Otago Home-Based Strength and Balance Retraining Improves Executive Functioning in Older Fallers: A Randomized Controlled Trial

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OBJECTIVES: To primarily ascertain the effect of the Otago Exercise Program (OEP) on physiological falls risk, functional mobility, and executive functioning after 6 months in older adults with a recent history of falls and to ascertain the effect of the OEP on falls during a 1-year follow-up period.

DESIGN: Randomized controlled trial.

SETTING: Dedicated falls clinics.

PARTICIPANTS: Seventy-four adults aged 70 and older who presented to a healthcare professional after a fall.

INTERVENTION: The OEP, a home-based program that consists of resistance training and balance training exercises.

MEASUREMENTS: Physiological falls risk was assessed using the Physiological Profile Assessment. Functional mobility was assessed using the Timed Up and Go Test. Three central executive functions were assessed: set shifting, using the Trail Making Test Part B; updating, using the verbal digits backward test; and response inhibition, using the Stroop Color-Word Test. Falls were prospectively monitored using daily calendars.

RESULTS: At 6 months, there was no significant between-group difference in physiological falls risk or functional mobility ($P \geq .33$). There was a significant between-group difference in response inhibition ($P = .05$). A falls histogram revealed two outliers. With these cases removed, using negative binomial regression, the unadjusted incidence rate ratio of falls in the OEP group compared with the control group was 0.56. The adjusted incidence rate ratio was 0.47.

CONCLUSION: The OEP may reduce falls by improving cognitive performance. **J Am Geriatr Soc 56:1821–1830, 2008.**

Key words: executive functioning; exercise; older adults; falls

According to the World Health Organization, falls are the third leading cause of chronic disability worldwide,[1] and approximately 30% of community dwellers aged 65 and older experience one or more falls every year.[2] Although not all falls lead to injury, approximately 20% require medical attention, and 5% result in fracture, with one-third of those being hip fractures. Fall-related injuries are the leading cause of mortality due to unintentional injuries in people aged 65 and older.

Falls are associated with cognitive dysfunction.[2,3] Recent evidence suggests that even mild cognitive decline is a risk factor for falls.[2,4,5] Even in older adults with Folstein Mini-Mental State Examination (MMSE) scores of 24 or greater, baseline cognitive performance was linearly and inversely associated with rate of falling over 8 years.[5] A critical domain of cognitive function is executive function—the higher-order cognitive processes that control and integrate other cognitive abilities.[6] In older adults, impaired central executive functioning is associated with falls[4,7,8] and with risk of a major fall-related injury. The successful performance of a challenging or complex locomotor task depends on integrity and functionality of the neurological structures that subserve the central executive function.[9]

Evidence is emerging that physical activity maintains and enhances cognition across the life span.[10] In a 5-year prospective study, physical activity was associated with lower risk of cognitive impairment, Alzheimer's disease

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(AD), and dementia.[11] A recent meta-analysis concluded that aerobic training had robust but selective benefits for cognition; the largest benefits occurred for executive functioning.[12] However, this meta-analysis[12] also highlighted that aerobic training programs combined with resistance training had a greater positive effect on cognition than aerobic training alone. Thus, aerobic training may not be the only type of exercise that promotes cognitive health in older adults.

Effective falls prevention exercise programs, such as the Otago Exercise Program (OEP),[13,14] consist of resistance training and balance training exercises.[13,14] The current thought is that these types of exercises reduce falls by improving physiological functions (by improving balance and strength),[14] although improved cognitive function, specifically improved executive functioning, may be another mechanism by which these types of exercises reduce falls in older adults. However, this research question has been largely unaddressed, because few exercise trials of falls prevention have included measures of cognitive function.[15] Furthermore, no previous study of the influence of exercise on cognition has specifically included older adults with a history of falls. Thus, a 1-year randomized controlled trial with a primary objective of ascertaining the effect of the OEP on physiological falls risk, functional mobility, and executive functioning after 6 months in older adults with a recent history of falls was conducted. Specifically, the aim was to compare the effect of the OEP, delivered as a facilitated and mandatory component, with guideline falls prevention care on physiological falls risk, functional mobility, and executive functioning in older adults who presented to a healthcare professional after a fall. As a secondary objective, the effect of the OEP on falls was ascertained during a 1-year follow-up period.

METHODS

Study Design

A randomized controlled 1-year prospective study (NCT00323596) with two assessment sessions (baseline and 6-month) for physiological falls risk, functional mobility, and executive functioning was conducted. Falls were prospectively monitored for 1 year.

Participants

The sample consisted of men and women who attended a falls clinic and participated in a 1-year randomized controlled trial of the OEP. Participants were enrolled over a 19-month period beginning July 2004 from two dedicated referral-based falls clinics in Vancouver, British Columbia. The geriatricians who staffed the falls clinic accepted general practitioner referrals of patients aged 70 and older who had fallen and were considered at risk for further falls. Patients who attended the falls clinic received a falls risk factor assessment followed by a comprehensive geriatric assessment. The falls clinic care pathway was based on the American Geriatrics Society/British Geriatrics Society/American Academy of Orthopaedic Surgeons Falls Prevention Guidelines[16] (hereafter referred to as "Guideline Care").

Community-dwelling men and women aged 70 and older were eligible to participate in the randomized controlled trial if they attended the dedicated falls clinics. Participants needed to be able to walk at least 3 meters, because the OEP has a walking component. Participants also needed to meet one of the following criteria: one additional nonsyncopal fall in the previous year, to enroll participants whose index fall was suspected clinically to be due to carotid sinus syndrome; a Timed-Up and Go (TUG) test time of greater than 15 seconds, because this threshold has been associated with greater risk for falls;[17] or a Physiological Profile Assessment (PPA) z-score of 1 or greater, to enroll participants who were at risk for falls, because this tool can discriminate between multiple and nonmultiple fallers.[18] Participants were excluded if they had a progressive neurological condition (e.g., Parkinson's disease); life expectancy of less than 12 months as determined by the falls clinic geriatric medicine physician; or an MMSE score less than 24.[19] Figure 1 is the Consolidated Standards of Reporting Trials study flow diagram for this study.

The Clinical Research and Ethics Board at the University of British Columbia, Vancouver Coastal Health Research Institute, and the British Columbia Women's Hospital approved the study. All participants gave written informed consent.

Descriptive Variables

Age was measured in years, standing height in centimeters, and mass in kilograms in all participants. Global cognitive state was assessed using the MMSE.[19] Education was assessed in number of years in high school plus number of years in university or college. All participants also underwent a comprehensive geriatric assessment at baseline and 6 months later.

The 15-item Geriatric Depression Scale (GDS)[20,21] was used to screen for depression. The GDS was designed specifically for assessing depressed mood in older people; a score of 11 and greater indicates severe depression.[21]

Current level of physical activity was determined using the Physical Activities Scale for the Elderly (PASE) questionnaire.[22,23] This 12-item scale for subjects aged 65 and older measures the average number of hours per day spent participating in leisure, household, and occupational physical activities over the previous 7-day period. The PASE questionnaire is valid and reliable for older adults.[22,23]

At baseline, the Functional Comorbidity Index was calculated to estimate the degree of comorbidity associated with physical functioning.[24] It contains diagnoses such as arthritis not found on indices used to predict mortality. The Functional Comorbidity Index also explains more variance in physical function scores than indices designed to predict mortality.[24] This scale's score is the total number of comorbidities.

Physiological Falls Risk

Participant's physiological falls risk was assessed using the Physiological Profile Assessment (PPA) (Prince of Wales Medical Research Institute, Randwick, Sydney, NSW, Australia).[18] The PPA is a valid and reliable tool for assessing fall risk in older people. Based on the performance of five physiological domains (postural sway, hand reaction time, quadriceps strength, proprioception, and edge contrast sensitivity), the PPA computes a fall risk score (standardized

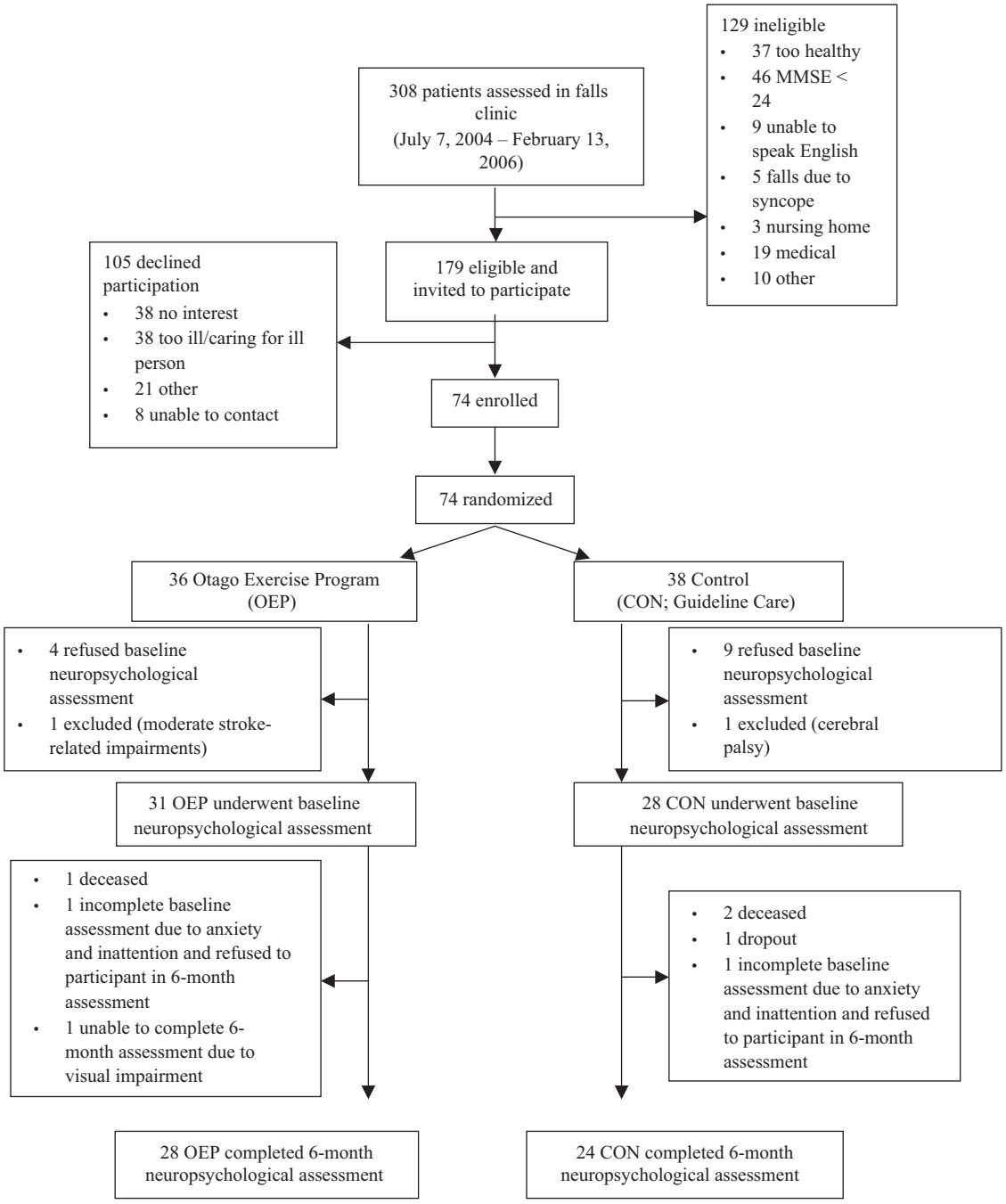

Figure 1. Consolidated Standards of Reporting Trials study flow diagram.

score) for each individual; it has 75% predictive accuracy for falls in older people.[18] A PPA *z*-score of 0 to 1 indicates mild risk, 1 to 2 moderate risk, 2 to 3 high risk, and 3 and above marked risk.[25]

Postural sway was assessed using a sway-meter that measured displacement of the body at the level of the waist with participants standing on a foam rubber mat (eyes open) for 30 seconds. Simple hand reaction time was assessed using a light as the stimulus and a computer mouse as the response and was measured in milliseconds. Dominant quadriceps strength was assessed with the participant seated using a strain gauge to the nearest 0.5 kg. Proprioception was assessed using a lower limb matching task recording errors in degrees using a protractor inscribed on a vertical clear acrylic sheet placed between the legs. Edge contrast sensitivity was assessed using the Melbourne Edge Test.[20] This test presented circular patterns containing edges with reducing contrast. Correct identification of the orientation of the edge measures contrast sensitivity in decibel units (dB), where $dB = -10 \log_{10}$ contrast.

Functional Mobility

General mobility was assessed using the TUG.[26] Participants were instructed to rise from a standard chair with arms (seat height 45 cm, arm height 62 cm), walk a distance

of 3 meters, turn, walk back to the chair, and sit down again. A stopwatch was used, and the mean of two trials was calculated and used for statistical analysis.

Central Executive Functions

This study focused on three central executive functions: set shifting, updating (i.e., working memory), and response inhibition.[27] A previous[28] demonstrated that, although these three executive functions are moderately correlated with one another, they are clearly separable. These functions are often hypothesized to contribute to performance of complex "frontal" tasks. They are also highly specific and can be defined in a fairly precise manner.[28] Set shifting requires one to go back and forth between multiple tasks or mental sets.[28] Updating (working memory) involves monitoring incoming information for relevance to the task at hand and then appropriately updating the informational content by replacing old, no longer relevant information with new incoming information. Response inhibition involves deliberately inhibiting dominant, automatic, or prepotent responses. Previous studies have demonstrated that poor set shifting (e.g., Trail Making Test Part B) and response inhibition (e.g., Stroop Color-Word Test) are predictive of falls.[7,29]

Baseline cognitive performance of executive functioning was assessed in the homes of each participant within 2 weeks after study entry. All standard neuropsychological tests of executive functioning were reassessed 6 months later. To minimize participant fatigue, administration time was restricted to approximately 1 hour.

Set Shifting

The Trail Making Test Part B was used to assess set shifting. This standardized test of set shifting consists of a page with encircled numbers and letters (the numbers extend from 1 to 13 and the letters from A to L). Participants were instructed to draw a line as quickly and as accurately as possible from 1 to A, A to 2, 2 to B, B to 3, and so on, until they completed the task. The amount of time (in seconds) it took to complete the task and the number of errors made were recorded. Reliability scores for the Trail Making Test Part B range from moderate to excellent (0.44–0.90).[30] Total time to complete the task was the measure used for statistical analysis. Shorter Trail Making Test Part B times are indicative of better cognitive flexibility.

Updating (Working Memory)

The verbal digits backward test was used to assess working memory.[31] This test consists of seven pairs of random number sequences that the assessor reads aloud at the rate of one per second. The sequence begins with three digits and increases by one at a time up to a length of nine digits. The participant's task is to repeat each sequence in an exactly reversed order. The test includes two sequences of each length, and testing ceases when the participant fails to recollect any two with the same length. The score recorded, ranging from 0 to 14, is the number of successful sequences. Higher scores indicate better performance.

Response Inhibition

The Stroop Color-Word Test[32] was used to assess response inhibition. Response inhibition, an essential component of self-regulation, is the ability to suppress automatic reactions in favor of alternative, planned behaviors.[30] The Stroop Color-Word Test is based on the finding that it takes longer to say the color names of colored patches than to read words. Lezak[33] has found that people who do poorly on this test have difficulty concentrating, and difficulty warding off distractions. For the Stroop Color-Word Test, participants were shown a page with Color-Words printed in incongruent colored inks (e.g., the word "blue" printed in red ink). Participants were asked to name the ink color in which the words are printed (while ignoring the word itself). The time (in seconds) participants took to read 112 words was recorded, and this measure was used for statistical analysis. The number of corrected and uncorrected errors was also recorded. Shorter times indicate better response inhibition.

Randomization

The randomization sequence was computer generated (www.randomization.com) and consisted of three strata (sex, whether index fall had necessitated an emergency department visit, and falls clinic physician) and blocks of six participants. The Family Practice Research Coordinator at the University of British Columbia held this sequence independently and remotely. Participants were randomized to the OEP or control (guideline care only).

Sample Size

The sample size of 74 assumed a PPA baseline score of 1.73 in both groups.[34] IT was assumed that the PPA *z*-score in the control group would increase by 0.51 U (greater risk of falling) with a standard deviation of 0.9 U and that the PPA *z*-score would remain unchanged in the OEP group over a 6-month period, with a standard deviation of 0.9 U. Assuming $\beta = 0.2$, $\alpha = 0.05$, and 15% attrition, this required a sample size of 60 participants (30 per study arm).

Blinding

This was a single-blind (assessor) study. Research assistants who administered the fall risk assessments and conducted the monthly telephone interviews were all blinded to group assignment.

Otago Exercise Program

The OEP is a home-based balance and strength retraining program.[14,35] The exercises consisted of the following strengthening exercises: knee extensor (four levels), knee flexor (four levels), hip abductor (four levels), ankle plantarflexors (two levels), and ankle dorsiflexors (two levels). The balance retraining exercises consisted of the following: knee bends (four levels), backwards walking (two levels), walking and turning around (two levels), sideways walking (two levels), tandem stance (two levels), tandem walk (two levels), one-leg stand (three levels), heel walking (two levels), toe walking (two levels), heel toe walking backwards (one level), and sit to stand (four levels). Details of the exercise program are illustrated and detailed in a dedicated publication.[35]

The two physiotherapists who delivered the OEP had 27 and 16 years of clinical experience with older persons. For each patient randomized to the OEP, one of the

physiotherapists visited the home and prescribed a selection of exercises at the first visit. The same physiotherapist returned every other week three additional times to make progressive adjustments to the exercise protocol according to the OEP exercise manual. Participants were encouraged to perform the exercise program three times per week (approximately 30 minutes) and to walk at least twice per week. Each participant was given an exercise manual with a picture and description of each exercise and an ankle cuff weight that could be adjusted in 0.9-kg increments, from 0.9 to 9 kg. The physiotherapist also visited the participant's home one final (5th) time 6 months after the initial visit to check that the program was being performed correctly and to encourage the participant to persist.

Concurrent Guideline Care

The clinic accepted referrals from general practitioners of subjects aged 70 and older who had fallen and were considered at risk of further falls. The clinic provided falls risk factor assessment followed by a comprehensive geriatric assessment and treatment. The falls clinic care pathway was based on the American Geriatrics Society/British Geriatrics Society/American Academy of Orthopaedic Surgeons Falls Prevention Guidelines.[16]

Geriatricians' baseline clinic consultation letters were photocopied, and all patient identifiers were removed. Two researchers (KMK, MGD) who were blinded to treatment allocation abstracted relevant medical history and current medication and supplement use from the baseline consult letters.

Monitoring of Falls and Adherence to the OEP

Ascertainment of falls and adherence to the OEP were documented on monthly calendars that were returned in prepaid preaddressed envelopes at the end of each month. Falls were defined as "unintentionally coming to the ground or some lower level and other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure.'"[36] Adherence was defined as the number of OEP days completed divided by the number of OEP days prescribed. A research assistant who was not blinded to treatment group but was unaware of the study hypotheses made three attempts by telephone to contact participants at the end of each month. The purpose of each phone call was to inquire about falls (both groups) and exercise adherence (OEP group only) for all participants regardless of whether the calendar was returned. The research assistant also encouraged those in the OEP group to perform their exercises three times per week.

Statistical Analysis

Data were analyzed using SPSS (Windows Version 15.0, SPSS, Inc., Chicago, IL) and SAS (version 9.1, SAS Institute, Inc., Cary, NC). All analyses were "full analysis set"[37] (defined as the analysis set that is as complete as possible and as close as possible to the intention-to-treat ideal of including all randomized participants).

Descriptive data are reported for variables of interest. Between-group differences in physiological falls risk (PPA *z*-score), functional mobility, and executive functioning were compared using forced-entry multiple linear regression analysis. In these models, baseline scores and experimental group were included as independent variables in the models. This analysis procedure provides a more precise indication of the treatment effect than provided by group by time analyses of variance.[38] The overall alpha was set at $P \leq .05$.

The incidence of falls over a 12-month observation period between the two experimental groups was compared using negative binomial regression[39] and the 95% confidence interval (CI) for the incidence rate ratio. It was specified a priori that these models would be adjusted for age, sex, falls clinic physician, and whether the index fall resulted in presentation to the emergency department.

RESULTS

Participants

In this randomized controlled trial, 74 participants recruited over 19 months represented 41% (74 of 179) of those eligible for the study. Of those 74, two were excluded from neuropsychological testing; one had cerebral palsy, and the other had moderate stroke-related impairments. Of the remaining 72 participants, 59 (31 OEP group and 28 control group) agreed to partake in the standard neuropsychological testing sessions. Of these 59 participants, two individuals were unable to complete the baseline neuropsychological assessment session because of anxiety and inattention. At the 6-month follow-up session, one of the 59 participants had dropped out, three had died, and one could no longer complete the neuropsychological testing because of visual impairment (macular degeneration that progressed rapidly). Thus, 52 of the 74 participants completed both of the neuropsychological testing sessions (28 OEP group and 24 control group; Figure 1).

The mean baseline age $\pm$ standard deviation of the 59 participants was 82.2 ± 6.3. This is comparable with the mean age of the entire cohort, which was 82.5 ± 6.4. Baseline demographic and clinical characteristics of the 59 participants at baseline are shown in Table 1. The median, rather than the mean, is reported for the PASE score and TUG time. In both groups, the variability of the PASE score was substantial—standard deviations of 50.1 and 41.0 for the OEP and control group, respectively. For TUG time, one participant of the control group required 75 seconds to complete the TUG at baseline.

Guideline Care Recommended

There were no significant differences between the two groups in clinical care recommendations and treatments. The most frequent treatments prescribed by the geriatricians at the patients' first appointments were vitamin D (14 in OEP; 17 in control) and exercise for balance and gait impairments (20 in OEP; 20 in control). However, based on the data extracted from the geriatricians' reports at 6 months and 1 year, no participants in the control group took up the recommendation to exercise. No patients were prescribed anticholinesterase inhibitors, and none were taking medications known to alter cognitive function.

Table 1. Baseline Demographic and Clinical Characteristics for the Otago Exercise Program (OEP) Group and CON Group (N = 59)

Characteristic	OEP Group (n = 31)	Control Group (n = 28)
Age, mean ± SD	81.4 ± 6.2	83.1 ± 6.3
Female, n (%)	22 (71.0)	19 (67.8)
Height, cm, mean ± SD	161.0 ± 9.1	161.3 ± 9.4
Weight, kg, mean ± SD	67.9 ± 15.8	67.2 ± 11.5
Living status, n (%)		
Alone	18 (58.1)	13 (46.4)
With partner	9 (29.0)	10 (35.7)
With family	2 (6.4)	4 (14.3)
Assisted living	2 (6.4)	1 (3.6)
Referral route, n (%)		
Emergency department	20 (64.5)	20 (71.4)
Family physician	11 (35.5)	8 (28.6)
Number of falls in previous 12 months, mean ± SD	1.8 ± 1.5	2.0 ± 1.6
Physical Activity Scale for the Elderly score, median (IQR)	71.0 (43.0, 130.0)	56.5 (33.0, 91.0)
Geriatric Depression Scale score, mean ± SD	2.6 ± 2.1	2.3 ± 2.7
Mini-Mental State Examination score, mean ± SD	28.0 ± 2.0	28.0 ± 1.6
Functional Comorbidity Index Score, mean ± SD	2.5 ± 1.3	2.5 ± 1.8
Comorbid conditions, n (%)		
Diabetes mellitus	5 (16.1)	2 (7.1)
Thyroid condition	7 (22.6)	5 (17.9)
Chronic obstructive pulmonary disease	5 (16.1)	2 (7.1)
Depression	3 (9.7)	5 (17.9)
Eye disease	13 (41.9)	11 (39.3)
Osteoarthritis or rheumatoid arthritis	10 (32.3)	12 (42.9)
Postural hypotension	1 (3.2)	0 (0)
Osteoporosis	15 (48.4)	14 (50.0)
History of stroke	5 (16.1)	5 (17.9)
Peripheral neuropathy	1 (3.2)	7 (25.0)
Other neurological disease or condition	6 (19.3)	3 (10.7)
Coronary artery disease	9 (29.0)	5 (17.9)
Congestive heart failure	1 (3.2)	1 (3.6)
Valve disease	5 (16.1)	3 (10.7)
Arrhythmia	9 (29.0)	3 (10.7)
Peripheral vascular disease	1 (3.2)	2 (7.1)
Hypertension	22 (71.0	17 (60.7)
Medications		
Number of medications, mean ± SD	5.3 ± 3.1	4.9 ± 3.2
Selective serotonin reuptake inhibitor, n (%)	6 (19.3)	1 (3.6)
Tricyclic antidepressant, n (%)	1 (3.2)	3 (10.7)
Other antidepressant, n (%)	1 (3.2)	1 (3.6)
Long-acting benzodiazepine, n (%)	0	1 (3.6)
Short-acting benzodiazepine, n (%)	7 (22.6)	6 (21.4)
Non-benzodiazepine hypnotic, n (%)	2 (6.5)	2 (7.1)
Neuroleptic, n (%)	0	0
Antiepileptic, n (%)	1 (3.2)	3 (10.7)
Narcotic, n (%)	3 (9.7)	4 (14.3)
Other central nervous system–acting medication, n (%)	6 (19.3)	4 (14.3)
Cardiovascular medication, n (%)	21 (67.7)	20 (71.4)
Vitamin D, n (%)	8 (25.8)	9 (32.1)
Calcium, n (%)	8 (25.8)	10 (35.7)
Bisphosphonate, n (%)	11 (35.4)	12 (42.9)
Timed Up and Go time, median (IQR)	13.6 (10.3, 19.1)	14.7 (11.0, 25.5)
Physiological Profile Assessment *z*-score, mean ± SD	2.1 (1.4)	2.3 (1.4)

n (%) = number and percentage of "yes" cases within each group; SD = standard deviation; IQR = interquartile range.

Adverse Events

Two participants in the OEP group reported low back pain associated with the exercises. One resumed exercising, and the other discontinued the exercises.

Adherence to the OEP

Twenty-five percent (7/28) of all participants randomized to the OEP completed the exercise program three or more times per week, 57% (16/28) two or more times per week, and 68% (19/28) at least once per week.

Physiological Falls Risk

The mean values and standard deviations for physiological falls risk (PPA *z*-score) at baseline and 6 months for the 52 participants who completed both the baseline and 6-month follow-up neuropsychological assessment sessions are shown in Table 3. There was no significant between-group difference in physiological falls risk ($P = .98$; Table 2) or in any of the five subcomponents ($P \geq .33$; Table 4) after 6 months.

Functional Mobility

The mean values and standard deviations for functional mobility (TUG time) at baseline and 6 months for the 52 participants who completed both the baseline and 6-month follow-up neuropsychological assessment sessions are shown in Table 2. There was no significant between-group difference in functional mobility after 6 months ($P = .36$).

Table 2. Physiological Falls Risk, Functional Mobility, and Executive Functions at Baseline and 6-Month Follow-Up (N = 52)

	OEP Group (n = 28)		Control Group (n = 24)	
	Baseline	Six Months	Baseline	Six Months
Outcome Measures	Mean ± Standard Deviation			
Physiological Profile Assessment *z*-score	2.0 ± 1.3	1.9 ± 1.2	1.9 ± 1.3	1.9 ± 1.2
Timed Up and Go Test, seconds	14.2 ± 4.6	13.6 ± 4.3	17.4 ± 10.4	18.1 ± 10.5
Trail Making Test Part B, seconds	222.4 ± 200.1	203.1 ± 262.3	224.7 ± 106.4	232.9 ± 127.1
Verbal Digits Backward Test (maximum 14 points)	3.8 ± 2.0	3.9 ± 2.3	3.1 ± 1.8	2.8 ± 1.8
Stroop Color-Word Test, seconds	157.6 ± 83.0	137.4 ± 49.5	151.7 ± 44.0	167.2 ± 103.4*

* Significantly different from Otago Exercise Program (OEP) group at $P = .05$.

Central Executive Functions

The mean values and standard deviations for the test measures at baseline and 6 months for the 52 participants who completed both the baseline and 6-month follow-up neuropsychological assessment sessions are shown in Table 3. There was a significant between-group difference in response inhibition (i.e., Stroop Color-Word Test; $P = .05$). Specifically, the OEP group demonstrated 12.8% improvement, and the control group demonstrated 10.2% deterioration in response inhibition. There were no significant differences between the two groups in set shifting and working memory after 6 months ($P \geq .09$).

Falls

Sixty-seven percent of the standard care group and 43% of the OEP group fell at least once (Table 4). Using negative binomial regression, the unadjusted and adjusted incidence rate ratios of falls in the OEP group compared with the control group were 0.65 (95% CI = 0.25–1.70) and 0.68 (95% CI = 0.26–1.70), respectively.

A falls histogram revealed two outliers. These two participants experienced at least 18 falls each over the 1-year period of observation. Clinically, one participant was suspected of having carotid sinus syndrome, and one patient had severe residual effects from a previous stroke that resulted in right foot scuffing and repeated falls over a step at home. With these cases removed, the unadjusted incidence rate ratio of falls in the OEP group compared with the control group was 0.56 (95% CI = 0.26–1.2). The adjusted incidence rate ratio was 0.47 (95% CI = 0.24–0.96).

DISCUSSION

It was found that the OEP, a home-based resistance and balance training program that has been shown to reduce falls,[13,14,40] also significantly improved executive functioning, specifically response inhibition, after 6 months. To the authors' knowledge, this study is the first to demonstrate that an exercise program aimed at reducing falls can significantly benefit executive functioning in older adults with MMSE scores of 24 or greater.

Although previous intervention have improved physiological functions and reduced falls,[13,14] the novelty of the current study is the indication that an exercise program, the OEP, may reduce falls by improving cognitive performance. The OEP reduced the incidence of falls in the OEP group by 47% after 1 year even though it did not significantly reduce physiological falls risk (PPA *z*-scores) and improve functional mobility (TUG) after 6 months. Although not statistically significant, the OEP group demonstrated a mean 5% improvement in PPA *z*-scores, whereas the control group demonstrated a mean 0% change. It is conceivable that, in frail older adults such as the participants in the study, a 5% improvement in PPA *z*-scores may reduce the incidence of falls. If a 5% improvement in the PPA *z*-score represents a clinically significant change, a minimum sample size of 236 persons (118 per study arm) would be required to detect this between-group difference. In addition, in the meta-analysis

Table 3. Physiological Falls Risk Subcomponents at Baseline and 6-Month Follow-Up (N = 50)

	Otago Exercise Program Group (n = 27)		Control Group (n = 23)	
	Baseline	Six Months	Baseline	Six Months
Physiological Profile Assessment Subcomponents	Mean ± Standard Deviation			
Edge contrast sensitivity, dB	20.2 ± 2.1	20.4 ± 2.2	20.6 ± 1.8	20.1 ± 2.2
Hand reaction time, ms	304.9 ± 74.4	313.9 ± 70.4	309.5 ± 65.6	306.5 ± 68.8
Proprioception, °	2.1 ± 1.5	1.4 ± 1.3	2.3 ± 1.4	1.7 ± 1.4
Dominant quadriceps strength, kg	21.7 ± 9.5	22.0 ± 10.0	21.3 ± 9.6	21.3 ± 7.5
Postural sway, mm	360.3 ± 318.8	305.7 ± 204.1	285.2 ± 230.1	289.6 ± 203.3

Table 4. Proportion of Participants Experiencing One or More Falls over the 1-Year Observation Period (N = 52)

Number of Falls	Otago Exercise Program Group (n = 28)	Control Group (n = 24)
	n (%)	
0	16 (57.1)	8 (33.3)
1	7 (25.0)	7 (29.2)
2	1 (3.6)	5 (20.8)
3	2 (7.1)	0
≥4	2 (7.1)	4 (16.7)

n (%) = number and percentage of "yes" cases within each group.

of the four previous randomized controlled trials of the OEP, falls were significantly reduced 35%, whereas postural sway significantly improved only 9%, and there was no significant improvement in knee extension strength.[40]

The data from the current study may raise the question of whether the PPA is a sensitive tool to detect change in physiological falls risk factors in older adults who attend a falls clinic service (i.e., who are at high risk of falls), but the instrument has been used in studies in which it detected significant changes.[34,41] Specifically, in women aged 75 to 85 with low bone mass, a 6-month supervised agility training or high-intensity strength training program reduced participants' PPA *z*-scores (i.e., reduced physiological falls risk) 48% and 58%, respectively.[41] The participants in that study had mean baseline PPA *z*-scores that were similar to those of participants in the present study (i.e., 2 standard deviations greater risk for falls than normal for a 65-year-old).

It was found that the OEP significantly improved the executive process of response inhibition by 12.8%. Current evidence suggests that the executive function of response inhibition is highly relevant to falls prevention.[4,7,42,43] In a prospective study of inpatient falls in an urban rehabilitation hospital, performance on the Stroop Color-Word Test accounted for unique variance in falls beyond that explained by age and functional motor ability.[7] One study[42] also demonstrated that response inhibition was a significant determinant of successful obstacle avoidance; tripping is an important factor in a large percentage of falls. When considered together, the results of these studies and the current one strongly suggest that executive functioning—specifically response inhibition may moderate, in part, the influence of physiological impairment (muscle weakness and poor balance) on falls.

In recent years, there has been a strong interest in physical activity as a primary behavioral prevention strategy against cognitive impairment. As a modifiable risk factor, physical inactivity has been implicated in a variety of chronic conditions, including cognitive decline.[44] Most prospective intervention studies in this research area have focused on aerobic training—in animal studies[45–47] and human studies.[48–50] Animal and human studies suggest that aerobic-based physical activity may promote cognitive health through the enhancement of brain structure and function.[45–50]

The primary focus of the OEP is to improve muscular strength and balance; it does not have a specific aerobic-training component. However, resistance training may also benefit cognition[12] by increasing levels of insulin-like growth factor 1 (IGF-1)[51] and reducing serum homocysteine.[52] IGF-1 promotes neuronal growth, survival, and differentiation and improves cognitive performance.[53] Higher homocysteine levels are associated with impaired cognitive performance,[54] AD,[55] and cerebral white matter lesions.[56] In a 2-year prospective study, high homocysteine levels and increases in homocysteine levels were associated with poorer neuropsychological functioning in otherwise cognitively intact older adults.[57] One study[58] recently demonstrated that moderate- and high-intensity resistance training significantly improved cognitive function, as measured using standard neuropsychological tests, in men aged 65 to 75 after 6 months of training. They also demonstrate that IGF-1 serum levels were higher in the resistance training groups than in the control group.

Results from animal studies suggest that balance or agility training exercises also benefit cognition. For example, one study[47] demonstrated that rats exposed to nonaerobic motor skills (e.g., obstacle courses) had a larger number of synapses in the cerebellum than those that were exposed to extensive physical exercise (i.e., running on activity wheel) and those that were inactive. The results of the current study support the hypothesis that other types of exercise training, such as resistance and balance training exercises, may benefit cognitive function, even in frail older adults with a history of falls.

In addition to the home-based resistance and balance training exercises, the OEP protocol includes twice-weekly walks. Results from large prospective cohort studies indicate that regular participation in low-intensity physical activity, such as walking, is associated with a lower risk of dementia[59] and with better cognitive performance in older adults.[60] Thus, the walking component of OEP may have also contributed to the improvement in cognitive performance observed in this study.

Although the OEP significantly improved response inhibition, it did not improve set shifting or working memory. However, although not statistically significant, the OEP group demonstrated an 8.7% improvement in set shifting and 2.6% change in working memory. This is compared with 3.6% and 9.7% deterioration in set shifting and working memory, respectively, in the control group. More research is needed to ascertain the specific executive functions that are most pertinent to falls prevention and which of these specific functions are most amendable with exercise.

This small study has limitations. First, it included fewer than 50% of patients who were seen in the falls clinic. Although the rate of recruitment was high for an exercise intervention in this population, we may have recruited the healthier people in a frail population. Thirty-eight percent of the persons who declined to participate declared themselves "too ill" to take part in a study. Second, the study included men and women. Current evidence suggests that exercise-related cognitive benefits appear to be larger for women than for men.[12] The groups were balanced for sex, so there is little risk of the result being confounded, although the effect of group exercise on executive function in older women may have been underestimated. Finally, the study did not provide adequate sample size to ascertain the contribution of the observed change in executive

functioning to the reduction of falls in our participants. To adequately explore this contribution, statistical approaches such as structural equation modeling would be used; structural equation modeling requires large sample sizes, because it permits testing of complex models about relationships among variables (independent, dependent, and mediating). Thus, future studies with large sample sizes are required to provide estimates of the relative importance of factors (i.e., changes in executive and physiological functioning) to the reduction of falls.

In conclusion, a home-based exercise program of resistance and balance exercise program significantly improved the executive function of response inhibition in older adults who presented to a healthcare provider after a fall. This study provides interesting new data toward a hypothesis that effective exercise-based falls prevention programs, such as the OEP, may reduce falls by improving cognitive performance. It is recommended that future exercise interventions for falls prevention include measurement of elements of executive functioning.

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