Motor Learning Versus Standard Walking Exercise in Older Adults with Subclinical Gait Dysfunction: A Randomized Clinical Trial

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OBJECTIVES: To compare the effect of motor learning with that of standard exercise on measures of mobility and perceived function and disability.

DESIGN: Single-blind randomized trial.

SETTING: University research center.

PARTICIPANTS: Older adults (n = 40) with a mean age of 77.1 ± 6.0, normal walking speed (≥1.0 m/s), and impaired motor skills (Figure of 8 walk time >8 seconds).

INTERVENTIONS: The motor learning program incorporated goal-oriented stepping and walking to promote timing and coordination within the phases of the gait cycle. The standard program employed endurance training by treadmill walking. Both included strength training and were offered twice weekly for 1 hour for 12 weeks.

MEASUREMENTS: Primary outcomes were mobility performance (gait efficiency, motor skill in walking, gait speed, walking endurance); secondary outcomes were perceived function and disability (Late-Life Function and Disability Instrument).

RESULTS: Thirty-eight of 40 participants completed the trial (motor learning, n = 18; standard, n = 20). The motor learning group improved more than the standard group in gait speed (0.13 vs 0.05 m/s, $P = .008$) and motor skill (−2.2 vs −0.89 seconds, $P < .001$). Both groups improved in walking endurance (28.3 and 22.9 m, $P = .14$). Changes in gait efficiency and perceived function and disability were not different between the groups ($P > .10$).

CONCLUSION: In older adults with subclinical gait dysfunction, motor learning exercise improved some parameters of mobility performance more than standard exercise. **J Am Geriatr Soc 61:1879–1886, 2013.**

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Independent functioning is at the core of successful aging, and independent mobility is critical to independent function. Exercise for older adults is recommended because it promotes physical and mental health and may improve mobility and prevent walking difficulty.[1] Walking places demands on the musculoskeletal (muscles, bones, joints), cardiopulmonary (heart, lungs), and nervous (brain, spinal cord, peripheral nerves) systems.[2,3] Although musculoskeletal and cardiopulmonary impairments are widely recognized in older persons, neurological impairments, clinically overt as well as subtle, are also increasingly common with age.[3–5] It is likely that some combination of impairments in the musculoskeletal, cardiopulmonary, and nervous systems contributes to late-life mobility decline.[3]

Current exercise recommendations for health promotion target strength and flexibility of the musculoskeletal system and endurance in the cardiopulmonary system but rarely address the nervous system.[6] Neurological exercise focuses on motor learning through goal-oriented repetitive practice and has been applied in neurological disorders such as stroke and Parkinson's disease,[7–9] as well as in developing skills in sports and recreation.[10] It was hypothesized that motor learning would improve walking by applying task-specific exercises to challenge the brain to adapt to a well-controlled and environmentally responsive sequence and timing of movements within the postures and phases of gait. Improvements in walking occur by restoring the pattern of brain and neuromuscular activation that optimize the ability to meet walking demands.[11–15] Because subclinical neurological abnormalities are common with aging, neurologically oriented motor learning exercise might address an important missing aspect of exercise to promote independent mobility in late life.

A task-oriented motor learning exercise program that incorporates elements of motor learning often used in neurological rehabilitation was developed into an exercise

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program to promote walking in older adults. The program includes goal-oriented stepping and walking patterns to promote the timing and coordination of stepping integrated with the phases of the gait cycle. The ultimate goal of the training is to promote skill in walking. Adults who are skilled walkers have an energy-efficient gait, tire less easily, and as a result, are more likely to walk more, participate in more activities, and report less disability.[16] In prior work, the effect of motor learning walking exercise was compared with that of standard exercise in older adults with walking difficulty (defined as slow and variable gait). Motor learning exercise promoted greater gains in gait efficiency, gait speed, and self-perceived walking ability.[17] Although that population was similar to persons with neurological disorders, the potential effect of motor learning on the population of older persons who walk at a normal speed but have evidence of subclinical neurological deficits has not been explored. If motor learning training for walking improves mobility in older adults with such subclinical gait dysfunction (gait speed $\geq$1.0 m/s but impaired motor skill in walking), it might make sense to incorporate motor learning into exercise programs aimed at primary prevention of future mobility disability.

The goal of this randomized clinical trial was to compare motor learning with standard walking exercise in older adults with subclinical walking difficulty. It was hypothesized that both forms of exercise would improve walking speed and endurance but that the motor learning group would demonstrate greater improvements in motor skill and gait efficiency.

METHODS

Overview

The 12-week single-blind randomized pilot intervention trial compared two exercise interventions in older adults with subclinical gait dysfunction. The University of Pittsburgh institutional review board approved the Program to Improve Mobility in the Elderly, and all subjects provided informed consent. The study was registered at ClinicalTrials.gov (PRO09080228).

Participants

Eligible older adults had subclinical gait dysfunction, defined as near-normal gait speed ($\geq$1.0 m/s) and impaired motor skill in walking. Gait speed was assessed using an instrumented walkway. Subjects completed two trials, and the mean gait speed of the two trials was calculated and used to determine eligibility. Motor skill in walking was assessed using the Figure of 8 Walk Test.[18] The Figure of 8 Walk Test, which is associated with measures of movement control and planning during walking, has been validated as a measure of walking skill.[18–20] A score of 8.7 seconds or longer has been identified as an indicator of impaired function in community-dwelling older adults,[21] and a mean of 7.3 seconds has been reported in healthy young adults. Based on these preliminary findings, a score of 8 seconds or longer was selected as an initial indicator of impaired motor skill in walking.

All participants underwent a brief screening examination to identify any overt musculoskeletal, cardiopulmonary, or neurological conditions that were exclusion criteria. Participants had to be medically stable (excluded if reported dyspnea at rest or during activities, hospitalization in the past 6 months for acute illness or injury, or a progressive neuromuscular disorder such as Parkinson's disease) to be able to participate in the exercise program (excluded if reported persistent lower extremity or back pain, fixed or fused lower extremity joints, resting systolic blood pressure $\geq$200 mmHg, diastolic blood pressure $\geq$100 mmHg, or resting heart rate >100 beats per minute or <40 beats per minute), and have a Mini-Mental State Examination[22] score of 24 or greater. All participants had physician clearance to participate in a moderate-intensity exercise program.

Sample Size and Randomization

Because this was a pilot intervention trial, sample size ($n = 40$) was based on available resources rather than statistical power. The study's biostatistician (SP) generated the randomization sequence using a high-quality pseudorandom deviate generator in SAS (SAS Institute, Inc., Cary, NC). The study coordinator randomly assigned participants to motor learning or standard interventions in a 1:1 ratio. A blocked randomization scheme was used to force continued approximate balance between the numbers of subjects in each arm during recruitment. The block size was randomly four or six to prevent personnel from predicting treatment arm.

Interventions

Overview

Each protocol-driven, physical therapist–led intervention for one to two participants lasted 60 minutes twice a week for 12 weeks. The interventions were conducted at different times to avoid cross-contamination. The protocols defined each activity and gave standards for progression based on accuracy and ease of performance. The treating therapist documented treatment intensity at each session that was periodically reviewed to ensure treatment progression and fidelity. To equalize the time in treatment between the two intervention arms, both programs included a brief warm-up period (walking, lower extremity active range of motion such as ankle pumps, knee extension, hip extension, and gentle stretches for lower extremity and trunk muscles) and strength training. The strength training was conducted on stacked weight equipment (leg extension and curl combo, leg press machine, and multihip combo; Magnum Fitness Systems, South Milwaukee, WI) and included knee extension, knee flexion, leg press, hip abduction, and hip extension. When subjects were able to complete two sets of 15 repetitions with minimal effort (rating of perceived exertion (RPE) <10), resistance was increased for progression of the exercises.

Motor Learning Exercise

In addition to the warm-up and strength training described above, subjects in the motor learning group received 20 to 30 minutes of motor learning exercises. The motor learning program[17] was based on the principles that enhance "skill" or smooth, automatic movement control.[11,23–27] This previously described program[17] used goal-oriented, progressively more difficult stepping and walking patterns to promote the timing and coordination of stepping integrated with the phases of the gait cycle.[11,24,25,27] Conceptually, the exercise was intended to achieve its effects by shifting the center of pressure posterolaterally and then forward, encouraging hip extension before stepping, loading the trailing limb, coordinating activation of the abductors of the soon-to-be-swung leg with adductors of the stance limb, and shifting the center of pressure in medial stance to unload the stepping limb.[28–30] Progression of exercises was based on separately increasing the speed, amplitude, or accuracy of performance before undertaking a more-complex task.[31] For example, the progression of stepping patterns was self-paced step forward and across, increase stepping speed, alternate side of stepping, and alternate forward and backward stepping. Walking patterns incorporated patterns of muscle coordination and interlimb timing into walking. Walking patterns progressed by altering speed, amplitude (e.g., narrowing oval width), or accuracy of performance (e.g., without straying from the desired path) and then to complex walking patterns involving walking past others and with upper extremity object manipulation tasks, such as carrying or bouncing a ball.[27] Treadmill walking reinforced the rhythmic stepping and was completed at preferred walking speed with brief intervals of increased speed.

Standard Exercise

In addition to the warm-up and strength training described above, subjects in the standard group underwent endurance training. The endurance training consisted of treadmill walking at a submaximal workload with a self-reported RPE of 10 to 13 (somewhat hard). When subjects were able to tolerate a RPE of 10 to 13 for 15 minutes, the workload was increased by first increasing the duration (up to 30 minutes) and then by increasing walking speed. The goal was to achieve 30 minutes of continuous treadmill walking at a somewhat hard level of exertion.

For safety, all participants (motor learning and standard groups) were told they should stop walking immediately if they felt they could not continue (symptom limited), they or the physical therapist observed shortness of breath, they demonstrated problems in the walking pattern (e.g., toe drags on the floor during the swing-through phase of gait), or they reported or the physical therapist observed any of the general indications for stopping nondiagnostic exercise tests as recommended by the American College of Sports Medicine.[32]

Outcomes

Assessors masked to the intervention group assessed all outcome measures before and after the 12-week intervention.

Mobility

Gait Efficiency. The energy cost of walking reflects the energy used for all bodily actions during walking and was used as an indicator of gait efficiency.[33] Participants walked on a treadmill at a self-selected pace while oxygen consumption data was collected using open circuit spirometry and analysis of expired gases using a portable metabolic measurement system (VO2000; Medgraphics, Minneapolis, MN). All participants were familiarized with treadmill walking until comfortable walking on the treadmill before the baseline measurement. The mean rate of oxygen consumption and carbon dioxide production was determined over 3 minutes after reaching steady state.[33,34] The energy cost of walking (mL of O_2/kg/m) represents an estimate of energy expenditure per unit of gait speed[35–37] and relates to metabolic equivalents (METs). Because the energy cost of walking is standardized according to walking speed, it is time independent, is repeatable, reflects the physiological cost of gait,[33,34] is little influenced by fitness,[34] and can be compared between individuals and over time, regardless of changes in gait speed.[34,37]

Motor Skill in Walking. The Figure of 8 Walk was used as a measure of motor skill in walking. The test involved walking a figure 8 pattern around two markers placed 5 feet apart. Performance was scored based on the time needed to complete the figure 8 walk and the number of steps. No added value has been found for the qualitative portion of the Figure of 8 Walk, so only the quantitative measures are reported. The Figure of 8 Walk has established interrater reliability (intraclass correlation coefficient (ICC) = 0.90 for time, ICC = 0.92 for number of steps) and validity by comparison with measures of gait, motor control, and function.[18] Less time and fewer steps are an indicator of greater skill in walking.

Gait Speed. Participants walked at their usual, self-selected speed on a 4-m instrumented walkway (GaitMat II, E.Q. Inc., Chalfont, PA) with 2-m noninstrumented sections at either end to allow for acceleration and deceleration. After two practice trials, participants completed four trials that were used for data collection. Gait speed was averaged over the four trials. The test–retest reliability of gait speed measured using the GaitMat according to ICC is 0.98.[38]

Walking Endurance. The 6-Minute Walk Test (6MWT) of distance walked (meters) in 6 minutes, including time for rest as needed, was used to assess walking endurance.[39] The 6MWT has established psychometric properties, test–retest reliability (Pearson correlation coefficient (r) = 0.95) in older adults,[40,41] and construct validity for graded exercise test and functional classification.[42]

Lower Extremity Strength Related to Mobility. The repeated chair rise component of the Short Physical Performance Battery[43] was used as a measure of lower extremity strength. Participants were timed as they completed five repeated chair rises without the use of the upper extremities. Time to complete the five chair rises was recorded.

Function and Disability

Late-Life Function and Disability Instrument

The Late-Life Function and Disability Instrument (LLFDI), a pair of self-reported measures that assess physical function and disability in older adults with acute or chronic problems and is designed to be more sensitive to change than similar measures, was selected as the function and disability outcome measure.[44,45] The function component has 32 items in three areas: basic lower extremity, advanced lower extremity, and upper extremity. The disability component has 25 items in four domains: personal role, social role, instrumental role, and management role. The ICC for test–retest reliability ranged from 0.91 to 0.98 for the function subscales and from 0.68 to 0.82 for the disability domains.[44,45]

Data Analysis

All statistical analyses were performed using SAS version 9.3 (SAS Institute, Inc.). Participant characteristics and baseline measurements of the arms were compared using *t*-tests for continuous variables and chi-square tests for categorical variables. Paired-sample *t*-tests were used to assess significance of change in outcomes measures within each arm. To obtain adjusted comparison of outcomes between treatment arms, an analysis of covariance model was fitted using change form baseline to follow-up in each outcome as the response variable, treatment arm as the main factor of interest, and baseline value of the outcome as a covariate.

Outcomes for gait efficiency, the main mobility outcome, were examined in greater detail. To determine whether the change in gait efficiency was clinically meaningful, a meaningful difference was estimated from the baseline sample energy cost of walking using Cohen moderate effect size criteria (e.g., moderate effect = 0.5 × baseline standard deviation of energy cost).[46] Likewise, before and after the intervention, the percentage of subjects who had an energy cost of walking of 0.15 mL/kg/m or less, which is considered normal for adults, was examined according to treatment arm.[47]

RESULTS

Of 110 people initially screened over the telephone, 64 underwent onsite screening. Forty-one participants met all criteria, 40 were randomized (one subject deferred), and 38 completed the study (Figure 1). The two dropouts developed medical conditions unrelated to the study and walked more slowly than those who completed the study. Although these two subjects had a gait speed of 1.0 m/s or greater during their screening visit, their baseline testing gait speeds were <1.0 m/s (0.73 and 0.98 m/s).

Participants had a mean age of 77.1, normal gait speed (mean gait speed 1.18 m/s), and impaired motor skill in walking (mean Figure 8 time 9.2 seconds; Table 1). Although subjects had a normal gait speed, their baseline energy cost of walking was 0.22 mL/kg/m, nearly 50% greater than the 0.15 mL/kg/m energy cost of normal walking in young adults.[47] Baseline mean LLFDI score was similar to that of community-dwelling older adults without mobility limitations.[48]

Participants in the two treatment arms were similar on all baseline measures (Tables 1–3). Although not statistically significant, baseline gait speed was 0.08 m/s faster in the motor learning than the standard group, which is considered to be a small but meaningful difference.[49] All 38 individuals who completed the study participated in at least 22 exercise sessions, with 37 participants (97%) completing all 24 sessions.

The motor learning group had greater improvements than the standard group in motor skill and a greater reduction in time to complete the Figure of 8 test (adjusted group difference (standard error (SE)) −1.39 seconds (0.29 seconds), $P < .001$) and number of steps taken during the Figure of 8 test (adjusted group difference (SE) −1.09 (0.49), $P = .03$)—both indicators of improved

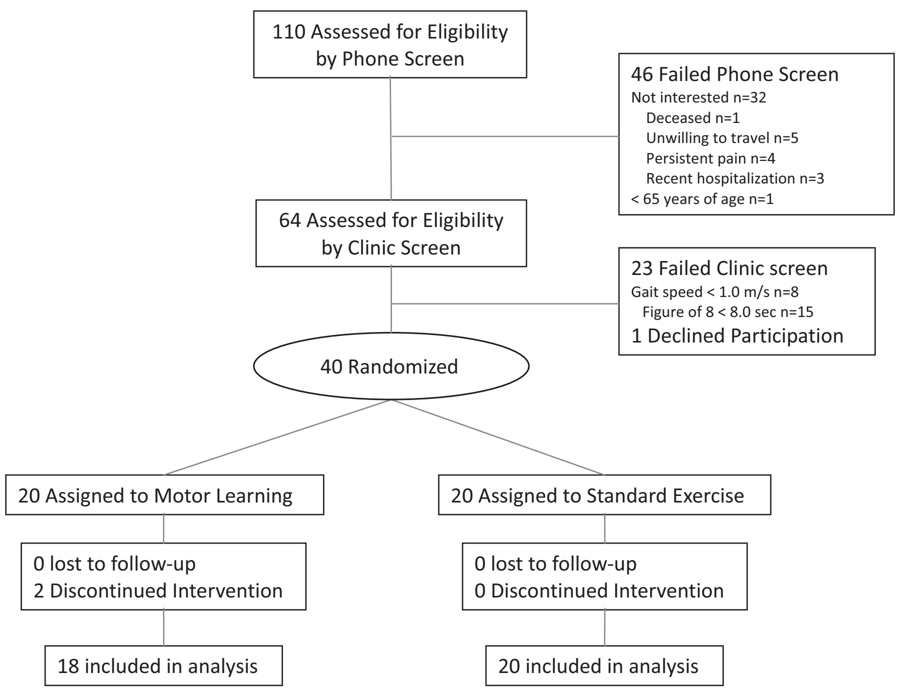

Figure 1. Study flowchart.

Table 1. Baseline Characteristics According to Treatment Group

Characteristic	Motor Learning, n = 18	Standard, n = 20	*P*-value
Age, mean ± SD	75.7 ± 5.5	78.5 ± 6.2	.16
Female, n (%)	10 (55.6)	13 (68.4)	.42
White, n (%)	18 (100)	19 (95)	.32
Married, n (%)	12 (67)	9 (47)	.36
Graduate education, n (%)	10 (56)	11 (58)	.99
Chronic conditions, n (%)			
Cardiac disease	2 (11)	1 (5)	.49
Musculoskeletal conditions	12 (67)	18 (90)	.08
Vision problems	13 (72)	18 (90)	.16
Diabetes mellitus	4 (22)	2 (10)	.30
Cancer	8 (44)	5 (25)	.21
Lung disease	4 (22)	2 (10)	.30
Gait speed, m/s, mean ± SD	1.22 ± 0.16	1.14 ± 0.15	.79
Figure of 8 Test, seconds, mean ± SD	9.1 ± 0.93	9.3 ± 0.92	.97

SD = standard deviation.

motor skill. The motor learning group also had greater improvement in gait speed than the standard group (Table 2). Because of equipment malfunction or poor data quality, seven of the 38 individuals who completed the study were missing baseline or postintervention data on the energy cost of walking. Missing data were equally distributed between treatment groups (motor learning group n = 3, standard group n = 4). The adjusted difference in change in energy cost of walking between the groups was 0.03 mL/kg/m ($P = .13$). Changes in walking endurance (6MWT), chair rise time, and perceived function and disability were not different between the groups ($P > .10$).

Motor skill in walking, gait speed, and walking endurance improved in the motor learning group, whereas only one indicator of motor skill in walking (Figure of 8 time) and walking endurance improved within the standard group (Table 2). Chair rise time did not change significantly in either group. The motor learning group but not the standard exercise group had improvements in the instrumental role and management disability domains of the LLFDI (Table 3). The function component of the LLFDI did not change with either intervention (Table 3).

A moderate effect size for energy cost of walking was determined to be 0.03 mL/kg/m (e.g., moderate effect = 0.5×0.05). After the motor learning intervention, the group mean energy cost decreased by 0.04 mL/kg/m to 0.17 mL/kg/m. It is likely that the 0.04 mL/kg/m change that the motor learning group exhibited is a meaningful change. This is in contrast to the standard exercise group, which improved only 0.02 mL/kg/m with the intervention. At baseline, only 6% of the subjects in the motor learning (1/15) and standard (1/16) groups had an energy cost of walking that was normal. After the interventions, 33% (5/15) of the subjects in the motor learning group had a

Table 2. Pre- and Postintervention Performance-Based Outcomes According to Treatment Group

Outcome	Motor Learning, n = 18				Standard, n = 20					
	Preintervention	Postintervention	Change		Preintervention	Postintervention	Change			
	Mean ± SD			*P*-Value[a]	Mean ± SD			*P*-Value[a]	Adjusted Group Difference (Standard Error)	*P*-Value[b]
Energy cost, mL/kg/m[c]	0.21 ± 0.05	0.17 ± 0.05	−0.04 ± 0.07	.06	0.22 ± 0.04	0.20 ± 0.04	−0.02 ± 0.06	.31	−0.03 (0.02)	.13
Figure of 8, seconds	9.1 ± 0.9	6.9 ± 1.0	−2.2 ± 1.1	<.001	9.3 ± 0.9	8.4 ± 1.0	−0.89 ± 0.8	.0001	−1.39 (0.29)	<.001
Figure of 8, steps	15.3 ± 1.7	13.8 ± 1.5	−1.5 ± 1.5	.001	16.1 ± 2.1	15.2 ± 1.8	−0.85 ± 2.1	.08	−1.09 (0.49)	.03
Gait speed, m/s	1.22 ± 0.16	1.35 ± 0.15	0.13 ± 0.11	.001	1.14 ± 0.15	1.19 ± 0.14	0.05 ± 0.14	.13	0.11 (0.04)	.008
6-Minute Walk Test, m	420.3 ± 53.1	448.6 ± 55.0	28.3 ± 29.6	.001	393.7 ± 65.6	416.6 ± 40.0	22.9 ± 42.8	.03	15.4 (10.3)	.14
5 chair rise, seconds	11.3 ± 3.2	10.9 ± 2.2	−0.5 ± 2.4	.43	12.6 ± 2.3	11.7 ± 2.3	−0.8 ± 2.8	.27	−0.38 (0.69)	.59

SD = standard deviation.

[a] Within-group comparison.

[b] Between-group comparison.

[c] Motor learning, n = 15; standard, n = 16.

Table 3. Pre- and Postintervention Self-Reported Function and Disability Outcomes According to Treatment Group

Outcome	Motor Learning, n = 18				Standard, n = 20				Adjusted Group Difference (Standard Error)	P-Value[b]
	Preintervention	Postintervention	Change	P-Value[a]	Preintervention	Postintervention	Change	P-Value[a]		
	Mean ± SD				Mean ± SD					
LLFDI function										
Overall	63.9 ± 8.8	64.0 ± 8.9	0.15 ± 5.5	.91	64.5 ± 8.5	63.8 ± 7.8	−0.72 ± 3.2	.35	0.75 (1.42)	.60
Basic lower extremity	76.9 ± 14.2	78.4 ± 15.1	1.5 ± 12.5	.62	74.3 ± 10.2	74.3 ± 11.0	−0.04 ± 6.3	.98	2.17 (3.14)	.49
Advanced lower extremity	56.1 ± 12.4	56.9 ± 13.9	0.87 ± 7.2	.62	57.5 ± 11.8	57.1 ± 10.1	−0.4 ± 4.4	.69	1.10 (1.93)	.57
Upper extremity	79.5 ± 11.6	76.7 ± 8.1	−2.8 ± 10.1	.25	82.0 ± 11.1	79.7 ± 10.7	−2.3 ± 8.0	.23	−1.69 (2.49)	.50
LLFDI disability										
Frequency	55.4 ± 5.7	56.4 ± 6.8	1.0 ± 3.3	.21	55.3 ± 6.7	56.8 ± 12.6	1.5 ± 7.6	.44	−0.50 (1.82)	.78
Personal role	65.1 ± 13.0	68.7 ± 18.4	3.6 ± 14.7	.31	63.0 ± 10.3	64.4 ± 16.8	1.4 ± 13.6	.67	2.39 (4.88)	.63
Social role	52.1 ± 7.9	53.2 ± 7.7	1.1 ± 3.7	.21	52.1 ± 9.5	54.1 ± 14.6	2.0 ± 7.6	.30	−0.82 (1.98)	.68
Limitation	74.5 ± 12.1	80.4 ± 13.3	6.0 ± 11.7	.05	74.3 ± 15.1	77.6 ± 15.2	3.4 ± 8.4	.12	2.66 (3.34)	.43
Instrumental role	74.7 ± 12.3	80.3 ± 13.8	5.6 ± 12.6	.08	74.2 ± 15.0	77.5 ± 15.1	3.3 ± 8.8	.14	2.46 (3.55)	.49
Management role	86.1 ± 11.6	93.3 ± 9.7	7.3 ± 9.4	.005	84.9 ± 15.7	88.2 ± 13.6	3.3 ± 11.4	.26	4.48 (2.98)	.14

SD = standard deviation; LLFDI = Late-Life Function and Disability Instrument, score range 0–100.
[a]Within-group comparison.
[b]Between-group comparison.

normal energy cost of walking, compared with only 12.5% (2/16) of the subjects in the standard exercise group (Figure 2).

DISCUSSION

Motor learning exercise improved markers of walking more than standard exercise in older adults with subclinical gait dysfunction, defined as generally adequate gait speed but impaired motor skill in walking. The motor learning program resulted in greater improvements in walking skill and gait speed. In addition, when the findings were examined within groups, only the motor learning group improved in self-reported disability.

The energy cost of walking was high in this population of older adults with generally adequate walking speed, suggesting that there were inefficiencies in their gait patterns. Gaits with altered timing and postures, which are often the result of neurological or orthopedic conditions, can double or triple the cost of walking.[50–52] Motor learning interventions that focus on the timing and coordination of movement during gait have reduced the energy cost of walking.[53] In contrast to previous studies and the hypothesis of the current study, the motor learning group did not demonstrate significant improvements in gait efficiency. Although the improvements were not statistically significant ($P = .06$), it is likely that they were clinically meaningful. This pilot study had limited power to detect a meaningful difference. The absolute difference in energy cost of 0.03 mL/kg/m is probably a moderate effect size, and the difference in the proportion that achieved normal energy cost is potentially clinically relevant.

The motor learning intervention also affected participation in daily activities (LLFDI disability domain). The findings of the current study are similar to the effect of a similar motor learning exercise program in older adults with slow and variable gait[16] in which self-reported function and disability also improved. Mechanistically, it is to be expected that improvements in gait efficiency would result in less fatigue and that, as a result, older adults would participate in more activities and report less disability.[16]

Intervention strategies challenge the brain to improve walking performance in different ways. An impairment-based intervention, such as the standard strength and

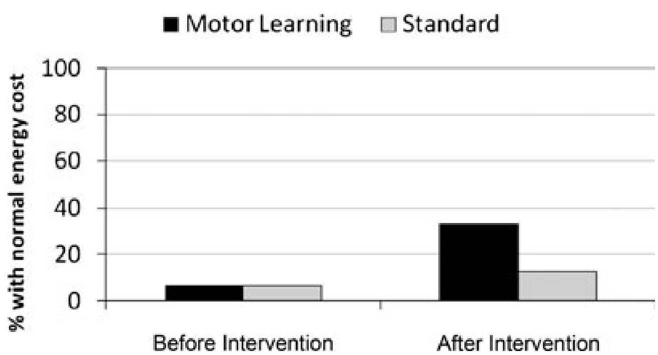

Figure 2. Percentage of subjects with normal energy cost of walking before and after the intervention according to treatment arm.

endurance program, challenges the brain to use increased capacity in body systems to compensate for gait difficulties. Walking performance probably improves secondary to greater ability to produce muscle forces, to move joints through a greater range of motion, and to deliver more oxygenated blood to the active tissues. The use of greater capacity of body systems for walking makes the outcome of the impairment-based intervention approach potentially inefficient and difficult to sustain. A motor learning–based approach challenges the brain to adapt and learn the sequence of movements and timing with the postures and phases of gait to improve walking. Improvements in walking occur by restoring the pattern of brain and neuromuscular activation that optimizes the use of capacities to meet the demands of the task of walking.[14,15] The task-oriented focus of the motor learning–based approach has the potential to lead not only to an efficient and automatic motor sequence pattern for walking, but also to reward-based adaptive changes in the brain that may be sustainable.[11]

Observational studies have shown a link between gait speed and disability or survival.[43,54–56] It is unknown whether interventions that increase gait speed prevent or delay disability or increase survival. Exercise interventions, such as motor learning exercise, that substantially improve gait speed should be investigated for their potential effect on disability and survival in older adults.

When interpreting the study's findings, the following limitations should be considered. This was a pilot study with a sample size based on feasibility (available resources) and not power; the lack of improvement in self-reported function may be because of the ceiling effect that this sample of high-functioning older adults experienced; the Figure of 8 walk is similar to some of the tasks involved in the motor learning exercise, so training of test-specific tasks needs to be considered; the validity of the Figure of 8 Walk Test was established in one small sample of older adults, and the cutoff score to indicate impaired motor skill was based on preliminary work; and the interventions were slightly overlapping, with both groups undergoing a warm-up and strength training. In addition, the overlapping interventions make it difficult to determine the effect of the motor learning exercises. It is likely that the differences in outcomes are in response to the differences in the interventions (the motor learning exercises) and not the similarities, although this will need to be proven in future studies. This study has several strengths. A sample of older adults with subclinical gait dysfunction was objectively identified, and the effect of a novel motor learning intervention on walking ability and self-reported function and disability was examined. Many exercise intervention trials in older adults examine the effect of exercise on walking, but fewer include the outcomes of function and disability.[16,57]

CONCLUSION

In older adults with subclinical gait dysfunction, motor learning exercise improved some parameters of mobility performance more than standard exercise. Given the many different contributors to walking difficulty (cardiovascular, musculoskeletal, neurological), motor learning exercise may be an important new addition to exercise programs for older adults that include primarily endurance and strength training.

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REFERENCES

1. Pate RR, Pratt M, Blair SN et al. Physical activity and public health: A recommendation from the Centers of Disease Control and Prevention and the American College of Sports Medicine. JAMA 1995;273:402–407.
2. Brach JS, Studenski S, Perera S et al. Stance time and step width variability have unique contributing impairments in older persons. Gait Posture 2008;27:431–439.
3. Ferrucci L, Baninelli S, Benvenuti E et al. Subsystems contributing to the decline in ability to walk: Bridging the gap between epidemiology and geriatric practice in the InCHIANTI study. J Am Geriatr Soc 2000;48:1618–1625.
4. Inzitari M, Baldereschi M, Carlo AD et al. Impaired attention predicts motor performance decline in older community-dwellers with normal baseline mobility: Results from the Italian Longitudinal Study on Aging (ILSA). J Gerontol A Biol Sci Med Sci 2007;62A:M837–M843.
5. Snijders AH, van de Warrenburg BP, Giladi N et al. Neurological gait disorders in elderly people: Clinical approach and classification. Lancet Neurol 2007;6:63–74.
6. Nelson ME, Rejeski WJ, Blair SN et al. Physical activity and public health in older adults: Recommendation from the American College of Sports Medicine and the American Heart Association. Med Sci Sports 2007;39:1435–1445.
7. King LA, Horak FB. Delaying mobility disability in people with Parkinson disease using a sensorimotor agility exercise program. Phys Ther 2009;89:384–393.
8. Morris ME, Iansek R, Kirkwood B. A randomized controlled trial of movement strategies compared with exercise for people with Parkinson's disease. Mov Disord 2009;24:64–71.
9. Morris ME, Iansek R, Matyas TA et al. Stride length regulation in Parkinson's disease. Normalization strategies and underlying mechanisms. Brain 1996;119:551–568.
10. Handford C, Davids K, Bennett S et al. Skill acquisition in sport: Some applications of an evolving practice ecology. J Sports Sci 1997;15:621–640.
11. Brooks VB. The Neural Basis of Motor Control. New York: Oxford University Press, 1986.
12. Welford AT. Motor skills and aging. In: Mortimer JA, Pirozzolo FJ, Maletta GJ, eds. The Aging Motor System. New York: Praeger Publishers, 1982, pp 152–187.
13. Welford AT. Reaction time, speed of performance, and age. Ann N Y Acad Sci 2004;515:1–17.
14. Milton J, Solodkin A, Hlustik P et al. The mind of expert motor performance is cool and focused. Neuroimage 2007;35:804–813.

15. Milton JG, Small SS, Solodkin A. On the road to automatic: Dynamic aspects in the development of expertise. J Clin Neurophysiol 2004;21: 134–143.
16. Van Swearingen JM, Perera S, Brach JS et al. Exercise to improve gait efficiency: Impact on activity and participation in older adults with mobility limitations. Phys Ther 2011;91:1740–1751.
17. Van Swearingen JM, Perera S, Brach JS et al. A randomized trial of two forms of therapeutic activity to improve walking: Effect on the energy cost of walking. J Gerontol A Biol Sci Med Sci 2009;64A:1190–1198.
18. Hess RJ, Brach JS, Piva SR et al. Walking skill can be assessed in older adults: Validity of figure-of-8 walk test. Phys Ther 2010;90:89–99.
19. Lowry KA, Brach JS, Nebes RD et al. Contributions of cognitive function to straight- and curved-path walking in older adults. Arch Phys Med Rehabil 2012;93:802–807.
20. Odonkor CA, Thomas JC, Holt N et al. A comparison of straight- and curved-path walking tests among mobility-limited older adults. J Gerontol A Biol Sci Med Sci 2013. doi: 10.1093/gerona/glt060
21. Hibbs RM, Van Swearingen JM, Studenski SA et al. Curved path walking predicts 12-month physical function in older adults without mobility limited physical function. J Am Geriatr Soc 2012;60:S70.
22. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psych Res 1975;12:189–198.
23. Nelson WL. Physical principles for economies of skilled movements. Biol Cybern 1983;46:135–147.
24. Daly JJ, Ruff RL. Construction of efficacious gait and upper limb functional interventions based on brain plasticity evidence and model-based measures for stroke patients. ScientificWorldJournal 2007;7:2031–2045.
25. Lay BS, Sparrow WA, Hughes KM et al. Practice effects on coordination and control, metabolic energy expenditure, and muscle activation. Hum Mov Sci 2002;21:807–830.
26. Newman MA, Dawes H, van den Berg M et al. Can aerobic treadmill training reduce the effort of walking and fatigue in people with multiple sclerosis: A pilot study. Mult Scler 2007;13:113–119.
27. Gentile A. Skill acquisition: Action, movement, and neuromotor processes. In: Carr JH, Shepherd RB, Gordon J et al., eds. Movement Sciences, 1st Ed. Rockville, MD: Aspen Publishers, 1987, pp 93–154.
28. Polcyn AF, Lipsitz LA, Kerrigan CD et al. Age-related changes in the initiation of gait: Degradation of central mechanisms for momentum generation. Arch Phys Med Rehabil 1998;79:1582–1589.
29. Capaday C. The special nature of human walking and its neural control. Trends Neurosci 2002;25:370–376.
30. Alexander RM. Walking made simple. Science 2005;308:58–59.
31. Schmidt RA. Organizing and scheduling practice. In: Schmidt RA, ed. Motor Learning and Practice: From Principles to Practice. Champaign, IL: Human Kinetics Books, 1991, pp 199–225.
32. Kenney WL, Humphrey RH, Bryant CX, et al. ACSM's Guidelines for Exercise Testing and Prescription, 5th Ed. Baltimore, MD: Williams & Wilkins, 1995.
33. Boyd R, Rodda J, Olesch C et al. High- or low-technology measurements of energy expenditure in clinical gait analysis? Dev Med Child Neurol 1999;41:676–682.
34. MacGregor J. The objective measurement of physical performance with long term ambulatory physiological surveillance equipment (LAPSE). In: Stott FD, Raftery EB, Goulding L, eds. ISAM 1979: Proceedings of the Third International Symposium on Ambulatory Monitoring. London: Academic Press, 1980, pp 29–39.
35. Bernardi M, Macaluso A, Sproviero E et al. Cost of Walking and locomotor impairment. J Electromyogr Kinesiol 1999;9:149–157.
36. Macko RF, Smith GV, Dobrovolny NA et al. Treadmill training improves fitness reserve in chronic stroke patients. Arch Phys Med Rehabil 2001;82:879–884.
37. Waters RL, Lunsford BR. Energy cost of paraplegic ambulation. J Bone Joint Surg 1985;67:1245–1250.
38. Brach JS, Perera S, Studenski S et al. Reliability and validity of measures of gait variability in community-dwelling older adults. Arch Phys Med Rehabil 2008;89:2293–2296.
39. Butland RJA, Pang J, Gross ER et al. Two-, six-, and 12-minute walking tests in respiratory disease. BMJ 1982;284:1607–1608.
40. Harada N, Chiu V, Darmon-Rodriguez J et al. Screening for balance and mobility impairment in elderly individuals living in residential care facilities. Phys Ther 1995;75:462–469.
41. Harada ND, Chiu V, Stewart AL. Mobility-related function in older adults: Assessment with a 6-minute walk test. Arch Phys Med Rehabil 1999;80:837–841.
42. Guyatt GH, Sullivan MJ, Thompson PJ. The 6-minute walk: A new measure of exercise capacity in patients with chronic heart failure. Can Med Assoc J 1985;132:919–923.
43. Guralnik JM, Simonsick EM, Ferrucci L et al. A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol 1994;49:M85–M94.
44. Haley SM, Jette AM, Coster WJ et al. Late life function and disability instrument: II. Development and evaluation of the function component. J Gerontol 2002;57A:M217–M222.
45. Jette AM, Haley SM, Coster WJ et al. Late life function and disability instrument: I. Development and evaluation of the disability component. J Gerontol A Biol Sci Med Sci 2002;57A:M209–M216.
46. Cohen J. Statistical Power Analysis for the Behavioral Sciences, 2nd Ed. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.
47. Waters R. Energy expenditure. In: Perry J, ed. Gait Analysis: Normal and Pathologic Function. Thorofare, NJ: Slack Inc., 2004, pp 443–489.
48. Sayers SP, Jette AM, Haley SM et al. Validation of the late-life function and disability instrument. J Am Geriatr Soc 2004;52:1554–1559.
49. Perera S, Mody SH, Woodman RC et al. Meaningful change and responsiveness in common physical performance measures in older adults. J Am Geriatr Soc 2006;54:743–749.
50. Malatesta D, Simar D, Dauvilliers Y et al. Energy cost of walking and gait instability in healthy 65- and 80-yr-olds. J Appl Physiol 2003;95:2248–2256.
51. Donelan JM, Kram R, Kuo AD. Mechanical work for step-to-step transitions is a major determinant of the metabolic cost of human walking. J Exp Biol 2002;205:3717–3727.
52. McGibbon CA, Krebs DE, Puniello MS. Mechanical energy analysis identifies compensatory strategies in disabled elders' gait. J Biomech 2001;34:481–490.
53. Van Swearingen JM, Perera S, Brach JS et al. Exercise to reduce the energy cost of walking: A randomized trial. J Gerontol A Biol Sci Med Sci 2009;64A:1190–1198.
54. Cesari M, Kritchevsky S, Bauer DC et al. Prognostic value of usual gait speed in well-functioning older people—results from the Health, Aging and Body Composition Study. J Am Geriatr Soc 2005;53:1675–1680.
55. Studenski S, Perera S, Patel K et al. Gait speed and survival in older adults. JAMA 2011;305:50–58.
56. Hardy SE, Perera S, Roumani YF et al. Improvement in usual gait speed predicts better survival in older adults. J Am Geriatr Soc 2007;55:1727–1734.
57. Helbostad JL, Sletvold O, Moe-Nilssen R. Home training with and without additional group training in physically frail older people living at home: Effect on health-related quality of life and ambulation. Clin Rehabil 2004;18:498–508.