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# Improving Motor Control in Walking: A Randomized Clinical Trial in Older Adults with Subclinical Walking Difficulty

**Jennifer S. Brach, PhD, PT**[1], **Kristin Lowry, PhD, PT**[2], **Subashan Perera, PhD**[3], **Victoria Hornyak, DPT, PT**[1], **David Wert, PhD, PT**[1], **Stephanie A. Studenski, MD, MPH**[4], and **Jessie M. VanSwearingen, PhD, PT**[1]

[1]Department of Physical Therapy, University of Pittsburgh, Pittsburgh, PA

[2]Department of Physical Therapy, Des Moines University, Des Moines, IA

[3]Division of Geriatric Medicine, University of Pittsburgh, Pittsburgh, PA

[4]Longitudinal Studies Section, National Institute on Aging, Baltimore, MD

## Abstract

**Objective—**The objective was to test the proposed mechanism of action of a task-specific motor learning intervention by examining its effect on measures of the motor control of gait.

**Design—**Single blinded randomized clinical trial.

**Setting—**University research laboratory.

**Participants—**Forty older adults 65 years of age and older, with gait speed >1.0 m/s and impaired motor skill (Figure of 8 walk time > 8 secs).

**Interventions—**The two interventions included a task-oriented motor learning and a standard exercise program. Both interventions lasted 12 weeks, with twice weekly one hour physical therapist supervised sessions.

**Main Outcome Measures—**Two measure of the motor control of gait, gait variability and smoothness of walking, were assessed pre and post intervention by assessors masked to treatment arm.

**Results—**Of 40 randomized subjects; 38 completed the trial (mean age 77.1±6.0 years). Motor control group improved more than standard group in double support time variability (0.13 vs. 0.05 m/s; adjusted difference, AD=0.006, $p$=0.03). Smoothness of walking in the anterior/posterior direction improved more in motor control than standard for all conditions (usual: AD=0.53, $p$=0.05; narrow: AD=0.56, $p$=0.01; dual task: AD=0.57, $p$=0.04).

**Conclusions—**Among older adults with subclinical walking difficulty, there is initial evidence that task-oriented motor learning exercise results in gains in the motor control of walking, while standard exercise does not. Task-oriented motor learning exercise is a promising intervention for

Corresponding Author: Jennifer S. Brach, PhD, PT, Department of Physical Therapy, University of Pittsburgh, 6035 Forbes Tower, Pittsburgh, PA 15260, Phone: 412-383-6533, Fax: 412-648-5970, jbrach@pitt.edu.

improving timing and coordination deficits related to mobility difficulties in older adults, and needs to be evaluated in a definitive larger trial.

### Keywords

motor control; gait; aging; exercise

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Exercise interventions to improve mobility and prevent functional decline in older adults primarily target strength, flexibility and endurance but rarely address the motor control of walking. These exercise programs which overlook the motor control of walking have resulted in only modest improvements in mobility.[1–6]

To specifically address the learning/relearning of the motor control of walking, an intervention was developed based on motor learning principles and focused on the practice of the smooth, coordinated aspects of walking throughout the gait cycle (i.e. task-oriented motor learning intervention).[7–10] We previously showed that in older adults with walking difficulty (slow and variable gait), the task-oriented motor learning intervention promoted greater gains in clinical measures of gait (gait efficiency, gait speed and self-perceived walking ability) compared to a standard exercise program.[11] Likewise, in older adults with subclinical walking difficulty (i.e. near normal gait speed > 1.0 m/s but impaired skill in walking, figure 8 walk time > 8 seconds), the task-oriented motor learning program promoted greater gains in mobility (gait speed and walking skill) than the standard exercise program.[7] Having shown the clinical effect of the task-oriented motor learning program, the current goal is to test the proposed mechanism of action of the intervention (e.g. improved motor control of walking). Therefore, the purpose of this study is to assess the impact of a motor learning versus a standard exercise program on the motor control of gait (i.e. gait variability and smoothness of walking) in community-dwelling older adults with subclinical gait deficits. Given that the motor learning program focuses on the smooth, coordinated aspects of gait timing, we expect that individuals in the motor learning exercise group will have greater improvements in gait variability and smoothness of walking than the standard group.

## METHODS

### Overview

The study protocol was approved by the University of Pittsburgh Institutional Review Board, and all subjects provided informed consent. The study was registered at ClinicalTrials.gov (PRO09080228). The Program to Improve Mobility in the Elderly (PRIME study) was a 12-week single-blind randomized clinical trial that compared two exercise interventions in older adults with subclinical gait dysfunction. Details of the methods and the main study outcomes have been published elsewhere.[7]

### Participants and Inclusion Criteria

Briefly, the eligible participants consisted of men and women 65 years of age and older who had subclinical gait dysfunction defined as near normal gait speed (i.e. gait speed ≥ 1.0 m/s) and impaired motor skill in walking.[7] Gait speed was assessed using an instrumented walkway. Motor skill in walking was assessed using the Figure of 8 Walk Test[12] with impaired motor skill defined as ≥8 seconds to complete the test. The Figure of 8 Walk Test assesses walking around curves in both clockwise and counter-clockwise directions. This complex task, which is associated with measures of motor control and planning,[12–15] requires smooth transitions from timing and coordination patterns of straight path walking to the different timing and coordination patterns of curved-path walking.[16–19] Individuals with impaired walking skill slow down and take several small steps when walking the curves of the Figure of 8 Walk Test. Additional exclusion criteria included 1) reported dyspnea at rest or during activities, 2) hospitalization in the past 6 months for acute illness or injury, 3) progressive neuromuscular disorder such as Parkinson's disease, 4) persistent lower extremity or back pain, 5) fixed or fused lower extremity joints, 6) resting systolic blood pressure greater than or equal to 200, diastolic blood pressure greater than or equal to 100, or resting heart rate greater than 100 beats per minute or less than 40 beats per minute, and 7) Mini Mental State Examination[20] score less than 24. All participants had physician clearance to participate in a moderate intensity exercise program.

## Sample Size and Randomization

As a pilot intervention trial, sample size (n=40) was based on feasibility within available resources rather than a given level of statistical power. The randomization sequence was generated by the study biostatistician using the high quality pseudo-random deviate generator in SAS® (SAS Institute, Inc., Cary, North Carolina) in 1:1 ratio and a blocked randomized scheme, and placed in sequentially numbered sealed envelopes. Participants were assigned to motor learning or standard interventions by the study coordinator at the time of randomization.

## Interventions

**Overview—**Both interventions were physical therapist led, protocol driven interventions that lasted 60 minutes twice a week for 12 weeks. The programs included a brief warm-up period and strength training that was conducted on Magnum (Magnum Fitness Systems, South Milwaukee, WI) stacked weight equipment and included the following exercises: knee extension, knee flexion, leg press, hip abduction, and hip extension. When subjects were able to complete 2 sets of 15 repetitions with minimal effort (i.e. rating of perceived exertion < 10), resistance was increased for progression of the exercises.

**Motor Learning Exercise—**Subjects in the motor learning group also received 20–30 minutes of motor learning exercises in addition to the warm-up and strengthening exercises. The previously described motor learning program[7, 9, 10] was based on the principles that enhance "skill" or smooth and automatic movement control.[21–26] The motor learning exercise program included both stepping and walking patterns. The goal oriented, progressively more difficult stepping patterns were designed to shift the center of pressure posteriolaterally then forward, encouraging hip extension prior to 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.[27–29] Walking patterns incorporated patterns of muscle coordination and interlimb timing into walking and were progressed by altering speed, amplitude (e.g.

narrowing oval width), or accuracy of performance (e.g. without straying from the desired path). More complex walking patterns involved walking past others and with upper extremity object manipulation tasks, such as carrying or bouncing a ball.[26] Treadmill walking reinforced the rhythmic stepping and was completed at preferred walking speed with brief intervals of increased speed.

**Standard Exercise—**Subjects in the standard group also received endurance training in addition to the warm-up and strengthening exercises. The endurance training consisted of treadmill walking at a submaximal workload with a self-reported rating of perceived exertion (RPE) of 10–13, somewhat hard. Once subjects tolerated a 10–13 RPE level for 15 minutes, the workload was increased by first increasing the duration of walking 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 (i.e. RPE 10–13).

## Measures of Motor Control of Gait

Aging and disease alter the motor control and the timing and coordination of gait as reflected by slowed neuromotor performance, increased gait variability[30] and reduced smoothness of movement.[31–34] In order to capture the motor control of walking we measured gait variability and smoothness of walking. All outcomes were assessed before and after the 12 week intervention by individuals masked to the intervention group.

**Gait Variability—**Gait variability, defined as fluctuations in gait characteristics from one step to the next, is an important indicator of impaired mobility in older adults. We were primarily interested in gait speed and variability of step length, step width, step time, stance time, and double support time. These were selected because they represent both spatial and temporal characteristics and because they have been studied by other investigators,[35–38] and shown to be predictive of future falls[35, 37] and mobility disability.[39]

The GaitMat II™ system was used for the analysis of speed and spatiotemporal variability.[40] The GaitMat II™ is an instrumented 4-meter long walkway that records and analyzes footfall data. In addition to the 4-meter instrumented walkway, there are initial and final one meter inactive sections that allow for acceleration and deceleration of the participant. After two practice passes on the GaitMat II™, each participant completed four passes on the GaitMat II™ at their self-selected walking speed for data collection. The within-subject standard deviations of the gait characteristics determined from all of the right and left steps recorded over 4 passes were included in the calculation for each person and used as measures of gait variability. Approximately 25–30 steps were collected from 4 passes on the GaitMat which is more than adequate to achieve a stable measure of gait variability. Our prior work has shown that 20 steps are sufficient to achieve a reliability of ICC=0.75 and 30 are sufficient for ICC=0.80.[41]

**Smoothness of Walking—**Smoothness of walking, quantified by harmonic ratios (HRs), measures the symmetry and repeatability of the timing and magnitude of trunk accelerations in antero-posterior (AP), vertical (V) and mediolateral (ML) directions.[42] Harmonic ratio theory and calculation has been previously described.[43, 44] Briefly, HRs have been used to characterize the complex acceleration trajectories for each direction of motion as a single value for a given stride by quantifying the deviation from an ideally symmetrical acceleration pattern. Higher HRs are interpreted as greater walking smoothness.[43] Older adults, who likely have impaired gait biomechanics and neural control,[31, 45–47] individuals with Parkinson's disease,[48, 49] and individuals with sensory impairment,[50] are less smooth in walking than young adults or individuals without disease. In addition, smoothness of walking is related to physical function, independent of gait speed, thus suggesting smoothness represents aspects of the motor control of walking important for physical function.[51]

A triaxial accelerometer (BIOPAC Systems, Inc., Santa Barbara, CA, USA) secured over the third lumbar spine vertebra and wireless transmission technology were used to record 3D trunk accelerations.[45] Trunk accelerations were sampled at 100 Hz. A footswitch system was used to determine heel contact events for stride segmentation. HRs were determined for each stride and averaged across strides resulting in a mean HR for each direction of motion. Acceleration data were recorded during three over ground walking conditions, usual pace, narrow, and dual task which are described below:

- Usual walk: Subjects walked 12.2 m over ground at their usual, preferred speed.
- Narrow path walk: Brightly colored tape was used to mark a 15 cm wide, 4 meter long rectangular path in the center of the 12 meter long walkway. Subjects walked 4 meters on the usual width walkway, 4 meters in the narrow path, and then 4 meters on the usual width walkway at their preferred speed.
- Dual task walk: While standing, subjects listened to a string of digits (presented at the rate of one digit per second), with the number of digits defined by subject's memory span, as determined prior to gait testing. The digit list was provided to the subjects prior to the walk, the subject then walked for 12.2 m over ground at their preferred speed, and then upon stopping was asked to recall the digits in reverse order.

Trunk triaxial accelerometric gait analysis has shown high test-retest reliability, with $ICC_{3,1}$ values ranging from .77 to .96[52, 53] and high stride-to-stride reliability for trunk acceleration signals across a range of walking speeds (coefficient of multiple determination, a waveform repeatability statistic, ranged from .60 to .95).[54]

## Data Analysis

All statistical analyses were performed using SAS® version 9.3 (SAS Institute, Inc., Cary, NC). Participant characteristics and baseline measurements were compared between arms using *t*-tests for continuous variables and chi-square tests for categorical variables. To obtain adjusted differences of outcomes between treatment arms, we fitted a series of analysis of covariance models using baseline to follow-up change in each outcome as the response variable; treatment arm as the main factor of interest; and baseline value of the outcome and baseline gait speed as covariates.

# RESULTS

Of 110 people initially screened by telephone, 64 underwent on site screening. Forty-one participants met all criteria and 40 were randomized (1 subject deferred) and 38 completed the study.[7] All 38 completers participated in at least 22 exercise sessions with 37 participants (97%) completing all 24 sessions. The two drop-outs developed unrelated medical conditions and walked more slowly than those who completed the study. Participants had a mean age of 77.1 years, near 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. Participants in the two treatment arms were similar on all health and demographic characteristics (Table 1).

## Baseline Motor Control of Walking

Participants in the two treatment arms were similar on all baseline gait measures. Though 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.[55] The group mean baseline values of gait variability and smoothness of walking were indicative of impaired motor control in walking (Tables 2 and 3). Baseline stance time variability was 0.39 s which is greater than the 0.034 s cut-off value for future mobility disability,[56] and baseline smoothness of walking during the usual walking condition ranged from 2.00 to 3.03 which is much less than the values for young adults (i.e. 4.46).[45]

## Baseline to Post-Intervention Change in the Motor Control of Walking

The motor learning group had greater improvements than the standard group in double support time variability (Table 2). Improvements in step length, step width, step time, and stance time variability did not differ between the two groups. The motor learning group had greater improvements in smoothness of walking than the standard group (Table 3). The motor learning group had a greater increase than the standard group in AP and V smoothness measured specifically during the narrow and dual task walks. Changes in ML smoothness during all walking conditions were not different between the groups ($p>0.10$).

# DISCUSSION

Older adults with near normal gait speed and subclinical gait deficits who participated in a task-oriented motor learning exercise program demonstrated greater improvements in the motor control of walking than those who participated in a standard impairment-based exercise program. Individuals in the motor learning program had greater improvements in gait variability (double support time variability) and smoothness of walking ($HR_{AP}$ and $HR_{V}$ during narrow and dual task conditions) two indicators of the motor control of walking.

The standard impairment-based exercise program and the task-oriented motor learning exercise program have very different proposed underlying mechanisms for improving walking.[8] The standard impairment-based exercise program aims to increase the physiologic capacity in body systems that contribute to walking, but does not include the task specific exercise necessary to make use of the capacities for the walking. The result is a bigger engine for walking – the ability to use the excess capacity to tolerate the age-related gait abnormalities and high energy cost of poor walking. Whereas, the task-oriented motor learning program is intended to improve the older adult's appropriate motor plan selection from an enhanced repertoire of motor plans for walking. More specifically, the task-specific motor learning intervention aims to improve the motor skill of walking by re-aligning biomechanical and neuromotor control, strengthening motor programs, and improving feedback for adjusting movements. In a sense it is comparable to a "tune-up" of an engine. The result is a more efficient system for walking which requires less energy and can last longer. The improvements in motor control of walking in the task-oriented motor learning group and not the standard impairment-based group support the proposed underlying mechanisms of the interventions.

Differences in gait variability between the groups after the intervention were smaller than expected. This may be partially explained by the fact that both groups trained on a treadmill, which acts as an external pacer and step generator and has been shown to reduce gait variability.[57] Though the rationale and the protocol for training on the treadmill were different for the groups, both groups did walk on the treadmill as part of their intervention. Therefore, it is not surprising that both groups improved or reduced their step time and stance time variability after training.

The motor learning group demonstrated consistent improvements in smoothness of walking (HR values increasing after intervention) across all walking conditions whereas the standard group demonstrated consistent worsening (HR values decreasing after intervention). Group differences in smoothness of walking were more apparent during the challenging conditions of narrow and dual task walking. In higher functioning older adults, a challenge may be necessary to bring out deficits and demonstrate improvements with intervention.[58] Also, neither group practiced these specific challenging tasks as part of their exercise intervention. The task-oriented motor learning approach prepares the older adult to select the appropriate motor plan for walking. The goal is not to practice every possible walking condition (which is virtually impossible) but to train the older adult to make the appropriate motor plan selection for the walking task. To make appropriate changes in the selection of motor plans, the brain needs to be updated about the body capacities through continued recent and relevant movement experiences in walking.[25] The stepping and walking patterns included in the task-oriented motor learning program provide the older adult with such movement experiences relevant to walking.

Smoothness of walking is related to gait speed,[43] so the improvements in smoothness of walking may be a result of the increased gait speed after the intervention. Though the motor learning group had greater improvements in gait speed than the standard group [adjusted group difference (SE) = 0.11 m/s (0.04), p=0.008] both groups did increase gait speed with the intervention.[7] Despite this increase in gait speed, the standard group's smoothness of walking worsened. Therefore, the improvements in the smoothness of walking in the motor control group cannot be attributed to the improvements in gait speed.

## Study Limitations

The current work has several limitations that must be considered when interpreting the findings. First, this was a pilot study that was not powered to detect differences between groups; the sample size was based on feasibility and availability of resources. However, we were able to find a few important differences with relatively smaller *p*-values despite low statistical power. Secondly, both groups trained on a treadmill which has been shown to impact gait variability.[57] Future studies examining the impact of standard versus task-oriented motor learning on the motor control of walking should utilize alternative forms of endurance training for the standard exercise group such as over ground walking. Lastly, given the number of comparisons the potential for Type I error needs to be considered. The current work also has strengths that should be recognized. The study's design, a single-blind randomized clinical trial minimizes unwanted bias. Secondly, motor control of walking was objectively quantified using measures of gait variability and smoothness of walking under usual and challenging walking conditions.

## CONCLUSION

Among older adults with subclinical walking difficulty, there is initial evidence that task-oriented motor learning exercise results in gains in the motor control of walking, while standard exercise does not. Task-oriented motor learning exercise is a promising intervention for improving timing and coordination deficits related to mobility difficulties in the older adults, and needs to be evaluated in a definitive larger trial.

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Clinical Trials registration number: PRO09080228

## Abbreviations

| | |
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| **AD** | adjusted difference |
| **AP** | antero-posterior |
| **HR** | harmonic ratio |
| **ICC** | intraclass correlation coefficient |
| **ML** | mediolateral |
| **m/s** | meters per second |
| **RPE** | rating of perceived exertion |
| **V** | vertical |

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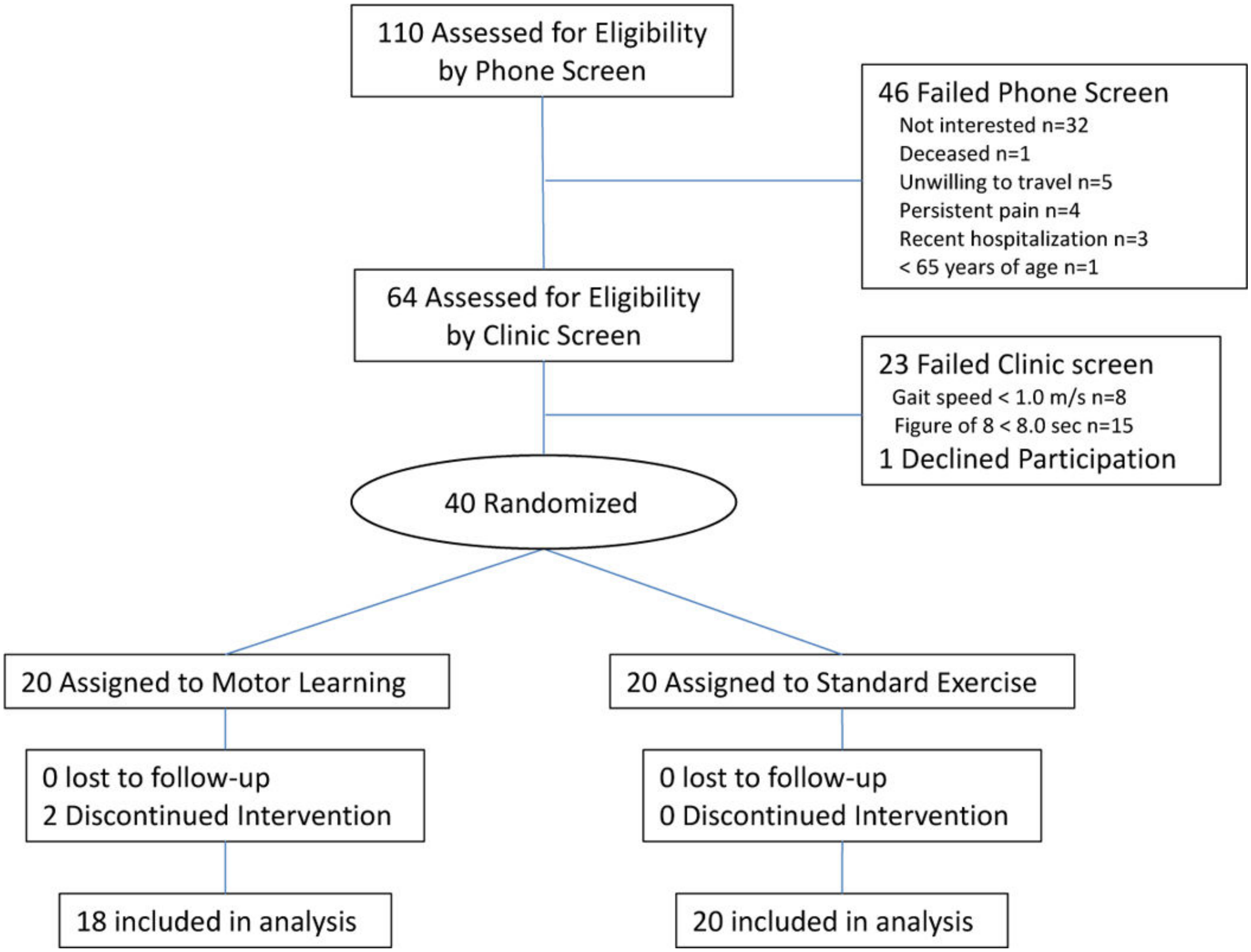
110 Assessed for Eligibility by Phone Screen
46 Failed Phone Screen
Not interested n=32
Deceased n=1
Unwilling to travel n=5
Persistent pain n=4
Recent hospitalization n=3
< 65 years of age n=1
64 Assessed for Eligibility by Clinic Screen
23 Failed Clinic screen
Gait speed < 1.0 m/s n=8
Figure of 8 < 8.0 sec n=15
1 Declined Participation
40 Randomized
20 Assigned to Motor Learning
20 Assigned to Standard Exercise
0 lost to follow-up
2 Discontinued Intervention
0 lost to follow-up
0 Discontinued Intervention
18 included in analysis
20 included in analysis

**Table 1**

Baseline characteristics by treatment group

| | Motor Learning n=18 | Standard n=20 | P |
|---|---|---|---|
| Age, years | 75.7 (5.5) | 78.5 (6.2) | 0.16 |
| female, n (%) | 10 (55.6) | 13 (68.4) | 0.42 |
| white, n (%) | 18 (100) | 19 (95) | 0.32 |
| married, n (%) | 12 (67) | 9 (47) | 0.36 |
| Graduate education, n (%) | 10 (56) | 11 (58) | 0.99 |
| Chronic conditions | | | |
| Cardiac, n (%) | 2 (11) | 1 (5) | 0.49 |
| Musculoskeletal, n (%) | 12 (67) | 18 (90) | 0.08 |
| Visual, n (%) | 13 (72) | 18 (90) | 0.16 |
| Diabetes, n (%) | 4 (22) | 2 (10) | 0.30 |
| Cancer, n (%) | 8 (44) | 5 (25) | 0.21 |
| Lung, n (%) | 4 (22) | 2 (10) | 0.30 |
| Gait speed, m/s | 1.22 (0.16) | 1.14 (0.15) | 0.79 |
| Figure 8, s | 9.1 (0.93) | 9.3 (0.92) | 0.97 |

## Table 2

Baseline and post-intervention gait variability by treatment group

| | Treatment Group | | | | | |
|---|---|---|---|---|---|---|
| | Motor Learning n=18 | | Standard n=20 | | Adjusted group differences | |
| **Gait Variability** | **Baseline Mean (SD)** | **Post-intervention Mean (SD)** | **Baseline Mean (SD)** | **Post-intervention Mean (SD)** | **Adjusted group Difference (SE)** | ***p*** |
| Step length, m | 0.031 (0.012) | 0.030 (0.010) | 0.033 (0.013) | 0.036 (0.011) | −0.005 (0.003) | 0.09 |
| Step width, m | 0.034 (0.010) | 0.033 (0.008) | 0.032 (0.009) | 0.031 (0.005) | 0.002 (0.002) | 0.48 |
| Step time, s | 0.032 (0.024) | 0.021 (0.010) | 0.036 (0.022) | 0.024 (0.010) | −0.003 (0.003) | 0.45 |
| Stance time, s | 0.039 (0.023) | 0.026 (0.010) | 0.039 (0.020) | 0.031 (0.011) | −0.005 (0.004) | 0.14 |
| Double support time, s | 0.019 (0.006) | 0.015 (0.003) | 0.022 (0.012) | 0.021 (0.012) | −0.006 (0.003) | 0.03 |

## Table 3

Baseline and post-intervention smoothness of walking during usual, narrow path and dual task conditions by treatment group

| | Treatment Group | | | | | |
|---|---|---|---|---|---|---|
| | Motor Learning n=18 | | Standard n=20 | | * Adjusted group differences | |
| **Harmonic Ratio** | **Baseline Mean (SD)** | **Post-intervention Mean (SD)** | **Baseline Mean (SD)** | **Post-intervention Mean (SD)** | **Adjusted group Difference (SE)** | ***p*** |
| **Vertical $HR_V$** | | | | | | |
| Usual | 3.03 (1.10) | 3.38 (0.92) | 2.94 (1.17) | 2.79 (1.07) | 0.58 (0.35) | 0.10 |
| Narrow path | 2.77 (1.00) | 2.95 (0.78) | 2.39 (0.86) | 2.26 (0.78) | 0.71 (0.27) | 0.01 |
| Dual task | 3.10 (1.27) | 3.50 (0.91) | 2.71 (1.13) | 2.55 (1.04) | 0.89 (0.35) | 0.01 |
| **Antero-Posterior $HR_{AP}$** | | | | | | |
| Usual | 2.45 (0.99) | 2.67 (0.67) | 2.27 (0.78) | 2.12 (0.85) | 0.53 (0.26) | 0.05 |
| Narrow path | 2.18 (0.73) | 2.37 (0.67) | 1.91 (0.60) | 1.76 (0.54) | 0.56 (0.21) | 0.01 |
| Dual task | 2.46 (0.93) | 2.65 (0.76) | 2.31 (0.96) | 2.03 (0.93) | 0.57 (0.27) | 0.04 |
| **Mediolateral $HR_{ML}$** | | | | | | |
| Usual | 2.01 (0.65) | 2.24 (0.61) | 2.00 (0.81) | 1.96 (0.79) | 0.31 (0.21) | 0.16 |
| Narrow path | 1.81 (0.53) | 1.83 (0.53) | 1.72 (0.49) | 1.68 (0.62) | 0.13 (0.18) | 0.48 |
| Dual task | 2.00 (0.77) | 2.10 (0.53) | 1.94 (0.75) | 1.91 (0.81) | 0.17 (0.23) | 0.46 |

[*] Adjusted for baseline value of each outcome and baseline gait speed.