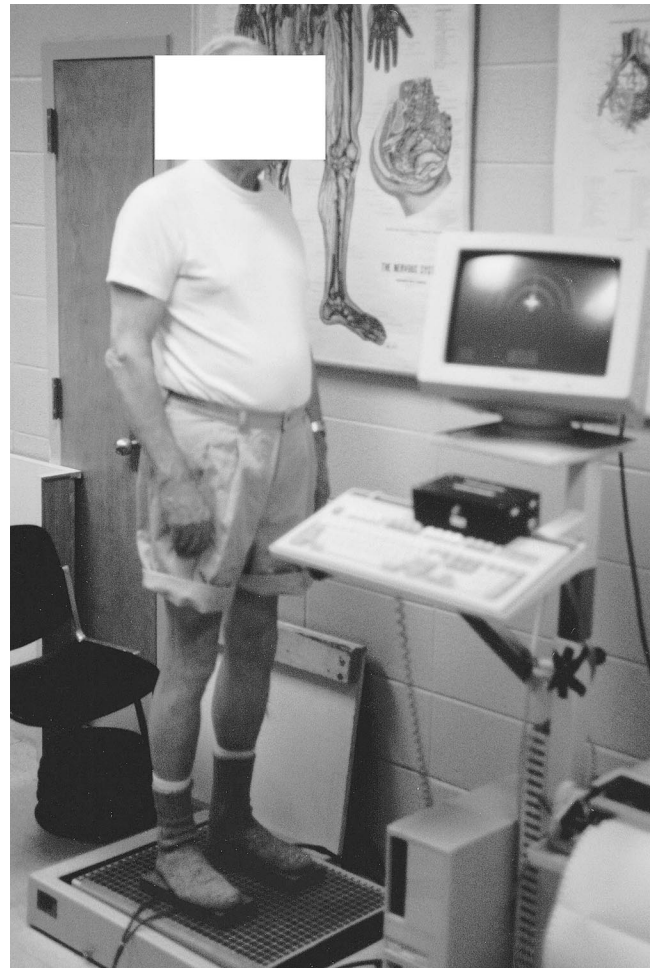


Figure 1. Balance assessment.

and after training only to minimize the effects of learning. Postural sway was represented by the variable "sway index" (SI), calculated using deviations from the subject's COB in the x and y coordinate directions. Sway index reflects the anterior-posterior (A-P) and medial-lateral (M-L) shifts in the subject's COB during each test condition, thus yielding a single value that expresses the subject's sway pattern. Unidirectional postural sway also was examined in the M-L and A-P directions. These procedures have been described elsewhere (15).

For static conditions, the subjects stood still for 10 seconds while measurements of postural sway were recorded, first with eyes opened and then with eyes closed. For dynamic conditions, the subjects stood first with eyes opened and then with eyes closed as the test platform moved in a 4° dorsiflexion (toes up) motion during a 10-second period. The perturbation movement was designed to angle up (dorsiflex) 4° in the first 5 seconds and return to a horizontal position in the last 5 seconds. The eyes-opened condition was always tested before the eyes-closed condition, and the subjects were instructed to focus on a visual marker located on a wall 3 m directly in front of the device

and 6 ft above the floor. No practice repetitions were offered, apart from the orientation session conducted at least 48 hours before baseline data collection. The actual data recorded included a single repetition for each of the 4 conditions with 30 seconds between conditions.

Maximal Voluntary Isometric Strength

Maximal voluntary isometric strength of the quadriceps femoris was measured using the self-reported dominant leg. Maximal voluntary isometric strength was measured using an Interface SM-1000 load cell (S/N C65680) connected to a Grass P511 strain-gauge amplifier (Grass Instruments Corp., Quincy, MA) in series with the Bio-Pac Data Acquisition System (Bio Pac Systems, Santa Barbara, CA). Data were stored by the Bio-Pac Data Acquisition System after conversion of the analog signal to a digital signal with a 12-bit A-D board. Weekly calibrations were conducted to maintain an error of less than 1% with a resolution of 0.13 lb. Before testing, intratester reliability was calculated (see Results).

The subjects were supine, with the knee of the test leg resting on the edge of the padded table and the nontest leg flexed 45° at the hip and 90° at the knee with the foot resting flat upon the table. A variable-length chain in series with the load cell was adjusted for each subject to allow 35° of knee flexion. A non-elastic Velcro ankle strap was positioned just proximal to the ankle joint. Each subject was given 2 maximal practice repetitions. Testing was completed by positioning the subject's knee passively at the test angle of 35° flexion to remove any slack in the chain. Upon a verbal signal to begin, subjects extended their leg as forcefully as possible for 3–4 seconds. Ninety seconds of rest was allowed between each repetition. Data included 3 repetitions recorded at 0, 6, and 12 weeks. Of the 3 repetitions, the one with the greatest force was selected for data analysis.

One Repetition Maximum

Dynamic leg strength of each subject was measured by a modified 1RM testing procedure using the Eagle Fitness Cybex supine bilateral leg press (LP) and seated bilateral knee-extension (KE) machines at 0 and 12 weeks. Subjects were positioned on each device, given 3–5 unresisted practice repetitions, and then made to perform 3 repetitions with a load estimated to be 25% of the subject's maximal strength. The load was then increased to approximately 50% of the estimated 1RM, and the subject performed 2 repetitions. The load was then increased for the attempted completion of a single repetition. If the repetition was completed successfully, resistance was increased for another repetition after 90 seconds of rest. This process continued until the subject was no longer able to complete a repetition. The 1RM value recorded was the last weight the subject

was able to lift throughout the test range. Testing began with either LP or KE, followed by the other, and for the 12-week retest the order of testing was reversed.

Training Protocol

The 12-week training protocol was designed as a single set of 8–12 repetitions to volitional failure involving 5 exercises: LP, KE, seated chest press, seated rowing, and seated latissimus pull-downs. Volitional failure was defined as the point at which the subject could no longer complete another repetition through the entire range of motion. When the subject could complete more than 12 repetitions at the specified weight, the resistance was increased so that the subject could complete approximately 8, but no more than 12, repetitions during the next session. If fewer than 8 repetitions were performed, the weight was returned to the preceding weight until the subject completed at least 8 repetitions at that weight.

Because these subjects were older and not experienced in strength training, this protocol was designed as a beginner program with an initially low training volume and intensity. Subjects trained for 2 sessions per week, with an interval of 48 hours between sessions, for 12 weeks. The first 2 weeks of training were designed to be an introductory period in an effort to minimize the incidence of injury and to condition the subjects to future progressive increases in resistance (8). The initial load for the first week was 40% of the 1RM, increasing to 60% at week 2, and each subject performed a single set of 15 repetitions. After the first 2 weeks the resistance for each exercise was increased to begin the single-set-to-failure, 8- to 12-repetitions format.

Statistical Analyses

SPSS statistical software (version 9.0 for Windows) was used for all the analyses. Conventional statistical methods were used for determination of means and standard deviations. The 1RM and MVC data were analyzed using a 2-way analysis of variance (ANOVA) (gender \times time) with repeated measures on time. For the 1RM variables the repeated measures were over 2 time periods (0 and 12 weeks), whereas for MVC the repeated measures were over 3 time periods (0, 6, and 12 weeks). For analysis of balance data under ML, AP, and SI directions, the 4 test conditions (EOS, ECS, EOU, ECU) were collapsed to analyze the data as a 2-gender \times 2-time periods \times 4-condition ANOVA. When significance was noted within the ANOVA (Wilk's Lambda test), posthoc pairwise comparisons using *t*-tests were used to compare within-gender differences over time and between-gender differences within each time period. Power values for measures of 1RM were 0.75 for LP and 0.91 for KE, whereas power for MVC was 0.07 (gender \times time). Power values for

Table 1. Subject demographics.*

	Age (y)	Height (cm)	Weight (kg)
Men ($n = 11$)	67.7 \pm 4.7	179.1 \pm 5.2	85.8 \pm 9.6
Women ($n = 11$)	67.7 \pm 6.4	161.8 \pm 3.1	72.3 \pm 13.3

* There were no significant differences between genders.

measures of balance ranged from 0.07 (gender \times time \times condition) to 0.61 (M-L gender \times time).

Results

Before training, there were no significant differences in the age, height, or weight of the 2 gender groups (Table 1). The data for the 1RM of LP and KE are depicted in Table 2. On completion of the 12-week training program, a significant gender \times time interaction ($p = 0.012$) was noted for 1RM strength on the LP. At the start of the training the men were significantly stronger than the women, with a mean of 1,662.9 \pm 298.9 N vs. 1,066.5 \pm 204.8 N ($p < 0.001$). A 23% within-gender improvement was noted in the women as they increased their 1RM by 247.7 \pm 37.8 N ($p < 0.001$). Likewise, there was a within-gender improvement of 25% in the men as they improved their 1RM by 414.5 \pm 225.6 N ($p < 0.001$). Not surprisingly, a significant between-gender difference at 12 weeks was noted because the men were 58% stronger ($p < 0.001$). For the KE, a significant gender \times time interaction ($p = 0.002$) was noted, with a 30% increase within the women's group ($p < 0.001$) and a 26% increase within the men's group ($p < 0.001$). At the onset of training, the 1RM of the women was 353.8 \pm 65.9 N and increased to 458.9 \pm 82.8 N, whereas the men improved to 834.0 \pm 97.1 N from 664.7 \pm 97.5 N. As in the case of the LP, there was a significant between-gender difference at week 12 because the men were 81% stronger for the KE ($p < 0.001$).

The data for the MVC are depicted in Table 3. Intratester reliability for measures of MVC demonstrated an ICC of 0.92. For the measures of MVC, there was no significance noted in the gender \times time interaction ($p = 0.858$), indicating that the change in strength was not significantly different between genders. However,

Table 2. One repetition maximum strength (N) (\pm SD).

	Leg press		Knee extension	
	Week 0	Week 12	Week 0	Week 12
Men	1,662.9 \pm 298.9*	2,077.4 \pm 375.7*†	664.7 \pm 97.5*	834.0 \pm 97.1*†
Women	1,066.5 \pm 204.8	1,314.2 \pm 243.9†	353.8 \pm 65.9	458.9 \pm 82.8†

† Significantly greater than in week 0 ($p < 0.001$).

* Significantly greater than for women in the same week ($p < 0.001$).

Table 3. Maximal isometric quadriceps strength (N) (\pm SD).

	Week 0	Week 6	Week 12
Men	560.9 \pm 98.4*	591.2 \pm 67.6*	623.1 \pm 88.2*
Women	341.4 \pm 47.2	370.5 \pm 54.4	392.6 \pm 45.5

* Significantly greater than for women in the same week ($p < 0.001$). There were no significant differences within genders.

a significant main effect for gender was noted ($p < 0.001$) as the men generated greater strength at each time period. The within-gender changes showed a nonsignificant 11% increase in MVC among the women and a nonsignificant 15% increase among the men during the 12-week period.

The data for control of balance are depicted in Tables 4–6. Intratester reliability ICCs on 10 subjects, 48 hours apart, were 0.85 for SI, 0.65 for the A-P direction, and 0.58 for the M-L direction. For the measures of balance, there were no significant third-order interactions (gender \times time \times condition) noted for the M-L, A-P, or SI directions ($p = 0.068$ – 0.434). For SI (Table 4) and A-P (Table 5), there also were no significant second-order interactions ($p = 0.111$ – 0.486). For both variables SI and A-P, however, the main effect of gender was significant ($p = 0.034$ – 0.043) because the men showed significantly greater sway in all 4 test conditions. For the M-L direction (Table 6), there was a significant second-order interaction ($p = 0.029$) for time \times gender, indicating that for the conditions EOS, ECS, and ECU, the men showed a worsening in control of balance in the M-L direction. In the men, sway increased an average of 36.5% among the 4 conditions, reaching statistical significance with EOS (47% more sway), ECS (55% more sway), and ECU (33% more sway). At 12 weeks, however, only ECU showed a significant between-gender difference in balance ($p = 0.014$).

Discussion

The major finding of this investigation was that initial adaptations to low-volume, low-intensity strength

Table 4. Control of balance: sway index ($\pm SD$),*

	EOS	ECS	EOU	ECU
Men				
Week 0	0.34 \pm 0.22†	0.57 \pm 0.23†	1.16 \pm 0.39†	1.81 \pm 0.56†
Week 12	0.33 \pm 0.15‡	0.52 \pm 0.18‡	1.03 \pm 0.30‡	1.83 \pm 0.49‡
Women				
Week 0	0.30 \pm 0.10	0.39 \pm 0.19	0.96 \pm 0.20	1.57 \pm 0.30
Week 12	0.27 \pm 0.10	0.41 \pm 0.10	0.83 \pm 0.14	1.43 \pm 0.45

* There were no significant within-gender differences. EOS = eyes open stable; ECS = eyes closed stable; EOU = eyes open unstable; ECU = eyes closed unstable.

† Significantly greater than for women at Week 0.

‡ Significantly greater than for women at Week 12.

Table 5. Control of balance: anterior-posterior sway (cm) ($\pm SD$),*

	EOS	ECS	EOU	ECU
Men				
Week 0	1.34 \pm 0.67†	2.20 \pm 0.79†	4.96 \pm 1.7†	7.58 \pm 2.0†
Week 12	1.21 \pm 0.47‡	2.16 \pm 0.90‡	4.35 \pm 1.5‡	7.24 \pm 2.1‡
Women				
Week 0	1.13 \pm 0.45	1.61 \pm 0.77	4.14 \pm 0.77	6.40 \pm 1.1
Week 12	1.01 \pm 0.38	1.59 \pm 0.45	3.63 \pm 0.51	5.70 \pm 1.7

* There were no significant within-gender differences. EOS = eyes open stable; ECS = eyes closed stable; EOU = eyes open unstable; ECU = eyes closed unstable.

† Significantly greater than for women at Week 0.

‡ Significantly greater than for women at Week 12.

Table 6. Control of balance: medial-lateral Sway (cm) ($\pm SD$),*

	EOS	ECS	EOU	ECU
Men				
Week 0	0.56 \pm 0.29	0.76 \pm 0.29	1.15 \pm 0.39	1.70 \pm 0.53
Week 12	0.83 \pm 0.56†	1.02 \pm 0.55†	1.28 \pm 0.32	2.26 \pm 0.63†‡
Women				
Week 0	0.52 \pm 0.25	0.68 \pm 0.35	1.04 \pm 0.27	1.62 \pm 0.47
Week 12	0.53 \pm 0.17	0.81 \pm 0.29	1.07 \pm 0.17	1.55 \pm 0.40

* EOS = eyes open stable; ECS = eyes closed stable; EOU = eyes open unstable; ECU = eyes closed unstable.

† Significantly greater than at Week 0 within genders ($p \leq 0.014$).

‡ Significantly greater than for women in the same week.

training resulted in increased leg strength in healthy, older men and women but did not result in improved control of balance because postural sway worsened in the older men and there was no change in the women. The lack of improvement in balance observed in both groups after training is similar to the findings of Crilly et al. (7) and Topp et al. (26), who reported no change in the ability of older men and women to control bal-

ance after 12–14 weeks of exercise, although exercise was inadequately defined as “calisthenics” and “resistant rubber bands,” and no intensities were defined. However, these findings and ours differ from those of others who reported up to 26–33% improvement in balance after various strength-training protocols in men and women up to 80 years of age (18, 24).

The worsening of postural control in the M-L di-

rection observed in these older men after a strength-training program has not been reported previously because this is the first study to report gender-specific differences in multidirectional control of balance after a strength-training program. Furthermore, the reliability of the strength and balance measurements in this study indicates that the results are not merely random effects. The increases in strength in the present study are in keeping with previous data (8, 9, 16, 20, 23). However, what remains unknown is the extent to which increases in strength may relate to functional tasks such as control of balance (3–5, 7, 14, 17, 26). Although the major finding of this study does not elucidate this point, the gender-specific results in control of balance after training have broken new ground.

Although an initial conclusion may be that the mechanism for the worsening in M-L balance in these men was the influence of the training protocol, further consideration of the protocol is warranted. All the exercises were sagittal plane (A-P) movements and failed to address any frontal plane (M-L) movements. As a result, the concentration on sagittal plane muscle groups may have facilitated a muscle imbalance between sagittal and frontal plane muscle groups or development of motor learning of sagittal plane movement patterns, resulting in a worsening in M-L control in the men. Examination of the strength data shows that the men were approximately 50% stronger on the LP and 80% on the KE. This disparity in sagittal plane motions and muscle groups may be a factor underlying the lack of postural control in the M-L direction in these men.

What must be further considered as well are the effects of training variables other than intensity, volume, and duration. The biomechanical stresses of the training protocol were not specific to the balance task measured. The fixed nature of the training devices used at present fails to correspond to the dynamic nature of balance. None of the leg exercises used required an upright body position, the position in which balance is most evident. Thus, it is possible that the strength-training protocol per se did not negatively affect balance in these men, but rather the training lacked specificity to balance. The inclusion of exercises which themselves require balance, i.e., squats and lunges, would have added greater specificity, presented differing training stresses, and possibly yielded different results. Therefore, it would be wrong to conclude from these data that strength training on the whole does not improve balance when program design is likely to make a difference.

These findings support the previous findings of Brooks et al. (1) and Rutherford et al. (22), who stated that training-related adaptations are specific to the exercise stress that induces the change. Adaptation of muscle, either structurally or functionally, is partly related to the specifics of the stress applied during the

exercise. This concept of specificity is supported when examining the worsening of M-L control in the men. Had frontal plane movements been addressed in the training protocol, then perhaps different findings would have been observed in balance control in the men.

This investigation was predicated on the association between decreased muscular strength and increased incidence of falls in older adults and, more specifically, the decrease in leg muscle strength (19, 21). Thus, this investigation sought to provide a training stimulus that would increase leg strength and then examine the initial effect of increased strength on balance control. A single-set protocol was selected for strength training. Because of the age and inexperience of the subject group, this protocol was designed as a beginner program. Partly to minimize injury, but also to serve as a further introduction to strength training, the initial training intensity and volume were kept low. The improved 1RM data support the use of this protocol for increasing leg strength, but the balance data do not. What effect a training protocol using higher volume and intensity may have had on the balance of these older subjects is unknown.

Although considerable evidence indicates that multiple-set training yields greater increases in strength than does single-set training (24), the difference in strength gained between the two is likely a matter of total training volume. Kramer et al. (11) advocated the use of multiple-set training for strength vs. single set but advised that the intensity required may not be appropriate for older adults. In consideration of this, a single-set protocol was selected, and this protocol proved efficacious for increasing strength, as evidenced by the significant training-induced increases in strength in this study. However, because the subjects examined in this study were healthy, community-dwelling older adults, their baseline levels of strength were likely greater than those of less healthy, frail elderly people, in whom decreased strength may be a more significant factor in control of balance. Thus, although the present training protocol resulted in increased strength, it is possible that the increased strength had minimal to no initial effect on balance in these "normal," older adults. What effect a similar program would have on less healthy adults with a history of falling is a matter of conjecture.

These data do not support the use of this low-volume, low-intensity strength-training protocol for improving balance. Confusion persists as to interpretation of conflicting reports of different studies, with some reporting improved balance and others not. In light of this confusion, further consideration of the present design is warranted. The objective measurement of balance is a precarious task because balance is a multifaceted manifestation of several physiologic systems. Although previous studies have reported the as-

sociation of strength and balance, one cannot overlook the influence of other factors such as visual acuity, vestibular function, and endurance without risking erroneous interpretations of data. Measurements of balance are designed to measure some physical event or parameter, which is then interpreted in some manner as balance. This would be an example of an operational definition. An operational definition of balance is therefore adopted based on the physical event or variable measured, in this case the amount of sway from the COB. Considering the multifaceted nature of balance, the use of an operational definition of balance necessarily introduces risk of error in interpretation of the variable as a reflection of the physical event under examination. By assuming an operational definition, one risks excluding other potential influences on that same variable. For researchers, the ability to define balance is somewhat enigmatic, and this may explain the variability within the literature regarding the outcomes of interventions aimed at improving balance. Nonetheless, this study does not support the use of low-volume, low-intensity strength training as a means of improving balance in older men and women.

Practical Applications

Aging is associated with declining strength and increased risk of falling. Recent studies have examined strength training as a means of improving balance in older adults; however, there is a lack of evidence to support the use of strength training for improving balance. The findings of this study demonstrate that this initially low-volume, biweekly, single-set-to-failure protocol, using variable resistance machines, may even worsen control of balance in healthy older men. Future investigations of this type should consider the use of higher training volumes in the initial weeks of training and perhaps the use of free-weight exercises performed in the upright, weight-bearing position. Thoughtful and informed design of exercise-training programs for older adults may provide the means for improving balance, but the training protocol used here does not appear to be the right choice for improving balance. The concept of specificity appears to be supported by this investigation, and future use of exercise training for improving balance in older adults will benefit from adherence to the idea of specificity of training.

Note: David R. Gater is now with the Department of Physical Medicine and Rehabilitation at the University of Michigan, Ann Arbor, MI.

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