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Effects of Isometric Exercise on Muscle Activity and Body Balance Ability in Asymmetrical Walkers*

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Abstract

Purpose: This study was to investigate the effects of isometric exercise on muscle activity and body balance ability in asymmetrical walkers. **Research design, data, and methodology:** Twenty gait asymmetry people were divided to unilateral exercise group (UG, n=10) and bilateral exercise group (BG, n=10). UG were performed unilateral exercise for 60 minutes, three times a week, and 16 weeks, and BG were performed one side and then the other side alternately for 60 minutes, three times a week, and 16 weeks. Muscle activity and body balance ability were measured before, after 4 and 16 weeks isometric exercise. Moreover, SI (symmetry index; SI) was calculated from the measured value of SL (step length). Statistical analyses were conducted using one-way ANOVA and two-way ANOVA with repeated measures, a paired t-test, and multiple comparisons according to Scheffe. **Results:** In the muscle activity, ST decreased significantly in short step length(S-SL) and BG of LS compared to before isometric exercise($p<.05$), and GCM decreased significantly in BG of S-SL($p<.05$). As for body balance ability, the mSEBT-A difference between L-SL and S-SL was decreased significantly in UG($p<.05$). And the respective total scores of L-SL and S-SL, mSEBT-PM and mSEBT-PL were increased significantly in BG($p<.05$). **Conclusions:** As a result, in this study above, it was confirmed that isometric exercise improved muscle activity and body balance ability in asymmetrical walkers.

Keywords: Isometric Exercise, Muscle Activity, Body Balance Ability, Asymmetrical Walker

JEL Classification Code: I10, I12, I18

1. Introduction

According to the "Life Table" data from the Korean Statistical Office in 2021, the average life expectancy for Koreans in 2020 was 80.5 years for men and 86.5 years for women, with an overall average of 83.5 years. According to the World Health Organization's health statistics for 2020, the healthy life expectancy of Koreans, measured by prevention and management rather than disease treatment, was 73.1 years for both genders. The average age for Korean women experiencing menopause, which can lead to rapid changes in health due to hormonal fluctuations, was 49.3 years. The concept of healthcare is shifting from simply extending life expectancy through disease treatment to extending healthy life expectancy through prevention and management. In terms of exercise science, research has provided significant evidence for preventing degenerative diseases and lifestyle-related illnesses, as well as increasing quality of life and healthy aging. Furthermore, physical inactivity has become a significant risk factor for various diseases, including COVID-19, in addition to aging and transplant

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history. As a major guideline for disease prevention, exercise habits are recommended in the field of public health (Varela et al., 2021; Park, 2021). As medical technology advances, many patients are experiencing discomfort in walking, which is the ultimate goal of rehabilitation programs due to a decrease in physical function, including balance, strength, walking speed, and stroke caused by aging-related diseases after their 60s (Perry & Burnfield, 2010; Sharma & Kaur, 2017). Therefore, in addition to positive results, there are many aspects to consider regarding abnormal results in research to improve walking, the most common activity among all human activities (Sadeghi et al., 2000). Herzog et al. (1989) quantified the symmetry and asymmetry of walking in healthy people using the Symmetry Index (SI) and considered a range of asymmetrical walking between 4% and 13% as a threshold for abnormal walking. Mills (1994) focused on symmetry improvement, observing low levels of asymmetry in the early stages of disease and high levels of asymmetry in the later stages. Studies conducted with a focus on unilateral exercise, considering asymmetry, include research comparing the effects of unilateral exercise that considers lower limb muscle asymmetry and bilateral exercise that does not consider lower limb asymmetry. Other studies have investigated the effects of unilateral exercise on balance and temporal gait variables in stroke patients, demonstrating significant functional improvements in static, dynamic, and functional balance abilities and temporal gait variables. Additionally, research has been conducted on unilateral exercise for bowling players who are prone to easy left-right asymmetry, providing an appropriate stretching training program to improve body misalignment symptoms and correct incorrect posture to prevent injury (Kim et al., 2014; Park, 2014). Furthermore, research on isokinetic exercise aimed at reducing asymmetry by applying exercise unilaterally is currently underway, but further research is needed as the evidence is not yet sufficient (Bishop et al., 2021; Gonzalo-Skok et al., 2015; Núñez et al., 2018; Bishop et al., 2018).

2. Methods

2.1 Subject

The subjects were selected from members registered at the G center in K region who had no orthopedic surgery or deformity, no neurological damage, and had a symmetry index (SI) of 4-13% in one-step length during walking, which indicates asymmetric gait (Zifchock et al., 2008). The SI was calculated using the formula presented by Robinson et al. (1987) to determine the asymmetry index of walking. Using G-Power 3.1.9.7, a sample size of eight subjects was required, assuming an effect size of .50, a significance level of .05, and a power of .80, accounting for potential dropouts. Thus, 20 subjects were recruited, with 10 participants in the unilateral exercise group (UG) and 10 in the bilateral exercise group (BG). Participants were briefed on the purpose and experimental procedures of the study and only those who had no issues with the PAR-Q Test were included. The physical characteristics of the study participants are shown in <Table 1>. This study was approved by the Institutional Review Board of E University (EU22-56).

Table 1: Physical characteristics of subjects

Group(n)	Age (years)	Weight (kg)	Height (cm)	SMM (kg)	Leg length (cm)	SI (%)
UG(10)	48.1±3.38	64.17±8.80	157.48±4.46	21.01±2.09	80.60±3.57	5.04±0.65
BG(10)	48.8±3.11	57.34±9.17	160.73±4.22	22.22±1.96	80.10±2.26	4.75±0.86

means ± SD.

2.2 Interventions

The exercise program was conducted for 16 weeks, 3 times per week, for 60 minutes each session, with feedback provided by experienced instructors in a 1:1 setting. The specific exercise regimen consisted of six weight-bearing exercises (calf raise hold, split squat, resisted knee flexion, prone leg lift, single leg deadlift, single leg bridge) targeting the muscle groups activated during walking, preceded by a 10-minute warm-up on a treadmill and followed by a 10-minute cool-down on the same treadmill (Tsaklis et al., 2015; Perry & Burnfield, 2010). The exercise protocol was divided into two groups: the unilateral exercise group (UG) and the bilateral exercise group (BG). The UG group performed each exercise for 30 seconds, 5 sets per session, with a 30-second rest between sets and a 120-second rest between exercises, for a total of 40 minutes per session<Table 2>. The UG group selected the longer stride length side between the left and right sides for each exercise. The BG group alternated between left and right sides for each exercise, following the same protocol as the UG group. The intensity of all exercises was set at a subjective intensity level of RPE 11-13 (11-easy, 12-moderate, 13-slightly difficult), and the exercise intensity was adjusted by increasing the angle range of each exercise based on RPE measurements every four weeks.

Table 2: Exercise program

Order	Type		Intensity	Time	Frequency
Warm-up	treadmill walking		RPE 11~13	10 min	
Main exercise	calf raise hold	30 sec	5 sets, rest between sets: 30 sec, rest between exercises: 120 sec, Pain free RPE 11~13 (Exercise intensity adjustment by measuring RPE every 4 weeks)	40 min	3 times / w
	split squat	30 sec			
	Resisted knee flexion	30 sec			
	prone leg lift	30 sec			
	single leg deadlift	30 sec			
	single leg bridge	30 sec			
Cool-down	treadmill walking		RPE 11~13	10 min	
Note	When performing sets in the BG group, perform one side and then the other side alternately.				

2.3 Metrics

2.2.1 Muscle Activity

Muscle activation was measured using wireless electromyography equipment (mini DTS, Noraxon Inc., USA) before exercise, 4 weeks, 8 weeks, 12 weeks, and 16 weeks after exercise. Electrode attachment sites recommended in the electromyography manual were used, which are important for diagnosing cerebral palsy and sports injuries in athletes, and for affecting energy consumption during walking in elderly people. The measurement was conducted on the semitendinosus muscle of the thigh, which has a significantly high amplitude during walking, and the medial gastrocnemius muscle, which increases stability during the stance phase of walking, among the calf muscles (Konrad, 2005; Blitz & Eliot, 2007; Aquino et al., 2010; Jang, 2010). The skin was shaved with a razor to minimize skin resistance, and alcohol was used to disinfect and remove measurement errors. EMG wet gel electrodes (Single electrode T246H, SEED TECH, KOREA) were used to attach the electrodes to the muscle belly. The muscle impedance was kept below 70K ohms, and the sampling rate was set at 1,500 Hz with a frequency bandwidth of 20-500 Hz to filter out noise. The collected data were analyzed using Noraxon MR3 3.14 software. For each muscle, the maximal voluntary isometric contraction (MVIC) was performed three times for five seconds each time (Kendall et al., 2005), and the electromyography signal was collected from the first left initial contact to four strides using GAITrite, which allowed for natural walking. The muscle activation data were quantified as the root mean square (RMS) value and standardized as a percentage of MVIC (%MVIC) during walking.

2.2.2 Body Balance Ability

The study used the Modified Star Excursion Balance Test (mSEBT) with a high reliability of 0.89-0.94 for evaluating dynamic balance to measure the physical balance ability before exercise and at 4, 8, 12, and 16 weeks after exercise (Gribble et al., 2013; Fullam et al., 2014). The mSEBT evaluates balance ability by finding and evaluating the minimum overlapping information of the 8 directions with a 45° interval in the Star Excursion Balance Test (SEBT), which includes the anterior (SEBT-A), anterior-medial (SEBT-AM), medial (SEBT-M), posterior-medial (SEBT-PM), posterior (SEBT-P), posterior-lateral (SEBT-PL), lateral (SEBT-L), and anterior-lateral (SEBT-AL) directions. The evaluation was simplified by using only three directions, the anterior (ANT), posterior-medial (PM), and posterior-lateral (PL), which could be easily used for management (Hertel et al., 2006). The study drew lines and had participants stand on one leg in the center while reaching out with the other leg as far as possible along each direction's line. The distance from the tip of the toe of the extended leg to the center was measured in cm. Limb length (LL) was measured from the anterior superior iliac spine to the most superior point of the medial malleolus while lying down, and data for each direction were calculated. The participants were given an explanation of the measurement procedure and a demonstration before measuring the average of three repetitions (Bulow et al., 2019). If the extended foot did not touch the ground, the supporting foot lost contact with the ground, or the starting position could not be returned to after extending the foot, it was considered a failure, and the measurement was repeated. Both left and right sides underwent mSEBT.

3. Results

3.1 Muscle Activity

The changes in muscle activity of the unilateral exercise group and bilateral exercise group over 16 weeks are presented in <Table 3>. The results of the two-way repeated measures ANOVA for muscle activity of the ST and GCM showed significant differences in ST in the BG of S-SL at 4 weeks (p=0.030), 8 weeks (p=0.016), 12 weeks (p=0.007), and 16 weeks (p=0.018) compared to before exercise, and there was no significant interaction between group and time (F=5.253, p<0.001). In addition, there were significant differences in L-SL's BG at 4 weeks (p=0.002), 8 weeks (p=0.000), 12 weeks (p=0.000), and 16 weeks (p=0.000) compared to before exercise, and there was a significant interaction between group and time at 8 weeks (p=0.004), 12 weeks (p=0.000), and 16 weeks (p=0.000) (F=8.123, p<0.001), but there was no significant difference between groups. GCM showed significant differences in S-SL's BG at 4 weeks (p=0.009), 8 weeks (p=0.010), 12 weeks (p=0.030), and 16 weeks (p=0.020) compared to before exercise (F=2.526, p<0.05), and there was no significant interaction between group and time. On the other hand, there were no significant differences in group, time, or interaction between group and time for L-SL.

Table 3: Changes in muscle activity in two groups for 16 weeks

		group (n=10)	before	4-wk	8-wk	12-wk	16-wk	Δ%	repeated measure ANOVA		
										F-value	*P*-value
ST (%)	S-SL	UG	94.69 ±22.63	85.41 ±13.20	81.39 ±15.51	82.09 ±12.89	80.00 ±12.62	-15.51	G	0.339	0.562
									T	5.253	0.001**
		BG	108.24 ±32.96^{a}	75.73 ±19.20^{b}	76.86 ±17.69^{b}	72.51 ±15.71^{b}	78.80 ±14.39^{b}	-27.20	G×T	1.181	0.325
		t-value	1.017	-1.246	-0.578	-1.414	-0.188				
		p-value	0.324	0.231	0.572	0.176	0.853				
	L-SL	UG	96.00 ±22.91	87.86 ±12.57	79.97 ±16.62	83.63 ±12.30	80.49 ±10.96	-16.16	G	0.764	0.385
									T	8.123	0.000***
		BG	126.20 ±46.66^{a}	90.49 ±18.38^{b}	84.72 ±11.50^{b}	71.92 ±18.43^{b}	73.86 ±12.04^{b}	-41.47	G×T	2.704	0.036*
		t-value	1.743	0.354	0.706	-1.586	-1.221				
		p-value	0.101	0.728	0.491	0.132	0.240				
GCM	S-SL	UG	93.29	76.05	76.23	81.06	81.89	-12.22	G	1.396	0.241

(%)		±41.66	±24.93	±24.96	±18.04	±22.93		T	2.526	0.047*
	BG	94.43 ±19.17a	70.85 ±18.54b	71.83 ± 7.60b	73.12 ±19.04b	70.01 ±13.76b	-25.86	G×T	0.201	0.937
	t-value	0.075	-0.502	-0.506	-0.908	-1.332				
	p-value	0.941	0.623	0.620	0.377	0.201				
L-SL	UG	93.29 ±41.66	82.48 ±15.83	75.48 ±23.99	74.29 ±18.42	74.70 ±39.97	-19.93	G	0.015	0.904
								T	1.182	0.325
	BG	85.39 ±14.41	83.99 ±14.49	79.82 ±28.82	72.98 ±21.76	74.80 ±16.87	-12.40	G×T	0.144	0.965
	t-value	-0.537	0.211	0.347	-0.137	0.007				
	p-value	0.598	0.835	0.733	0.893	0.995				

means ± SD. * $p < .05$. ** $p < .01$. *** $p < .001$.

[a,b,c,d]Significantly different from before($p < .05$).

ST; Semitendinosus. GCM; Gastrocnemius Muscle.

S-SL; Short Step Length. L-SL; Long Step Length.

UG; Unilateral exercise Group. BG; Bilateral exercise Group.

3.2 Body Balance Ability

3.2.1 DB and TS

The changes in the balance abilities of DB and TS in the unilateral exercise group and bilateral exercise group over 16 weeks are presented in <Table 4>. The two-way mixed-design ANOVA for mSEBT of DB and TS showed that there was a significant difference between groups for DB in the UG (F=4.268, p<.05), but no significant interaction effect between time and group or time alone. For TS, there was a significant difference between groups for both S-SL and L-SL in BG (F=4.756, p<.05; F=8.563, p<.05), but no significant interaction effect between time and group or time alone.

Table 4: Changes in dynamic balance ability in two groups for 16 weeks

		group (n=10)	before	4-wk	8-wk	12-wk	16-wk	Δ%	repeated measure ANOVA		
										F-value	*P*-value
DB (cm)		UG	6.35 ±2.56	4.12 ±3.06	4.50 ±2.79	4.06 ±3.10	3.68 ±1.31	-42.05	G	4.268	0.042*
									T	0.406	0.804
		BG	5.91 ±2.97	6.64 ±5.17	5.38 ±3.01	6.08 ±4.86	6.10 ±3.48	3.21	G×T	0.613	0.654
		t-value	0.335	-1.255	-0.642	-1.049	-1.957				
		p-value	0.742	0.227	0.530	0.310	0.068				
TS (score)	S-SL	UG	7.82 ±0.56	7.18 ±0.78	7.24 ±0.82	7.64 ±0.81	7.98 ±0.94	2.05	G	8.563	0.004*
									T	0.864	0.489

	group	before	4-wk	8-wk	12-wk	16-wk	Δ%		F-value	P-value
	BG	7.69 ±1.29	7.98 ±1.23	8.17 ±1.28	8.10 ±1.01	8.17 ±0.75	6.24	G×T	0.610	0.656
	t-value	0.064	-1.919	-1.915	-1.323	-1.418				
	p-value	0.950	0.073	0.074	0.204	0.175				
L-SL	UG	7.43 ±1.21	7.03 ±1.00	7.01 ±1.02	7.41 ±1.12	7.67 ±1.28	3.23	G	4.756	0.032*
								T	0.673	0.612
	BG	7.47 ±1.11	7.94 ±1.03	8.09 ±1.34	8.01 ±0.73	8.39 ±0.84	12.32	G×T	0.891	0.474
	t-value	0.284	-1.635	-1.838	-1.062	-0.483				
	p-value	0.950	0.122	0.085	0.304	0.636				

means ± SD. * $p < .05$.

DB; Discrepancy Between Long-Short

TS; Total Score

S-SL; Short Step Length. L-SL; Long Step Length.

UG; Unilateral exercise Group. BG; Bilateral exercise Group.

3.2.2 mSEBT-PM, mSEBT-PL, and mSEBT-A

The changes in mSEBT-PM, mSEBT-PL, and mSEBT-A of the unilateral exercise group and the bilateral exercise group's physical balance abilities over 16 weeks are presented in <Table 5>. The two-way mixed-design ANOVA for mSEBT-PM, mSEBT-PL, and mSEBT-A showed that mSEBT-PM significantly differed between groups in S-SL and L-SL in BG(F=6.903, p<0.05; F=6.560, p<0.05), but no significant interaction was found between time, group, and time, and no significant difference was found for mSEBT-PL in time, group, and time interaction. Moreover, mSEBT-A did not show any significant difference in group, time, and group and time interaction after exercise compared to before exercise.

Table 5: Changes in dynamic balance ability in two groups 16 weeks

		group (n=10)	before	4-wk	8-wk	12-wk	16-wk	Δ%	repeated measure ANOVA		
										F-value	*P*-value
mSEBT -PM (%)	S-SL	UG	77.31 ±9.53	69.22 ±12.14	68.53 ±11.93	75.83 ±14.02	78.89 ±14.12	2.04	G	6.903	0.010*
									T	0.366	0.832
		BG	78.59 ±24.09	83.14 ±24.95	83.94 ±13.38	86.12 ±14.48	81.91 ±12.10	4.22	G×T	0.724	0.578
		t-value	-0.148	-1.505	-2.578	-1.531	-0.488				
		p-value	0.884	0.152	0.020+	0.145	0.632				
	L-SL	UG	70.19 ±23.56	66.26 ±15.86	66.59 ±17.78	70.36 ±21.08	75.35 ±24.97	7.35	G	6.560	0.012*
									T	0.758	0.556

		BG	73.14 ±14.02	78.80 ±10.57	79.08 ±19.65	79.11 ±8.72	85.74 ±9.25	17.23	G×T	0.231	0.920
		t-value	-0.322	-1.974	-1.415	-1.151	-1.170				
		p-value	0.752	0.066	0.176	0.267	0.259				
mSEBT -PL (%)	S-SL	UG	92.61 ±5.82	83.10 ±7.62	85.60 ±8.24	89.49 ±11.95	94.78 ±13.43	2.34	G	3.993	0.049^{*}
									T	1.231	0.304
		BG	89.87 ±11.11	92.72 ±11.59	96.20 ±19.31	93.91 ±14.60	98.98 ±14.52	10.14	G×T	0.830	0.510
		t-value	0.656	-0.082	-1.515	-0.703	-0.638				
		p-value	0.521	0.054	0.149	0.492	0.532				
	L-SL	UG	88.93 ±13.33	81.25 ±11.70	80.98 ±11.46	87.88 ±12.42	89.92 ±15.52	1.11	G	16.004	0.000^{***}
									T	0.800	0.529
		BG	91.25 ±15.24	96.69 ±14.59	98.19 ±17.15	97.88 ±8.05	101.60 ±12.64	11.34	G×T	0.838	0.505
		t-value	-0.344	-2.476	-2.503	-2.028	-1.751				
		p-value	0.736	0.025^{+}	0.024^{+}	0.060	0.099				
mSEBT -A (%)	S-SL	UG	90.73 ±11.32	87.14 ±10.53	87.07 ±10.75	88.55 ±9.66	92.34 ±8.08	1.77	G	0.252	0.617
									T	0.260	0.903
		BG	87.76 ±13.60	90.00 ±11.36	92.10 ±14.45	90.10 ±7.75	91.57 ±8.08	4.34	G×T	0.377	0.825
		t-value	0.504	-0.555	-0.839	-0.376	0.203				
		p-value	0.621	0.587	0.414	0.712	0.842				
	L-SL	UG	88.57 ±10.34	86.73 ±10.62	86.13 ±10.39	88.92 ±8.78	90.32 ±8.67	1.98	G	0.443	0.507
									T	0.442	0.778
		BG	84.48 ±11.58	89.30 ±13.05	92.69 ±12.85	89.88 ±14.05	92.36 ±12.68	9.33	G×T	0.503	0.733
		t-value	0.791	-0.458	-1.190	-0.174	-0.398				
		p-value	0.440	0.653	0.251	0.864	0.696				

means ± SD. $^{*}p < .05$. $^{***}p < .001$. $^{+}p < .05$ vs between groups within time.
mSEBT; modified star excrusion balance test. PM; posterior-medial, PL; posterior-lateral. A; anterior.
S-SL; Short Step Length. L-SL; Long Step Length.
UG; Unilateral exercise Group. BG; Bilateral exercise Group.

4. Discussion

In this study, we designed an exercise program to increase balance and stability during walking by promoting complementary development of the muscles around the hip joint, knee joint, glutes, and spinal erectors. We compared a unilateral exercise group that performed stability exercises on one side and a bilateral exercise group that performed alternating stability exercises on both sides to analyze the changes in muscle activity of the tensor fasciae latae and adductor muscles, which greatly affect the early-midstance and late stance phases of the gait cycle.

The results showed that the %MVIC of the tensor fasciae latae decreased in both exercise groups, and the %MVIC of the adductor muscles on the shorter step side significantly decreased in both exercise groups. Calf raised hold exercise involves the tibialis anterior muscle, which reduces the time the front foot touches the ground during walking, leading to an increase in initial contact time. This is consistent with previous studies showing that an increase in initial contact time leads to increased muscle activation of the quadriceps, hamstrings, and tibialis anterior muscles (Khallaf et al., 2014; Sutherland, 2001). Split squat exercise improves muscle control of hip adduction during the stance phase of the gait cycle, enhancing stability (McCurdy, 2017), while resisted knee flexion exercise increases muscle activation of the adductor muscles of the inner thigh by rotating the knee joint inward (Yanagisawa & Fukutani, 2020). Prone leg lift exercise activates the spinal erectors, glutes, and hamstrings (Sakamoto & Teixeira-Salmela, 2009), and single-leg deadlift exercise activates the erector spinae muscles (Shaikh & Moharkar, 2020). Single-leg bridge exercise minimizes excessive use of the spinal erectors and acts as an important factor in reducing knee joint pain during walking or hill climbing by affecting knee joint angle (Pori et al., 2021). The increase in muscle activation of the tensor fasciae latae, which is responsible for hip abduction and knee flexion, observed in this study supports the results of Hubley-Kozey et al.'s (2009) study, which showed a higher amplitude of activation in the tensor fasciae latae than in the adductor muscles during walking. It also aligns with previous research showing significant changes in muscle activation after six weeks of exercise targeting the hamstrings in healthy adults. Therefore, this study confirms that a 16-week stability exercise program can positively affect muscle activation in middle-aged women.

In this study, the modified Star Excursion Balance Test (mSEBT) was used to measure the balance ability of a unilaterally-trained group that performed unilateral exercises for the contralateral side and a bilaterally-trained group that performed alternating unilateral exercises for both sides. The mSEBT-A was measured to compare the difference between the two sides, and the total scores of the left and right sides, mSEBT-A, mSEBT-PM, and mSBBT-PL were analyzed. The results showed that the difference between the two sides in mSEBT-A decreased in the unilaterally-trained group, and the total scores of the short step side and the long step side increased in the bilaterally-trained group. In addition, the reaching distance of mSEBT-PM and mSBBT-PL also improved in the bilaterally-trained group. These results are consistent with previous studies that reported enhanced leg strength, flexibility, and proprioceptive sensation after balance ability exercises in middle school volleyball players and increased total scores in the left and right sides after exercise in elementary school soccer players. Furthermore, it is suggested that the balance stability to maintain body balance is improved by controlling the bilateral muscle strength imbalance. Therefore, in this study, a 16-week balance exercise program was found to be effective in reducing the difference between the two sides by applying unilateral exercises and increasing balance ability by applying bilateral exercises, which could have a positive impact on the balance ability of middle-aged women and could serve as evidence for preventing fall accidents in the elderly caused by a decline in balance ability.

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