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Falls study: Proprioception, postural stability, and slips

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Abstract. The present study evaluated effects of exercise training on the proprioception sensitivity, postural stability, and the likelihood of slip-induced falls. Eighteen older adults (6 in balance, 6 in weight, and 6 in control groups) participated in this study. Three groups met three times per week over the course of eight weeks. Ankle and knee proprioception sensitivities and postural stability were measured. Slip-induced events were introduced for all participants before and after training. The results indicated that, overall, strength and postural stability were improved only in the training group, although proprioception sensitivity was improved in all groups. Training for older adults resulted in decreased likelihood of slip-induced falls. The study suggested that proprioception can be improved by simply being active, however, the results suggested that training would aid older adults in reducing the likelihood of slip-induced falls.

Keywords: Training, proprioception, postural stability, slips, falls

1. Introduction

The joint proprioceptors are located in muscles and joints active in body movement and orientation in space [1, 2]. The major class of receptors that provide information about position and movement are peripheral mechanoreceptors located in the joints, muscles, and skin. These mechanoreceptors provide motor programming with essential sensory information, allowing a person to accommodate unexpected perturbations or changes when visual information is not available [1, 2]. For example, a person does not continuously examine information about the surface or condition of the floor when walking unless their eyes are continuously directed toward the walking surface; therefore, visual information in regard to a slippery surface may not be available at all times. In particular, proprioceptors in the joints were suggested to play a critical role in maintaining the functional stability of the joints [2-4]. Information from joint proprioceptive receptors is integrated into the motor programming required for precision movements and contributes to reflex muscle contraction, providing dynamic joint stability [1, 2, 5-8]. Proper sensorimotor control of lower extremities is critical to sustain mobility and intact joint stability [2, 9-11]. For example, trainers suggested the

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rehabilitation of proprioception in order to improve joint stability after an injury. Similar to an injured joint, an aging joint that does not possess a highly sensitive proprioceptive feedback system may not respond appropriately to variations in forces placed upon it during unexpected movements.

With advancing age, degradations in the proprioception threshold or sensitivity result in failure to sense changes in the displacement of the body mass [4, 12, 13]. Accordingly, older adults with diminished proprioception sensitivity may not be able to detect and correct postural disturbances as promptly as younger adults [11, 14]. As a result, impaired postural stability [3, 4] and delayed responses to the perturbations [14-16] become apparent. Their inability to respond effectively to the balance perturbations, in turn, can result in unintentional falls resulting in permanent or fatal injuries to the hip, wrist, or head. An aging body exhibits decreased sensorimotor function in comparison to younger bodies [10, 15]; older adults were unable to respond to postural perturbation such as slips in a timely manner, resulting in a pronounced increase in fall rates. In an effort to prevent falls and minimize such injuries, neuromuscular training has been suggested to help delay the deteriorations of proprioception, thus improving the effectiveness of somatosensory information on postural control [16-19]. The two main forms of exercises currently utilized to improve proprioception and postural stability are machine weight training and balance training [20-23]. While free weight training is precarious for older adults, machine weight training has commonly been suggested to be safer and easier [24]. The present study hypothesized that neuromuscular training would rehabilitate joint proprioception sensitivity of older adults, affecting the likelihood of slip-induced falls and postural stability among older adults.

2. Method

2.1. Subjects

The present study was approved by the Institutional Review Board. Prior to the experiments, the participants were informed verbally of study procedures, and provided informed written consent to participate. No participants possessed any known physical disorder to complicate the study; Physical Activity Readiness Questionnaire *(PAR-Q)* was used as an initial screening tool. Eighteen older adults volunteers were randomly assigned to weight (age; 72.0±5.5, height; 158.8±2.9, weight; 69.4±5.3, BMI; 27.5), balance (age; 72.5±6.8, height; 165.7±9.6, weight; 70.7±12.0, BMI; 25.4), or control group (age; 76.5±8.3, height; 161.5±9.9, weight; 76.0±5.7, BMI: 30.5). The three groups were equivalent in age (p=0.48), height (p=0.37), and weight (p=0.41), though there was a subtle difference in BMI. Qualified participants for the present study had not participated in any form of exercise for 6 months prior to the study, or their current weight or balance exercise consisted of no more than thirty minutes per week. Any other form of exercise such as running, swimming, gardening, golf, etc. was not an exclusion criterion.

2.2. Treatments

Participants' daily activities were monitored throughout their participation in the study through daily interviews conducted by the experimenters and trainer. No participant engaged in any physical activities in addition to the exercises provided. Each group met three times per week over 8 weeks, each meeting lasting approximately one hour. The control group performed social activities (e.g. picnic, bingo, etc.); any activity that required physical performance was excluded with the exception

Table 1
Weight Exercise Regimen

Exercises	Target Muscle(s)	Synergist(s)
Leg extension	Quadriceps	Gleuteus maximus, adductor magnus, soleus.
Seated leg press	Quadriceps	Gluteus maximus, adductor magnus, and soleus
Calf press	Gastrocnemius	Soleus
Leg curl	Hamstring	Gastrocnemius and sartorius
Hip abduction and adduction	Gluteus medius, minimus, and maximus	Pectineus
Hip extension	Gluteus maximus	Gluteus medius and minimus

Note: prioprioception testing protocols to measure participant recognition of a previously presented reference position [28-33].

of walking. Balance Training was performed on the floor during the first week to familiarize participants with the instructional manual of Stability Trainer [25]. For the following weeks, volunteers were trained on the green stability trainer (intermediate challenge level). Blue stability trainers (advanced challenge level) were introduced if an individual performed exercises perfectly and confidently on the green stability trainer; among six volunteers, only two progressed to perform the exercises on the blue stability trainer. Weight Training was performed in the NS-4000 home gym model (Nautilus®, Vancouver, Washington 98684). Exercises mainly targeting lower extremities were developed (Table 1). Periodized strength training was employed because it was proven to be more effective in gaining strength than non-periodized strength training [26]. Two different hypertrophy phases were introduced for five weeks: three sets of ten repetitions at 50% maximum exertion for two weeks, and three sets of ten repetitions at 70% maximum exertion for three weeks. The strength phase encompassed the final three weeks, and consisted of three sets of seven repetitions at 85% maximum exertion. A 45-60 second resting period was observed between each set and a 150-190 second resting period was observed between exercises. Subjects performed 4-6 Repetition Maximum (RM) strength assessments for each exercise and determined 1 RM based on predicted values [27]. No upper body exercise was introduced.

2.3. Testing and evaluation

Two established methods to test proprioception are: 1) detection of movement and 2) recognition of a previously presented reference position. The present study adapted and applied previously published.

For the ankle proprioception test, participants were seated with their right foot on a footplate attached to Biodex System 3 (Biodex Medical Systems, Inc., Shirley, New York 11967). For the knee proprioception test, participants were seated with their right ankle strapped to a knee attachment and fixed to Biodex System 3. The subjects' ability to reproduce ankle and knee joint positions were tested once in each of two positions: 10° plantarflexoin and 5° dorsiflexion; both positions were identified to be least influenced by cutaneous sensory input in association with the extremes of the ROM [34]. Participants began in the common neutral position identified by experimenters. Each participant's right foot was placed on the footplate of the ankle attachment and rotated passively at the ankle joint in a direction of either plantarflexion or dorsiflexion. The ankle attachment was rotated at the speed of 1°/second to either 10° plantarflexion or 5° dorsiflexion from the neutral start position. Ten seconds were given for participants to observe these positions before the ankle attachment was rotated back to the neutral position. Participants were asked to press a switch when they perceived the original position (10° plantarflexion or 5° dorsiflexion) while the ankle attachment was rotating at the speed of 1° /second. For each trial, experimenters measured the difference in the angle between the original position (10° plantarflexion or 5° of dorsiflexion) and each attempt. For example, for a trial of 10° plantarflexion, if a participant pressed the switch when reaching 8° plantarflexion, the difference of 2° was recorded to evaluate statistical significances. Three trials were collected with one-minute intervals, and were averaged for statistical testing.

For the knee proprioception test, the knee attachment was rotated from a neutral start position of 90° knee flexion to allow extension at the knee joint. The knee attachment was rotated at the speed of 1°/second and stopped at 15° extension from the neutral start position. Ten seconds were given for participants to observe the position before the knee attachment was rotated back to the neutral position. Participants were asked to press a switch when they perceived the original position (15° extension) while knee attachment was rotating at the speed of 1° / second. The same technique was used to collect data for statistical testing.

Peak isokinetic ankle and knee strengths at 30°/second, 90°/second, and 120°/second, as well as isometric ankle strengths at 15° plantarflexion and isometric knee strengths at 15° extension were evaluated using Biodex System 3. Starting positions were identical to the explanation in 2.3.1.

Center of Pressure (COP) was evaluated using a force platform (BERTEC # K80102, TYPE 45550-08, Bertec Corporation, OH 43212, USA) with the participants' eyes closed. In this study, multivariate analysis (factor analysis) was used to evaluate balance stability while standing quietly. Specifically, the eigenvalue-based descriptors in multivariate analysis were used to describe the variance of each factor (x or y of COP); furthermore, ellipse areas were calculated using one eigenvalue as a long axis and the other eigenvalue as a short axis [35]. Stability was considered better if the calculated ellipse area was smaller, indicating smaller variance. In addition, COP*distance* were calculated to evaluate the reaction mechanisms by the following formula:

$$\mathrm{COP}\mathit{distance} = X(i+1) - X(i), \text{ where } X = \mathit{position\ of\ COP}$$

The average of the COP distance during 30 seconds of standing was parameterized.

Walking trials comprising the slipping and falling trials were conducted on a walking track (20 m), which was elevated 15 cm above the floor surface and consisting of vinyl tile [36]. The slippery surface was located 10m from the deck end. Participants were instructed to look forward and walk straight at their preferred walking speed. Participants' cadence was measured within a subsequent 20-minute session to ensure that their preferred walking speeds were consistent throughout the experiment. After ensuring that the preferred walking speeds were consistent, participants' natural posture and ground reaction forces were collected. While walking, participants were instructed to count colored circles in one of three different colors, flashed randomly and individually on a television screen located at each work station; this secondary task was provided to take away participants' attention from the floor surfaces. One of the main purposes of a walkway (during the slippery conditions) with two force plates embedded in the center (with sliding floor to switch from normal-dry floor surface to slippery floor surface) was to simulate real slip-induced fall events [36]. Some studies have simulated slip-induced fall events utilizing only 2-3 steps; in the present study, all walking trials lasted 15-20 minutes to better account for participants' natural gait characteristics, and the trial was terminated after the slippery surface was encountered. A fall arresting rig and safety harness was used to protect participants during the experiment, and was designed to permit participants to fall approximately 10 cm before arresting the falls and halting any forward motion. Slip distance, sliding heel velocity, COG velocity, and motion pictures were utilized to determine the fall frequency. To be considered a fall, the slip distance must exceed 10 cm, and peak sliding heel velocity must exceed COG velocity while slipping [10]. Peak sliding heel velocity represented heel displacement and COG represented body position while slipping. Also, videos for each participant were analyzed to see if falls had occurred. All of the above three conditions had to be met in order to be considered as a fall. Identical procedures were performed before and after training. All participants wore identical shoes during pre- and post-training data collections to ensure that the RCOF was not influenced by differences in shoe sole.

2.4. Data analysis

Ground reaction forces were used to determine Center of Pressure (COP) for 30 seconds at 120 Hz. The force data was filtered using fourth order zero-lag lowpass-Butterworth-filter at cut-off of 6 Hz. Power analysis was performed to satisfy Type I error of 0.05 and Type II error of <0.35 (power>0.65). Power (>0.65) was chosen as the acceptable power for analysis of a 6-week strength training regimen (Knight and Kamen, 2001; isometric strength difference between pre- and post-training = 176.8-136 = 40.8 Nm). Potential threats to external validity may include the use of the lower statistical power (0.65). Training began immediately after the introductory meeting, with 24 initial participants. The study was evaluated with a mixed factor repeated measure design: 2 × 3 (time (pre and post training) × training (balance, weight, and control)). Training was a between-subjects factor and time was a within-subjects factor. The dependant measures, static balance stability, reaction time, isokinetic and isometric muscle strength, and proprioceptive sensitivity (joint position sensibility) were analyzed. Descriptive and inferential statistical analyses ($p \leq 0.05$) were performed by utilizing the JMP statistical packages (SAS Institute Inc. Cary, NC, USA).

3. Results

3.1. Effects on ankle and knee strength

Right and left isokinetic extensor strengths improved after the 8-week training in both the balance training and the weight training groups in comparison to the control group, illustrated by the (TM × Time) interactions of all isokinetic extensor strengths in Table 2. Isokinetic flexor strengths and isometric strengths improved in all groups including the control group as illustrated by the (TM × Time) interaction in Tables 2 and 3. Right and left isokinetic extensor and flexor strengths, as well as isometric strengths improved in both the balance training and weight training groups in comparison to the control group, as illustrated by the (TM × Time) interactions in Tables 3 and 4. Interestingly, the results in the interactions of left knee strength illustrated by (TM x Time) in Table 4 indicated that the control group also exhibited some improvement.

3.2. Effects on proprioception sensitivity

Proprioception sensitivity improved in all three groups after 8 weeks of training (Table 5). The results suggest that being socially active could result in the improvement of proprioception sensitivity in the ankle and knee.

Table 2
Isokinetic ankle strength (Nm) (*TM = Training method, R = Right, L = Left, Ex = Extension, Fx = Flexion)

		Weight (N=6)	Balance (N=6)	Control (N=6)	P (Time)	P (TM × Time)
R 30 Ex	Pre	38.3 ± 17.5	34.5 ± 8.5	22.7 ± 7.6	0.003	0.003
	Post	48.0 ± 9.2	45.7 ± 12.1	23.7 ± 6.0		
R 30 Fx	Pre	8.2 ± 2.6	10.5 ± 4.2	7.2 ± 3.4	0.0003	0.15
	Post	11.2 ± 2.6	11.5 ± 5.1	8.2 ± 3.0		
R 90 Ex	Pre	27.3 ± 17.3	30 ± 9.2	17.5 ± 6.9	0.01	0.05
	Post	40.2 ± 8.1	35.5 ± 11.8	17.0 ± 4.3		
R 90 Fx	Pre	5.7 ± 1.9	6.3 ± 3.3	4.0 ± 3.2	0.01	0.94
	Post	7.0 ± 1.4	6.3 ± 2.9	5.0 ± 3.0		
R 120 Ex	Pre	25.7 ± 16.0	29.0 ± 10.0	16.7 ± 6.6	0.001	0.02
	Post	35.0 ± 8.0	33.3 ± 9.8	16.7 ± 5.2		
R 120 Fx	Pre	5.2 ± 2.2	4.5 ± 3.4	2.4 ± 2.5	0.004	0.76
	Post	6.3 ± 1.0	5.0 ± 3.0	4.0 ± 2.8		
L 30 Ex	Pre	35.3 ± 9.6	37.2 ± 12.2	24.3 ± 6.9	0.0006	0.07
	Post	49.3 ± 9.0	45.0 ± 12.0	26.7 ± 10.0		
L 30 Fx	Pre	9.0 ± 4.0	11.0 ± 4.1	8.5 ± 7.3	0.03	0.55
	Post	11.0 ± 3.8	12.3 ± 4.3	9.0 ± 4.7		
L 90 Ex	Pre	29.2 ± 11.1	27.3 ± 12.1	17.3 ± 8.0	0.0006	0.02
	Post	38.5 ± 10.9	34.2 ± 10.9	17.3 ± 6.7		
L 90 Fx	Pre	5.8 ± 2.5	6.2 ± 3.1	4.7 ± 2.8	0.0001	0.1
	Post	7.7 ± 3.9	6.8 ± 2.0	5.3 ± 2.9		
L 120 Ex	Pre	27.0 ± 11.0	26.5 ± 12.3	17.7 ± 7.1	0.002	0.0008
	Post	34.7 ± 9.3	30.2 ± 9.3	18.5 ± 6.3		
L 120 Fx	Pre	5.0 ± 2.3	5.0 ± 3.4	3.9 ± 2.1	0.0007	0.41
	Post	7.0 ± 3.1	5.3 ± 2.1	5.0 ± 2.9		

Table 3
Isometric ankle and knee strength (Nm)

		Weight (N=6)	Balance (N=6)	Control (N=6)	P (Time)	P (TM × Time)
Ankle R15 Ex	Pre	52.2 ± 18.9	48.0 ± 13.7	31.8 ± 9.2	0.0021	0.28
	Post	66.5 ± 22.3	59.8 ± 17.5	35.7 ± 7.2		
R15 Fx	Pre	12.2 ± 4.5	14.8 ± 4.3	8.7 ± 5.5	0.02	0.08
	Post	13.5 ± 3.4	16.5 ± 6.9	8.2 ± 4.6		
Knee R15 Ex	Pre	75.5 ± 18.7	75.3 ± 21.2	65.0 ± 11.9	0.001	0.009
	Post	94.5 ± 15.7	98.7 ± 23.9	61.8 ± 11.2		
R15 Fx	Pre	34.3 ± 12.4	40.7 ± 12.1	31.2 ± 7.5	0.03	0.02
	Post	40.3 ± 12.0	45.3 ± 12.6	28.8 ± 7.8		

Table 4
Isokinetic knee strength (Nm)

		Weight (N=6)	Balance (N=6)	Control (N=6)	P (Time)	P (TM × Time)
R 30 Ex	Pre	68 ± 5.9	63.7 ± 12.7	53.5 ± 9.9	0.001	0.001
	Post	79.3 ± 13.9	73.3 ± 18.8	52.5 ± 10.3		
R 30 Fx	Pre	41.7 ± 6.7	40.7 ± 10.4	32.8 ± 6.8	0.0001	0.05
	Post	47.3 ± 11.8	45.3 ±11.0	34.5 ± 8.1		
R 90 Ex	Pre	52.3 ± 7.0	48.3 ± 14.5	40.7 ± 8.7	0.001	0.006
	Post	59.5 ± 7.6	56.0 ± 13.7	38.8 ± 10.8		
R 90 Fx	Pre	36.7 ± 6.3	37 ± 12.4	28 ± 2.5	<0.0001	0.001
	Post	43.0 ± 4.3	43.5 ± 11.0	27.8 ± 4.0		
R 120 Ex	Pre	47 ± 7.6	45.2 ± 16.2	36.2 ± 6.9	0.0001	0.0004
	Post	53.5 ± 8.1	48.2 ± 12.2	34.3 ± 7.2		
R 120 Fx	Pre	34.8 ± 7.6	36 ± 13.6	28.3 ± 2.2	0.0009	0.0013
	Post	41.3 ± 7.7	42.2 ± 11.1	26.2 ± 6.1		
L 30 Ex	Pre	57.8 ± 9.8	79.8 ± 32.6	40.8 ± 3.1	0.001	0.07
	Post	75.5 ± 14.4	81.8 ± 29.9	44.2 ±7.7		
L 30 Fx	Pre	35.0 ± 7.3	46.7 ± 18.3	30.8 ± 11.2	<0.0001	0.0009
	Post	49.5 ± 8.9	53.2 ± 14.2	30.0 ± 8.9		
L 90 Ex	Pre	46.5 ± 5.1	55.0 ± 27.5	28.2 ± 5.2	0.0007	0.24
	Post	55.7 ± 9.9	62.8 ± 22.1	31.3 ± 4.5		
L 90 Fx	Pre	31.3 ± 11.3	36.3 ± 16.0	25.5 ± 7.6	0.0004	0.01
	Post	43.0 ± 9.0	48.0 ± 12.5	25.5 ± 5.5		
L 120 Ex	Pre	41.5 ± 5.6	48.7 ± 22.6	28.7 ± 3.9	0.005	0.09
	Post	49.3 ± 9.4	55.5 ± 19.5	28.5 ± 3.9		
L 120 Fx	Pre	32 ± 5.1	38.3 ± 15.1	25.7 ± 7.1	<0.0001	0.0007
	Post	42.3 ± 7.3	46.0 ± 12.4	24.3 ± 4.8		

Table 5
Ankle (A) and Knee (K) Proprioception (degree) and Center of Pressure (COP) (mm^2 and cm)

		Weight (N=6)	Balance (N=6)	Control (N=6)	P (time)	P (TM × Time)
Proprioception (°) A Plantar 10	Pre	3.4 ± 1.3	2.5 ± 2.1	4.2 ± 3.1	0.0004	0.54
	Post	1.5 ± 0.6	0.5 ± 0.1	3.2 ± 2.7		
Proprioception (°) A Dorsi 5	Pre	0.9 ± 0.4	0.9 ± 0.4	2.6 ± 1.8	0.09	0.4
	Post	0.7 ± 0.3	0.4 ± 0.3	2.6 ± 1.7		
Proprioception (°) K Ex 15	Pre	2.8 ± 1.9	3.8 ± 3.1	5.0 ± 5.1	0.002	0.1
	Post	0.9 ± 0.4	2.3 ± 2.3	4.9 ± 5.3		
Center of Pressure Area (mm^2)	Pre	109.7 ± 57.0	166.2 ± 167.2	209.9 ± 115.2	0.0034	0.0227
	Post	70.7 ± 50.6	70.7 ± 80.7	181.9 ± 110.9		
Center of Pressure Distance (cm)	Pre	60.6 ± 33.8	76.2 ± 39.9	111.1 ± 75.5	0.0521	0.0123
	Post	49.6 ± 16.5	55.4 ± 27.5	111.3 ± 90.4		

3.3. *Effects on postural stability*

COP*area* (mm^2) and COP*distance* (cm) in balance training and weight training groups exhibited a significant improvement in comparison to the control group (Table 4). These results may suggest that balance and weight training play a role in improving somatosensory, particularly in detecting perturbations.

3.4. Fall frequency

Four individuals in each training group who fell in the pre-training stage recovered from slips in the post-training, and two individuals in each group who recovered from slips in the pre-training stage recovered from slips again in the post-training. In the control group, five individuals who fell in the pre-training stage fell again, and one individual who recovered from a slip again recovered. These results with consistent gait characteristics suggest that older individuals with training showed a greater ability to recover from slips.

4. Discussion

The objective of the present study was to evaluate if an 8-week balance or weight training program would be improve proprioception sensitivity or postural stability and reduce the likelihood of slip-induced falls. In the present study, after an 8-week training, the majority of individuals in training groups demonstrated improvement in ankle and knee isometric and isokinetic strengths [37-40] although the control group (social activity group) also showed slight ankle and knee improvement. Strength improvement in the control group was an interesting outcome in the present study because experimenters expected to see significant strength improvement in the balance and weight training social activity for older adults might also be beneficial [41-43]. The results also suggested that a reduction in strength with advancing age may not only be the result of physiological aging, but also, due to reduced social activity [41-43]. In order for the control group to socialize, they had to leave their residencies and, in many cases, were required to drive. Additionally, social activities often included walking in picnic areas, shopping malls, or museums. These kinds of activities were not a controlled physical training; however, these activities appear to have resulted in improved leg strength over 8 weeks. These results further indicated that older adults should be as active as possible to maintain their mobility.

Also, after 8 weeks, proprioception sensitivities for ankle plantarflexion and knee extension improved in all groups, including the control group. These results further indicated that being socially active could give appropriate stimulation for proprioceptive system and may attenuate this decline [33]. However, no statistical difference was observed in dorsiflexion proprioception sensitivity, likely due to the fact that the range of motion of dorsiflexion for the elderly was too small; 5° dorsiflexion was almost the full extent of rotation toward the body for most of the participants in the present study, which may have affected proprioceptive sensitivity level in dorsiflexion. Authors would not recommend evaluating 5° dorsiflexion for the elderly in future study. The results from the present study, however, indicated that postural stability improved in only training groups, and not in the control group. These results were somewhat surprising, because the strength and proprioceptive sensitivity improved in all groups including the control group (social activity group) after 8 weeks, whereas only individuals with formal weight or balance training exhibited improvements in postural stability. This may indicate that formal physical training is needed for the elderly to improve postural stability [37-40] although simply being active could be a factor in delaying degradations in strength as well as proprioceptive sensitivity.

For adequate postural stability, many different mechanisms are required to work simultaneously to keep the center of mass within the base of support. Integrations of the sensory system such as proprioceptive systems, skeletal muscle and central nervous system are particularly important; harmonious responses among the three systems are the major elements in maintaining stable upright posture [10, 20, 21, 28, 30, 44]. Although social activities could play a role in improving strength and proprioceptive sensitivity at the ankle and knee joints, it does not enhance postural stability as much as formal physical training. The results from the present study suggested that only formal physical training could enhance integration of the three systems and increase postural control [37-40]. Diminished proprioception with aging may result in failure to sense changes in the displacement of the center of mass [13]. These results suggest that older adults may not be able to detect and correct postural disturbances as promptly as younger adults [44, 45]. Particularly, these results from the studies above suggested that, due to the deteriorations in proprioception, the effectiveness of somatosensory information on postural control decreased with advancing age. These results suggested that there are positive effects of training on the likelihood of slips and falls. Overall, a decrease in the number of falls in training groups at post-stage evaluation in comparison to a same number of falls in the control group indicate the positive effects of training on fall rate. These results indicate that proprioception sensitivity, postural stability, and strength play a major role in reducing the likelihood of slip-induced falls.

In conclusion, postural stability, which required integration of the weight or balance-musculo-skeletal systems, improved only in training groups. This indicated that only the formal exercise training enhanced the ability to integrate these three systems. Additionally, improvements in postural stability after training accounted for the reduction in the likelihood of slip-induced falls. Of course, the ability to integrate these systems played a critical role in recovering from dangerous slips. Older adults in either balance or weight training programs improved leg strength. Improvements in leg strength and its positive relationship to the likelihood of slip-induced falls indicated that the ability of leg muscles to produce explosive force at the ankle and knee joints while slipping contribute to reducing the likelihood of slip-induced falls. In addition, improvements in postural stability through training and its positive relationship to the likelihood of slip-induced falls indicated that an increased ability to integrate weight or balance-musculo-skeletal systems while slipping accounted for reducing the likelihood of slip-induced falls.

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