In this randomized controlled trial (RCT), we compared the effects of 2 different training approaches for community-dwelling elderly. As the elderly face similar situations in daily life, we attempted to develop a seated stepping exercise in DT conditions that could be easily performed indoors. Our pilot research demonstrated that DT walking ability and seated stepping ability in DT conditions are correlated (unpublished data). In addition, since there is no risk of falling from a seated position, participants may safely exert maximum stepping effort. We hypothesized that divided attention in DT conditions would be improved with a seated stepping exercise in DT conditions (DT stepping exercise) to a greater extent than in ST conditions (ST stepping exercise). We expected that the DT stepping exercise would be more effective in improving locomotive performance in DT conditions.

METHODS

Participants

Participants were recruited through public relations magazine advertisements, and had to be community-dwellers of at least 65 years of age. All participants were classified as strongly right-handed according to the Edinburgh Handedness Inventory (10). An initial interview ensured that participants met the following criteria: age 65+ years, community-dwelling, had seen a primary care physician within the previous 3 years, a total score of 24+ on the Mini-Mental State Examination (11), independently ambulatory (could use a cane), willing to participate in group exercise classes for at least 6 months, access to transportation, minimal hearing and vision impairment, and no regular exercise during the previous 12 months. Exclusion criteria were severe cardiac, pulmonary or musculoskeletal disorders, pathologies associated with increased fall risk (i.e., Parkinson's disease or stroke), osteoporosis, and the use of psychotropic drugs. These criteria were assessed through participant interviews. Seventy-eight subjects volunteered to participate; of these, 25 subjects did not meet the inclusion criteria, resulting in a study population of 53 participants. Written informed consent was obtained from each participant in accordance with guidelines approved by the Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1975.

Study design and randomization

This RCT included 53 participants who met the inclusion criteria, randomized into 4 blocks. In this sequence, opaque envelopes bearing group names were numbered and the 53 participants were randomly assigned to the DT group (n=26) or ST group (n=27).

Intervention

All participants received 50-min group training sessions once a week for 24 weeks. Participants were randomly assigned to 1 of 2 training groups: 1) seated stepping exercise in DT conditions (DT group) or 2) seated stepping exercise in ST conditions (ST group). In order to judge the effect of pure DT training, a control group was not assigned in this trial. Each group was trained in a standardized format which included 20 min of moderate-intensity aerobic exercise, 20 min of progressive strength training, and 10 min of flexibility and balance exercises while seated, followed by exercises known to improve muscle strength and balance (12, 13). The aerobic exercise, performed from a seated position, involved movement of the legs, trunk and arms to involve all joint and major muscle groups. Strength training involved progressive resistance exercise involving movement of the legs and trunk against an elastic band. Participants did 2 sets (20 repetitions per set) of exercises on each muscle. Balance training consisted of lateral and anterior-posterior weight shifting (upper half of the body), also performed from a seated position. Participants did 2 sets (10 repetitions per set) of exercise in each direction. Although exercises could be performed while seated, there was emphasis on the importance of performing them in a standing position to improve balance. Physiotherapists made 2 evaluations during the study period, to ensure compliance with exercise protocols. The type, volume, and intensity of the exercises were the same in the two groups.

Both groups were instructed on seated stepping exercises using a standard dining room chair (Fig. 1). Par-

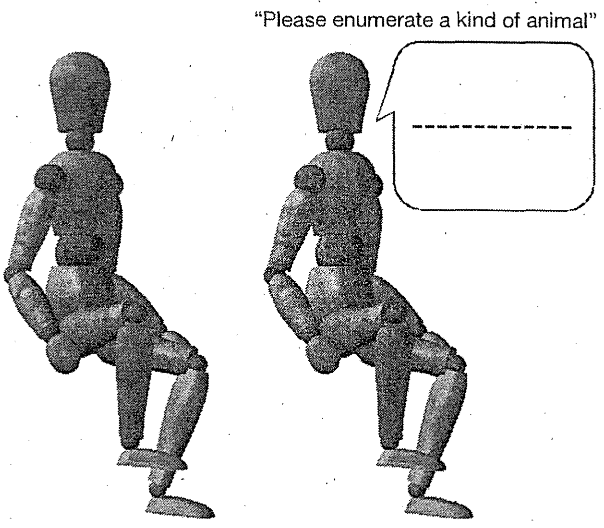

Fig. 1 - *Sketch of seated stepping exercise during dual-task condition. Participants were required to step out with both legs as quickly as possible and return legs to initial starting position. In DT group, participants were asked to perform a verbal fluency task during stepping (DT condition), consisting of enumerating words in a category (e.g., animal name, vegetable name, fruit name, fish name) or letter (e.g., a word that begins with "A") at a self-selected speed. In the ST group, participants were asked to perform stepping only (ST condition).*

ticipants stepped up and down alternating between left and right legs as quickly as possible while returning the legs to the initial starting position. The minimum lifting height for stepping was lifting the plantar surface from the ground. The intensity of the exercise was increased over the 12-week period by increasing the total stepping time. Both groups completed 10 sets of 5 s per set of stepping exercises in weeks 1-12, increasing to 10 sets of 10 s per set in weeks 13-24.

In the DT group, participants were asked to perform a verbal fluency task during stepping (DT condition), consisting of enumerating words within a category (e.g., animal name, vegetable name, fruit name, fish name) or letter (e.g., a word that begins with "A") at a self-selected speed. This task was self-generated; participants did not read from a list, but had to conceptualize and vocalize each word. The verbal fluency task was changed for each exercise session. Participants were not specifically instructed to prioritize either task, but were asked to combine both tasks as best they could. The instructions were as follows: "Please step as quickly as possible, and avoid making mistakes to the best of your ability." In the ST group, participants were asked to step without being given another task (ST condition). During exercises, the amount of stepping and number of terms given during the verbal fluency task were not measured.

Outcome measures

All participants underwent 7 measurements upon entry into the study (pre-test), including: timed up and go (TUG) test (14), functional reach (FR) (15), one-leg stand (OLS), 10-m walk in ST conditions (ST walking) (16), 10 m walk in cognitive-task conditions (CT walking) (17), 10 m walk in manual-task conditions (MT walking), and stepping while seated. After the 24-week period (post-test), they were evaluated by a physiotherapist who was blind to group allocation. All pre-test measures were completed prior to randomization. Before commencing the study, all staff members received training from the author (M.Y.) on the correct protocols for administering all assessment measures included in the study.

TUG is one of the most frequently used tests for balance and gait and is often used to assess fall risk in older adults. During TUG, participants were asked to stand up from a standard chair with a seat height of 40 cm, walk a distance of 3 m at a normal pace, turn, walk back to the chair, and sit down. Time measured in seconds began at the word "go" and ended when the participant's back touched the backrest of the chair. Shorter time intervals required to accomplish this task indicate better balance, strength and power. A practice trial was performed, followed by 2 recorded trials. The recorded times for the 2 trials were averaged to give the TUG score.

In FR, each participant was asked to stand near a wall with one arm raised at 90° and fingers extended. A yardstick was mounted on the wall at shoulder height. The distance covered while reaching forward from an initial upright posture to the maximal anterior leaning posture without moving or lifting the feet was visually measured in cm at the third fingertip position against the mounted yardstick. Distances measured for 2 trials were averaged to obtain the FR score, higher value indicating better balancing ability. FR was measured for both arms in all participants.

In OLS, participants were instructed to start from a position with a comfortable base as support, with eyes open and arms hanging by their sides. They were then instructed to stand unassisted on one leg (left or right, participant's choice). OLS was tested in seconds from the time one foot was lifted from the floor to when it touched the ground or the standing leg, longer times indicating better balance. Times measured for the 2 trials were averaged to obtain the OLS score.

In ST walking, participants walked 15 m at a comfortable speed in normal conditions. The time required to complete 10 m within the 15 m walk was recorded by a stopwatch. The times recorded for 2 trials were averaged for the ST walking score. The variables recorded were time, steps, and cadence (in steps/second).

In CT walking, participants walked 15 m at a comfortable speed while counting numbers aloud in reverse order starting at 50. The importance of simultaneous walking and counting was emphasized to all participants, who were asked to walk and count to the best of their ability without prioritizing either task. Before the test was performed, a trained evaluator gave standardized verbal instructions regarding the test procedure, together with a visual demonstration of the walking test (18). The numbers counted and steps taken were video-recorded. We defined the number of enumerated figures while walking as the number achieved at completion of the 10 m distance. Counting mistakes were not corrected (17). Test-retest reliability with the intra-class correlation coefficient (ICC [1.1]) was 0.978. The times recorded for the 2 trials were averaged to obtain the CT walking score. The variables recorded included time, steps, and cadence (in steps/minute). The CT cost was then calculated as follows:

*CT cost [%] = 100 * (ST walking speed – CT walking speed) / ((ST walking speed + CT walking speed) / 2)*

In MT walking, participants walked 15 m at a comfortable speed while carrying a ball (150 g, 7 cm diameter) on a tray (50 g, 17 cm diameter). The instructions were as follows: "Walk at a comfortable speed while carrying this tray and ball in your left hand (or the hand without a cane)". Dropping the ball or tray was considered as a failure. Before the test was performed, a trained evaluator gave standardized verbal instructions regarding the test procedure, together with a visual demonstration of the test. Test-retest reliability with the intra-class correlation coefficient (ICC [1.1]) was 0.976. The times recorded for the 2 trials were averaged to obtain the MT walking score.

Time, steps, and cadence (in steps/minute) were recorded as variables. The MT cost was then calculated as follows:

$MT\ cost\ [\%] = 100 * (ST\ walking\ speed - MT\ walking\ speed) / ((ST\ walking\ speed + MT\ walking\ speed) / 2)$

For stepping, participants were asked to count backwards from 70, aloud, while stepping from a seated position at 40 cm. They were asked to step as quickly as possible, and the 5-s step total was measured on a 60 × 55 cm step counter sheet (TKK 5301; Takei Scientific Instruments Co. Ltd., Niigata, Japan). We defined the number of enumerated figures while stepping as the number achieved within 5 s. Test-retest reliability with the intra-class correlation coefficient (ICC [1.1]) was 0.988. The number of steps measured for the 2 trials were averaged to obtain the Stepping score.

Required sample size

A preliminary survey for this study showed that the DT stepping exercise produced a large improvement in CT walking time among 15 community-dwelling Japanese elderly (pre-intervention= 12.6±3.4 s, post-intervention= 9.6±2.5 s). With a significance level of 0.05, a power of 80%, and a large effect size (0.9), 21 participants were needed in both intervention and control groups. Accounting for a potential 20% attrition rate, 50 participants were targeted for this study. The number of recruited participants was large enough to detect statistically significant differences.

Statistical analysis

Differences in baseline characteristics were compared between the DT and ST groups by Student's t-test or the chi-square test. The Kolmogorov-Smirnov test and Mann-Whitney U-test were used to evaluate the normality of distributions and differences in baseline characteristics between groups, respectively.

Analysis of covariance (ANCOVA) was used to determine the effect of the exercise program on each outcome measure, with baseline values as covariates. Tukey's *post-hoc* test was used to assess which group or time showed a significant difference. Data were analysed with the Statistical Package for Social Science (Windows version 11.0). A p-value <0.05 was considered statistically significant.

RESULTS

We enrolled 53 of 78 screened individuals (68%) who were eligible for this study. Of those who did not meet the inclusion criteria (n=25), most were excluded because they had exercised regularly for 6 months prior to screening. Three people who may have been eligible declined after a round of telephone screening. Of the 53 subjects, 50 (94%) completed the protocols and returned for their exit interviews and final testing (mean age, 80.8±6.7 yrs; range, 67-97 yrs) (Fig. 2).

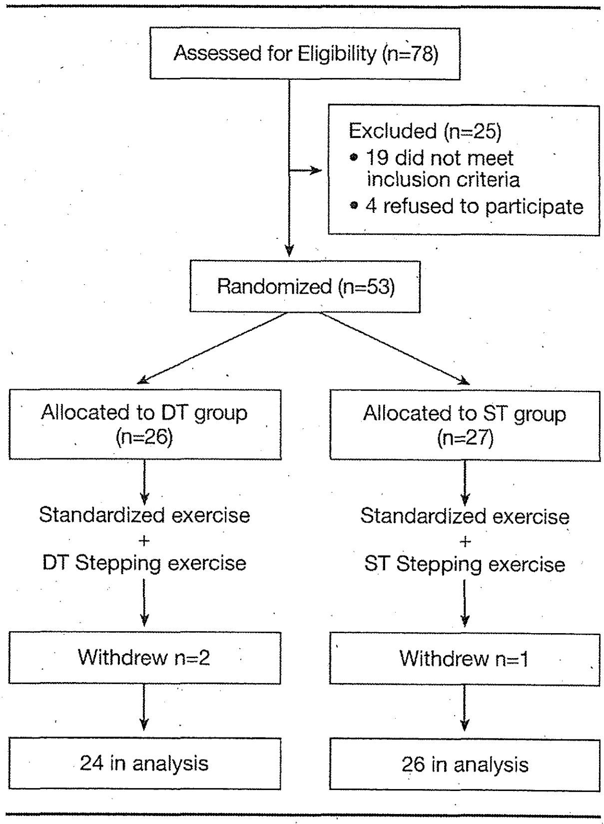

Fig. 2 - *Flow chart depicting participant positions throughout trial.*

All 24 of the scheduled intervention sessions were completed. The median relative compliance was 100% (25th-75th percentile, 95.8-100%) for the DT group and 100% (95.8-100%) for the ST group. No health problems, including cardiovascular or musculoskeletal complications, occurred during training or testing. Minor problems observed in both groups included aching muscles after initial training sessions and fatigue. All problems were easily managed through adjustment of the intervention and improved during intervention.

Baseline characteristics

The Kolmogorov-Smirnov test showed that the weight and MMSE score were not normally distributed. The DT and ST groups were comparable and well matched with regard to their baseline characteristics. No significant differences were noted between group means for age (DT= 80.3±5.4, range 67-97 yrs; ST= 81.2±7.6, range 71-89 yrs; p=0.631), gender distribution (DT= 75.0% female and ST= 76.9% female, p=0.567), body weight (DT= 52.8±6.9 kg, ST= 49.9±8.1 kg; p=0.151), height (DT= 148.1±5.6 cm, ST= 146.6±7.2 cm; p=0.394), walking aids (DT= 12.5%, ST= 34.5%; p= 0.704), fall occurrence within the previous year (DT=29.1%, ST=23.0%; *p*=0.751) or MMSE score (DT= 28.0±2.1 points, ST= 27.8±1.8 points; *p*=0.820).

Effect of exercise program on outcome measures

Pre-intervention and post-intervention group statistics and Group × Time interactions are shown in Tables 1 and 2. Significant differences were observed between the 2 groups for CT 10-m gait speed, CT 10-m walking cadence, CT cost, number of enumerated figures during CT, MT-10 m gait speed, MT-10 m walking cadence, MT cost, quantity of stepping, and number of figures enumerated during stepping with significant Group × Time interactions. Participants in the DT group demonstrated marked improvements in the above test items ($p<0.05$; Tables 1 and 2). Tukey's *post-hoc* test showed significant differences in favor of the DT group in MT 10-m gait speed, 10-m walking cadence, and cost ($p<0.05$).

DISCUSSION

Community ambulation requires the ability to integrate walking with other tasks in a complex environment. DT gait assessment may prove helpful for identifying those individuals with general gait performance difficulty when tested in a complex environment. In the present study, gait performance in DT conditions im-

Table 1 - *Functional fitness (locomotion) before and after intervention.*

	Pre-intervention	Post-intervention		Group × Time F-value p-value
SINGLE-TASK CONDITION				
ST 10-m gait speed, m/sec				
DT group	1.24±0.27 (0.55-1.53)	1.12±0.32 (0.60-1.94)		0.545
ST group	0.95±0.30 (0.57-1.83)	1.00±0.30 (0.62-1.80)		0.464
ST 10-m walking step, steps				
DT group	21.3±4.9 (14-30)	20.8±5.0 (14-30)		2.284
ST group	22.2±5.0 (14-32)	23.0±5.6 (16-38)		0.113
ST 10-m walking cadence, steps/min				
DT group	126.6±15.7 (98.3±158.7)	132.1±17.3 (95.5-162.7)		2.803
ST group	120.1±17.6 (78.8-153.8)	130.4±18.1 (103.7-172.6)		0.101
DUAL-TASK CONDITION				
CT 10-m gait speed, m/sec				
DT group	0.88±0.30 (0.39-1.53)	0.97±0.31 (0.46-1.63)	†	6.509
ST group	0.85±0.30 (0.36-1.69)	0.83±0.28 (0.41-1.68)		0.014*
CT 10-m walking step, steps				
DT group	21.2±4.6 (14-34)	20.3±4.6 (14-32)		0.862
ST group	22.2±4.5 (14-32)	22.1±4.8 (12-32)		0.429
CT 10-m walking cadence, steps/min				
DT group	105.9±22.4 (54.5-142.8)	112.4±21.8 (72.6-157.4)		5.128
ST group	108.3±25.9 (56.5-154.2)	103.5±17.8 (63.4-131.9)		0.027*
CT cost				
DT group	18.5±21.9 (-14.1-72.0)	14.7±17.5 (-11.7-67.3)		7.614
ST group	12.4±21.0 (-16.0-72.0)	22.0±17.5 (-8.8-56.2)		0.008**
CT number of enumerated figures, number/sec				
DT group	1.16±0.24 (0.6-1.6)	1.28±0.34 (0.6-2.0)	†	6.360
ST group	1.19±0.25 (0.6-1.6)	1.17±0.25 (0.8-1.7)		0.015*
MT 10-m gait speed, m/sec				
DT group	1.02±0.28 (0.43-1.54)	1.14±0.30 (0.51-1.69)	†	15.681
ST group	0.99±0.33 (0.40-1.84)	0.95±0.33 (0.54-1.86)	$	<0.001**
MT 10-m walking step, steps				
DT group	21.5±5.7 (14-38)	20.8±5.2 (16-36)		1.732
ST group	22.5±6.9 (14-46)	23.1±6.8 (14-42)		0.195
MT 10-m walking cadence, steps/min				
DT group	124.2±15.8 (95.2-153.1)	134.5±17.9 (101.1-162.1)	†	5.128
ST group	128.7±19.4 (79.4-163.6)	122.1±19.3 (91.3-156.1)	$	0.027*
MT cost				
DT group	2.17±16.45 (-35.8-40.2)	-1.63±9.60 (-25.3-17.6)		10.989
ST group	-2.62±15.66 (-24.3-35.5)	8.13±14.71 (-20.5-28.5)	$	0.002**

Columns indicating pre- and post-intervention values provide mean±standard deviation (minimum - maximum). †As calculated by comparison with pre-intervention values; p<0.05. $As calculated by group comparison; p<0.05. *p<0.05, **p<0.01.

Table 2 - *Functional fitness (other function) before and after intervention.*

	Pre-intervention	**Post-intervention**		**Group × Time F-value p-value**
TUG, s				
DT group	11.3±2.6 (8.0-17.2)	10.8±3.6 (6.8-21.8)		1.575
ST group	12.0±3.3 (6.6-18.4)	12.2±4.5 (5.6-24.3)		0.215
Functional reach, cm				
DT group	25.4±7.4 (8-35)	26.2±7.4 (8-36)		0.023
ST group	24.7±6.2 (11-41)	25.3±6.0 (15-38)		0.881
One leg standing, s				
DT group	7.3±6.8 (1.1-21.3)	8.7±6.0 (1.1-21.3)		0.379
ST group	6.9±8.2 (0.50-28.5)	10.5±17.5 (1.37-59.0)		0.541
Stepping step, steps/5sec				
DT group	25.1±7.7 (10-39)	28.6±7.3 (16-45)	†	10.458
ST group	26.4±10.3 (7-55)	25.0±11.8 (8-55)		0.002**
Stepping number of enumerated figures, number/5sec				
DT group	6.83±2.77 (3-12)	8.12±2.34 (3-11)	†	6.435
ST group	7.39±2.39 (4-12)	7.21±2.18 (3-12)		0.014*

Columns indicating pre- and post-intervention values provide mean±standard deviation (minimum - maximum). †As calculated by comparison with pre-intervention values; $p<0.05$. $As calculated by group comparison; $p<0.05$. *$p<0.05$, **$p<0.01$.

proved after intervention. Therefore, our novel DT stepping exercise program may help improve ambulatory function in the community.

Balance did not improve after intervention, as evaluated by TUG, FR and OLS. In other words, neither standard exercises nor stepping exercises improved balance. TUG is constructed by a number of elements: standing up, walking, turning, and sitting down. A stepping exercise only affects the walking component, not the standing up, turning, or sitting down components, which may account for the lack of TUG improvement. These results suggest that standard and stepping exercises are limited in preventing fall risk.

This study demonstrated significant improvements in walking speed in CT and MT conditions following DT stepping exercise. The reasons for these positive findings remain unclear. However, we used a task-oriented program in this study. Previous research on cognitive-sensory-motor DT situations has shown that older participants decline more in DT-related performance than young adults, and tend to focus their attention more strongly on the sensory-motor task when given two demanding tasks (19). Another explanation may be that traditional exercise regimens emphasize balance training in ST conditions, which may only improve ST functioning. This hypothesis is supported by Silsupadol et al. (20), who found that the elderly can improve their balance in DT conditions only following DT balance training. These outcomes also support the hypothesis of Kramer et al. (9) that improvements in novel DT processing skills can be generalized to other simultaneous tasks which are not directly trained. This suggests that explicit instructions should be provided to focus attention during balance training in DT conditions.

It is important to note that walking speed improved in both CT and MT conditions, despite the use of a cognitive task such as verbal fluency during exercise. This finding suggests that the elderly are able to improve their walking speed in DT conditions only after specific types of training. This in turn suggests that improvement in DT walking may be the result of both automatization of an individual task and the development of task coordination skills. Participants in the DT group may have learned to coordinate performances efficiently between the 2 tasks as they improved in each task (9). These results indicate the importance of instructions given while training in DT conditions. Participants may learn to allocate their limited attention between primary and secondary tasks during the DT stepping exercise. Improvements in division of attention may then influence DT walking ability. This motivates training across different DT modalities (cognitive and manual) to improve divided attention. This study demonstrated that our seated stepping exercise program can improve divided attention in DT conditions. Locomotive speed in a real-life environment is not necessarily fast because the walking speed at examination is fast. The improvement in DT walking speed becomes manifest as increased capacity in a real-life environment.

There are several limitations to this study. First, for the DT group, stepping numbers may have been reduced in comparison with those in the ST group because of the added burden of the secondary task. If the stepping numbers were normalized in the DT and ST groups in training, the DT group may experience further improvement. Second, no follow-up was conducted. Evidence regarding the long-term effects of exercise on fall prevention is poorly understood. Third, statistical analyses were performed for each of the 6 outcome measures, including the physical performance test, which increases the possibility of false-positive findings. Fourth, no control group was enrolled. The participants in both groups may have had greater motivation and interest in health issues and fall risk than the general elderly population.

CONCLUSIONS

This is the first study to examine DT stepping exercise in the elderly. The results suggest that the DT stepping exercise is more effective at improving ambulatory function in cognitive and manual task conditions than when performed in isolation.

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Article

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A four-week walking exercise programme in patients with knee osteoarthritis improves the ability of dual-task performance: a randomized controlled trial

Yoshinori Hiyama[1,2], Minoru Yamada[3], Akira Kitagawa[1], Norihiro Tei[1] and Shuichi Okada[2]

Abstract

Objective: To investigate whether a four-week walking exercise programme in patients with knee osteoarthritis improves the ability of dual-task performance in older adults with knee osteoarthritis.

Design: A randomized controlled trial with two groups: a walking group and a control group.

Subjects: Forty older adults with knee osteoarthritis, 20 participants in each group.

Intervention: The walking intervention was designed to increase the number of steps walked daily. The walking group was instructed to increase their number of steps to 3000 steps more than before the intervention.

Main outcome measures: Dual-task performance was computed by an automaticity index: the walking velocity under single-task condition/under dual-task conditions × 100 (%), defined as automaticity. The nearer to 100% automaticity, the better the dual-task performance. Decrease of the Trail Making Test (TMT) performance was defined as ΔTMT. ΔTMT was calculated as the difference between times (part B–part A) as a measure of executive function. In addition, functional ability was measured by the Japanese Knee Osteoarthritis Measure.

Results: The walking group improved significantly in automaticity ($P < 0.001$, from 75.2 (7.6) to 86.9 (10.4), ΔTMT ($P < 0.001$, from 63.4 (43.1) to 48.3 (29.6)) and Japanese Knee Osteoarthritis Measure score ($P < 0.001$, from 54.4 to 51.9) compared with before the intervention, while the control group displayed no significant differences.

Conclusions: We found that walking exercise improves executive function and dual-task performance.

Keywords

Dual-task interference, knee osteoarthritis, randomized controlled trial, walking

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[1] Anshin Clinic, Chuo-ku, Kobe-city, Hyogo, Japan
[2] Graduate School of Human Development and Environment, Kobe University, Nada-ku, Kobe, Japan
[3] Graduate School of Medicine, Kyoto University, Sakyo-ku, Kyoto, Japan

Corresponding author:
Yoshinori Hiyama, Anshin Clinic: 1-4-12, Minatojimaminamimachi Chuo-ku, Kobe-city, Hyogo, 650-0047, Japan
Email: yoshinori.hiyama@gmail.com

Introduction

Japan faces an ageing society without parallel in the world. Falls are a major health problem among older adults, and in Japan one-fifth of adults aged 65 or older living in the community fall at least once a year. Osteoarthritis, which causes substantial pain and disability, especially in older adults, has been shown to be an important risk factor for falls,[1–3] with more than 50% of people with knee osteoarthritis reporting falling in the past year.[4,5] In Japan, the number of cases of knee osteoarthritis is estimated to be 10 million, and it is thought that many older adults have knee osteoarthritis. Reducing the risk of falls is important for older adults with knee osteoarthritis.

Recent research has suggested that dual-task performance affects gait in older adults. For example, healthy elderly fallers, compared to non-fallers, demonstrate that their cadence, walking speed, stride length and step length are decreased and their stride time, step time and single-support time are longer under dual-task conditions than under single-task conditions.[6] In addition, elderly non-fallers decreased their swing times and their gait speed, fallers decreased their gait speed and the time spent in single support under dual-task conditions than under single-task conditions.[7] In this way, fallers and non-fallers demonstrate different effects on gait variability when they walk under dual-task conditions. Thus, assessment of dual-task performance may be a more sensitive indicator of falls than assessment of performance in a single-task context.[6–8] Although dual-task performance contains cognitive dual-task and motor dual-task aspects and both tasks affect gait in older adults,[6] cognitive dual-task performance, such as walking and talking, are performed simultaneously on a daily basis. Thus, it is important for older adults to improve cognitive dual-task performance in order to reduce the risk of falling.

A few studies have reported that dual-task performance can be improved. For example, training based on static and dynamic balance in dual-task conditions,[9,10] a ball exercise programme based on a dual-task concept,[11] and walking while performing various additional cognitive, manual and triple tasks[12] are effective in improving dual-task performance. Although these training programmes are specific, training programmes to improve dual-task performance should be easy and convenient for older adults. Walking, which is an easy and convenient exercise, not only confers a range of physical health benefits,[13,14] but also reduces pain in people with knee osteoarthritis as well as home-based quadriceps strengthening exercise.[15] In addition, walking has an effect on cognitive function.[16,17] Because it has been reported that dual-task performance is related to cognitive function,[18] we hypothesized that walking may be a good exercise in order to improve dual-task performance. Thus, we examined whether walking has the effect of improving dual-task performance, especially cognitive dual-task performance in older adults with knee osteoarthritis.

Methods

To be eligible for this study, participants had to have knee osteoarthritis, but candidates were excluded if they had: (a) progressive or debilitating conditions (metastatic cancer, major stroke or crippling arthritis) that would limit participation in a walking protocol; (b) pre-existing total knee arthritis or meniscectomy; (c) other musculoskeletal system disorders or secondary osteoarthritis of other joints; (d) rest pain and difficulty increasing the number of steps walked daily; or (e) cognitive impairment as measured by a score on the Mini-Mental State Examination[19] <24 points.

Forty female community dwellers were eligible by the study criteria and took part in this study. They were diagnosed at our clinic as having knee osteoarthritis and the side with more severe knee osteoarthritis was defined as the affected side. Written informed consent was obtained from all participants who met the eligibility criteria.

Participants were randomized to the walking group or to the control group by drawing a sealed envelope from a closed box that initially contained 40 envelopes numbered consecutively from 1 to 40; even numbers were assigned to the walking group and odd numbers to the control group. All of them participated in the measurements before randomization and the end of the four-week intervention.

Global cognitive status was assessed by the Mini-Mental State Examination.[19] This is widely used for dementia screening, and therefore is not described in detail here. It is scored out of a possible 30 points, and a cut-off score ≥ 24 was used as an inclusion criterion in this study.

Executive function was assessed using the Trail Making Test, a well-established psychomotor test originally developed as part of the Army Individual Test Battery.[20] The Trail Making Test consists of two parts: part A is a visual-scanning task, in which the participant is required to draw as quickly as possible lines sequentially connecting consecutively numbered circles (1–25) randomly arranged on a page; part B adds a measure of cognitive flexibility,[21] by asking the participant to connect the same number of circles in an alternating sequence of numbers and letters (1, a, 2, b, etc.). Both parts of the tests are timed. For this analysis, we used a different score defined as ΔTMT, calculated as the difference between times (part B–part A). The ΔTMT score is used to control for the effect of motor speed on TMT performance, and is considered a more accurate measure of executive function than performance on part B alone.[22,23]

Functional ability was measured by the Japanese Knee Osteoarthritis Measure[24] and range of motion of the knee. The Western Ontario and McMaster Universities Arthritis Index (WOMAC) is commonly used as a disease-specific measure for osteoarthritis of the hip and knee,[25] but there is a question as to if it meets Japanese specific circumstances and conditions. The Japanese Knee Osteoarthritis Measure, a self-reported knee osteoarthritis measure that is slightly different from the WOMAC or other widely used scales, has sufficient reliability and validity for studies of clinical outcomes of Japanese people with knee osteoarthritis.[24] It consists of four dimensions: pain and stiffness in knees, condition in daily life, general activities, and health conditions. A total score combining the four dimensions may be used. All Japanese Knee Osteoarthritis Measure data were normalized to a 0–125 scale (best to worst) for each dimension.

The passive range of motion was measured bilaterally for the knee, using a goniometer. This measurement was taken for extension and flexion of the knee.

The effects of dual-task on gait were examined under two conditions: (1) a single-task condition: usual walking with no dual-task; and (2) dual-task conditions: serial 3 subtractions. During the usual walking with no dual-task conditions, participants walked without any secondary task in a 16-m-long, 2-m-wide hallway. During the serial 3 subtraction task, participants walked while reciting out loud serial 3 subtractions, starting from 100 or 50. Before performing the task while walking, this task was conducted while sitting.

Participants were instructed to walk at their self-selected, normal (comfortable) pace under both conditions. The instructions for the dual-task conditions were to walk at a comfortable pace and to perform the additional task simultaneously. No instruction for prioritization of one of the tasks (walking vs. cognitive task) was given. The order of the two conditions was randomized.

Gait time was measured with a stop watch in hundredths of a second as the subject walked in the central 10 m of the walkway. Tape markings on the side of the walkway identified the central 10 m for the examiner. The two trials under each condition were averaged for use in analysis. Participants were able to use customary walking aids if necessary when walking under either condition.

Dual-task performance, defined as automaticity, was computed by an automaticity index.[26] Automaticity is the term used to indicate that a skill is performed with little demand on attentional resources and the walking velocity under dual-task conditions was expressed as a percentage of the walking velocity under the single-task condition. The nearer to 100% automaticity, the better the dual-task performance. In addition, the number of answers was measured to assess how much participants divided their attention to the cognitive task. The two trials were averaged for use in analysis.

The Timed Up and Go Test[27] and tandem walk were performed. Timed Up and Go Test is a simple but commonly used measurement of lower extremity function, functional mobility, and fall risk.[28] Participants were instructed to rise from a chair, walk 3 m, turn around, return, and sit down again. The time was measured with a stopwatch in hundredths of a second.

Tandem gait is commonly used as a measure of balance and fall risk. Participants were required to walk heel to toe along a 10-m line. They were asked to walk as quickly as they could without error. Errors included not walking heel to toe, stepping off the gait line, and losing balance. The time without errors was measured with a stopwatch in hundredths of a second.

The performance time of two trials of each task was averaged for analysis. Participants were able to use customary walking aids if necessary during Timed Up and Go Test and tandem gait.

Peak isometric knee extension and flexion torque (N m/kg) were measured using a μTas dynamometer (MF-01, Anima Co., Ltd., Chofu, Tokyo, Japan). Participants sat with their hands in their laps, on a chair designed to stabilize the body and minimize synkinetic movements. The knee joint was held at an initial angle of 90 degrees, and peak torque was estimated as the product of force and the distance between the attachment of the dynamometer (at the lateral malleolus) and the centre of rotation of the knee joint. Two attempts were allowed, and the larger measurement of the two was recorded. The intraclass correlation coefficients were satisfactory for both movements (ICC (1, 1) = extension: 0.912, flexion: 0.954).

All the outcome data was collected by the investigator who did not know which group a participant was in; in other words, all the outcome assessment was masked.

Participants in both the walking and the control groups attended physical therapy once a week, and they received ice therapy, range of motion exercises and muscle strengthening exercises at home every day. Furthermore, the walking group was asked to increase the number of steps walked daily. Before baseline assessments, the number of steps walked daily was recorded with a pedometer for a week. The walking group was instructed to increase their daily steps to 3000 more than their number of steps (median) before baseline assessments. It was thought that participants might to be concerned about experiencing an exacerbation of pain due to increasing their number of steps, so we told participants that walking is beneficial to physical health and furthermore that walking reduces pain and disability from knee osteoarthritis,[15] and these instructions were accepted. The period of the intervention was four weeks, and the number of steps was recorded every day. The number of steps was measured by pedometer (KenzLifecoder EX, Suzuken Co., Ltd., Nagoya, Aichi, Japan). Participants wore the pedometer on a waist belt at all times except when at home. The period of measurement was for one week before baseline assessments and four weeks of intervention.

Chi-square tests and Mann–Whitney *U*-tests were used for baseline comparison. Two-way analysis of variance (ANOVA) was performed on each dependent variable to determine those which possessed significant variance. If two-way ANOVA showed significant interaction for each variance, a Scheffe's post hoc test was used to identify the specific mean differences. Statistical significance was accepted at a *P*-value of 0.05 level of confidence.

Results

Forty-three participants were recruited into the study, and 40 fulfilled the inclusion criteria. Figure 1 shows the flow diagram for this study.

The walking group walked 4381 (median) steps daily, and the control group walked 4425 (median) steps daily. Data of baseline assessments is shown in Table 1. No participants

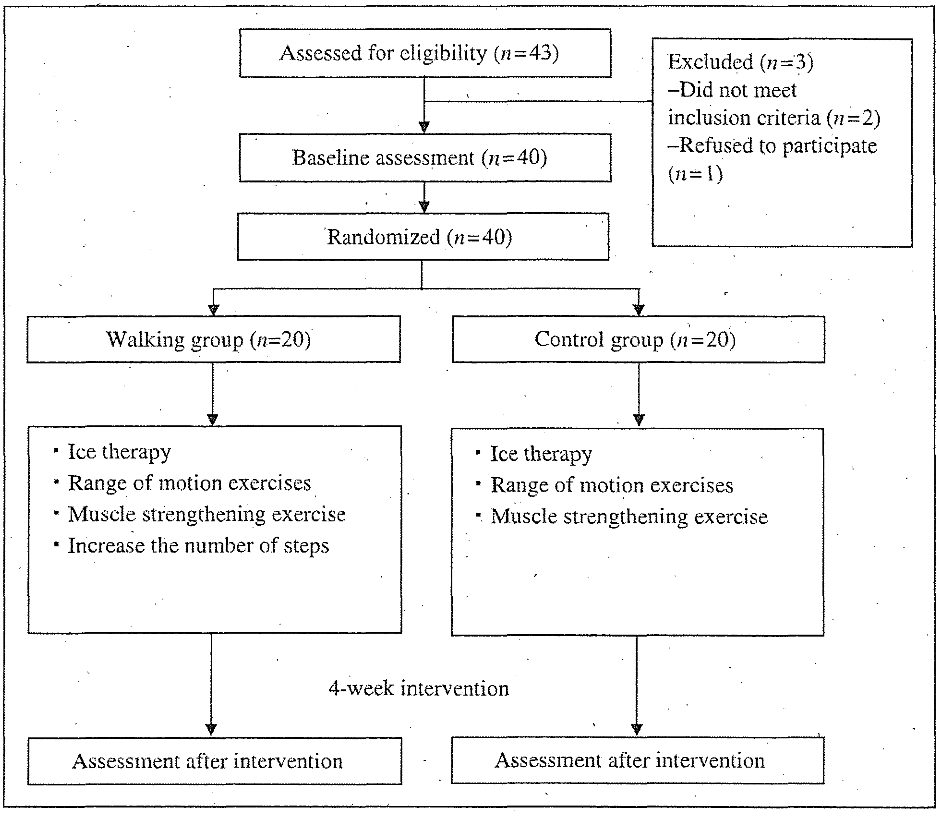

Figure 1. Flow diagram describing participants' progress throughout this study.

Table 1. Characteristics of patients at baseline

	Walking group ($n = 20$)	Control group ($n = 20$)	P-value
Age, years, mean (SD)	71.9 (5.2)	73.8 (5.7)	0.26
Height, cm, mean (SD)	158.6 (3.0)	157.4 (3.5)	0.22
Weight, kg, mean (SD)	60.0 (6.9)	58.7 (6.9)	0.47
BMI, mean (SD)	23.8 (2.2)	23.6 (1.9)	0.85
JKOM, mean (SD)	54.4 (11.9)	57.9 (12.4)	0.23

BMI, body mass index; JKOM, Japanese Knee Osteoarthritis Measure.

dropped out during the intervention period due to exacerbation of pain. No differences between the walking group and the control group were found for any variable at the baseline.

Table 2 shows walking parameters and Table 3 shows knee parameters prior to and after intervention. As an effect of the intervention in walking parameters, two-way ANOVA revealed a significant 'group × time' interaction in the number of steps daily ($F(1,38) = 83.1$, $P < 0.001$), automaticity ($F(1,38) = 23.1$, $P < 0.001$, Figure 2), ΔTMT ($F(1,38) = 17.5$, $P < 0.001$, Figure 3), Timed Up and Go ($F(1,38) = 11.1$, $P = 0.002$) and tandem gait ($F(1,38) = 4.7$, $P = 0.034$), indicating a significantly different pattern of them over the four-week intervention in the two groups. Scheffe's post hoc assessment showed that the control group displayed no significant differences over time in the number of steps ($P = 0.54$), automaticity ($P = 0.95$), ΔTMT ($P = 0.59$), Timed Up and Go ($P = 0.52$) and tandem gait ($P = 0.49$), while the walking group increased significantly their number of steps ($P < 0.001$) and improved significantly on automaticity ($P < 0.001$), ΔTMT ($P < 0.001$), Timed Up and Go ($P < 0.001$) and tandem gait ($P < 0.001$).

Table 2. Walking parameters at baseline and after intervention

	Walking group ($n = 20$)			Control group ($n = 20$)		Interaction effect
	T1	T2		T1	T2	*P*-value
The number of steps	4453 (1734)	7285 (1638)	**	4425 (1627)	4207 (1436)	<0.001
Automaticity	75.2 (7.6)	86.9 (10.4)	**	74.5 (5.2)	74.6 (6.2)	<0.001
Gait time (single-task)	10.4 (1.5)	10.3 (1.6)		10.4 (1.1)	10.5 (1.2)	0.22
Gait time (dual-task)	13.9 (1.4)	12.0 (1.8)	**	13.9 (2.4)	14.2 (2.6)	<0.001
The number of answersunder dual-task conditions	4.8 (1.2)	4.3 (1.5)		4.5 (1.6)	4.7 (18)	0.51
ΔTMT	63.4 (43.1)	48.3 (29.6)	**	58.1 (37.6)	60.3 (30.7)	<0.001
Timed Up and Go	12.9 (2.0)	12.0 (1.5)	**	13.0 (2.1)	13.0 (2.2)	0.002
Tandem gait	12.9 (1.8)	11.8 (1.4)	**	13.4 (1.7)	13.3 (12)	0.025

Data presented as mean (SD), with only the number of steps presented as median (SD) prior to (T1) and after (T2) intervention. *P*-values are given for group × time interaction effect as calculated using a two-way ANOVA. Double asterisk shows a significant difference between T1 and T2 by Scheffe post hoc ($P < 0.001$).

Table 3. Knee parameters at baseline and after intervention

	Walking group ($n = 20$)			Control group ($n = 20$)			Interaction effect
	T1	T2		T1	T2		*P*-value
Range of motion of unaffected side							
Flexion	128 (7)	127 (7)		123 (7)	125 (6)		0.08
Extension	−5 (4)	−4 (4)		−6 (5)	−5 (4)		0.80
Range of motion of affected side							
Flexion	123 (8)	125 (7)		120 (8)	122 (6)		0.977
Extension	−7 (5)	−6 (5)		−8 (5)	−7 (4)		0.99
Torque of unaffected side							
Extension	1.04 (0.14)	1.15 (0.2)	**	1.08 (0.21)	1.14 (0.15)	*	0.83
Flexion	0.64 (0.12)	0.77 (0.15)	**	0.67 (0.13)	0.75 (0.13)	*	0.30
Torque of affected side							
Extension	0.84 (0.15)	0.94 (0.17)		0.81 (0.16)	0.91 (0.18)	*	0.423
Flexion	0.54 (0.11)	0.62 (0.12)	*	0.55 (0.10)	0.61 (0.12)		0.838
JKOM all score	54.4 (11.9)	51.9 (11.3)	**	57.9 (9.3)	57.8 (9.0)		<0.001
JKOM pain/stiffness	19.05 (6.2)	17.5 (5.9)	**	20.9 (6.7)	20.8 (6.3)		<0.01

Data presented as mean (SD), with only the number of steps presented as median (SD) prior to (T1) and after (T2) intervention. *P*-values are given for group × time interaction effect as calculated by using a two-way ANOVA. An asterisk ($P < 0.05$) and double asterisk ($P < 0.01$) show a significant difference between T1 and T2 by Scheffe post hoc.
JKOM, Japanese Knee Osteoarthritis Measure.

As an effect of the intervention in knee parameters, two-way ANOVA revealed a significant 'group × time' interaction in Japanese Knee Osteoarthritis Measure score ($F(1,38) = 11.6$, $P < 0.01$), especially in the score of the domain 'pain/stiffness' ($F(1,38) = 5.9$, $P < 0.01$), indicating significantly different patterns of Japanese Knee Osteoarthritis Measure and the domain

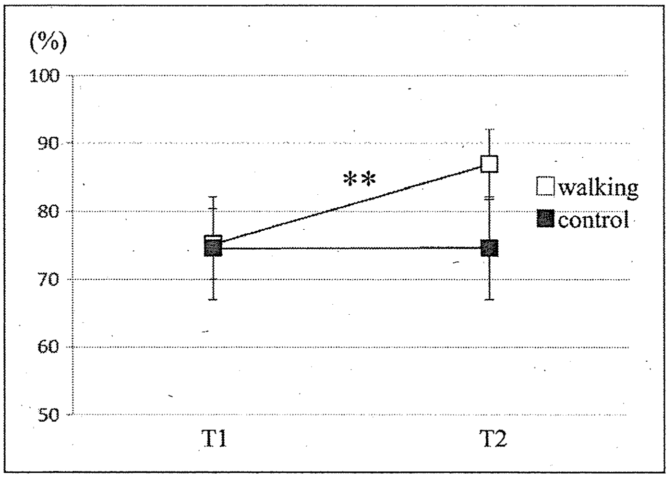

Figure 2. Means and standard deviations for the walking group and the control group prior to (T1) and after (T2) intervention for automaticity. **$P < 0.001$.

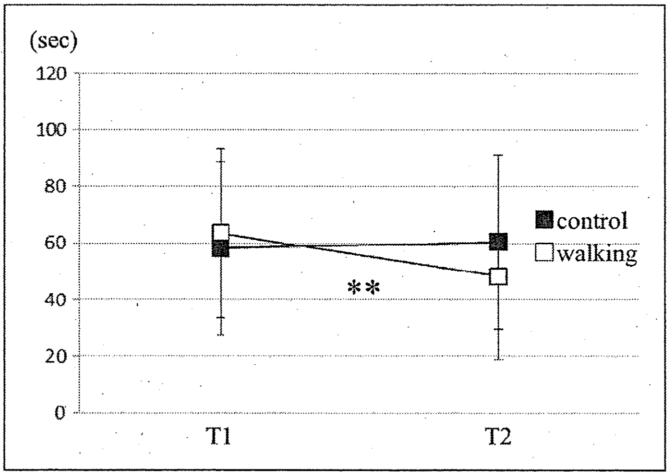

Figure 3. Means and standard deviations for the walking group and the control group prior to (T1) and after (T2) intervention for ΔTMT. **$P < 0.001$.

'pain/stiffness' over the four-week intervention in the two groups. Scheffe's post hoc assessment showed that the control group displayed no significant differences over time in Japanese Knee Osteoarthritis Measure score ($P = 0.81$) and the score of the domain 'pain/stiffness' ($P = 0.22$), while the walking group improved significantly Japanese Knee Osteoarthritis Measure score ($P < 0.001$) and the score of the domain 'pain/stiffness' ($P < 0.001$). Moreover, there was also a significant main effect over the four-week intervention in muscle strength in both the affected side and the unaffected side (extension: $P < 0.01$, flexion: $P < 0.01$), indicating significant improving between prior to and after intervention. Scheffe's post hoc assessment showed that the walking group improved significantly on extension ($P < 0.01$) and flexion ($P < 0.01$) of the unaffected side and flexion of the affected side ($P < 0.01$), and that the control group improved significantly on extension of the unaffected side ($P = 0.03$) and extension of the affected side ($P = 0.04$). Range of motion did not differ significantly between prior to and after intervention.

Discussion

This study demonstrates that walking improves the performance of Timed Up and Go and tandem gait. Timed Up and Go is correlated with levels of functional mobility such as balance and gait manoeuvres used in everyday life,[27] and tandem gait assesses a subject's dynamic balance.[29] It has been reported that long-term exercise involving walking exercise improved postural sway and dynamic balance in older adults.[30,31] Hence, it is thought that walking exercise improved dynamic balance in this study. In this study muscle strength improved and this improvement is perhaps caused not by walking exercise but by muscle strengthening exercise, because two-way ANOVA revealed no significant interaction in muscle strength. Nemoto et al. reported that the change in thigh muscle strength by moderate-intensity walking exercise is small.[32] Moderate-intensity walking exercise is thought to make little contribution to thigh muscle strength, and we think that our walking exercise hardly contributes to improvement in muscle strength. In addition, improvement in muscle strength in this study is very small, so it is thought that gait time under the single-task condition was not significantly improved. In addition, walking exercise did not improve range of motion of the knee. A peak knee flexion angle during walking is about 60 degrees and a peak knee extension angle during walking is about −5 degrees.[33] Participants in this study have enough range of motion which is required for gait, so walking exercise did not contribute to improvement in range of motion of the knee.

We found an improvement in gait time under dual-task conditions, as measured by automaticity and ΔTMT. The Trail Making Test is used to assess executive function, and ΔTMT is considered a more accurate measure of executive function. That is, Trail Making Test performance reflects cognitive function, and improvement of ΔTMT by walking reflects improvement in cognitive function. According to recent research, aerobically trained older adults showed an improvement in cognitive function,[34,35] and this study supports such research. Executive function plays an important role in older adults' ability to adequately allocate attentional resources that are necessary to successfully complete a given task.[36,37] Dual-task performance is thought to have a close relation to executive function. In this study, improvement in cognitive function, particularly executive function by walking exercise, resulted in improvement in dual-task performance.

Furthermore, it is reported that attentional processes during the completion of demanding tasks are interfered with by pain.[38] A specific cognitive mechanism is affected by chronic pain during task performance,[39,40] and knee pain in patients with knee osteoarthritis may also affect cognitive mechanisms. In this study, the walking group reduces knee pain and this result supports previous studies which demonstrated that aerobic exercise, such as walking exercise, reduces pain in people with knee osteoarthritis.[41] Thus reducing pain by walking exercise may contribute to improvement in cognitive function and dual-task performance. Finally, these results suggest that walking exercise improves dual-task performance.

One limitation of this study is that we only used the Trail Making Test to assess executive function. Although this is a widely used test, there are other measures of executive control that in conjunction with the Trail Making Test would have provided a more comprehensive evaluation of executive control functions. A second important limitation was that we could not use functional magnetic resonance imaging or positron emission computerized tomography. Recent research has shown that walking improves cognitive function,[42,43] but in this study it is not clear that walking exercise increased activity in or volume of the brain. A further limitation is the number of participants and gender. The number of participants in this study is quite small and they were all women.

Findings of this study suggest that walking exercise improves executive function and dual-task performance in patients with knee osteoarthritis. Walking exercise is thought to be a good exercise for older adults with knee osteoarthritis in order to improve their ability in dual-task performance. A larger study is needed to show that walking exercise will translate into a reduced rate of falls by improving their motor function, such as Timed Up and Go and tandem gait, and dual-task performance.

Clinical messages

- This study indicates that walking exercise improves dual-task performance by improving executive function and reducing pain in patients with knee osteoarthritis.
- Walking exercise may reduce rate of falls by improving motor function and dual-task performance but a larger study is needed.

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Using a Smartphone while walking: a measure of dual-tasking ability as a falls risk assessment tool

Sir—Falls are relatively common among older people; 30% of 65-year-old community-dwelling adults experience at least one fall per year. Of these falls, 6% result in fractures [1, 2]. Falls typically occur during locomotion; therefore, previous studies have focused on identifying the changes in locomotor performance which occur with increasing age [3, 4].

In every-day life, locomotion typically occurs under complicated circumstances with cognitive attention focused on other tasks. Lundin-Olsson *et al.* [5] reported a novel method for predicting falls based on the dual-task (DT) performance of subjects. In recent years, numerous studies have evaluated DT walking in elderly people. However, Beauchet *et al.* [6] reported that reliable conclusions cannot be drawn from the prediction of falls based on DT results due to the lack of standardisation in DT paradigms. We considered that the two main limitations of the previous research using DT protocols [7–12] were: (i) insufficient evaluation of the performance of the secondary task and (ii) the lack of standardisation of the DT protocols.

The aim of the present study was to evaluate the use of a Smartphone-based application for assessing dual-tasking ability as a tool for predicting the risk of falls in a community-dwelling elderly population.

Methods

Participants

Participants for this study were recruited through advertisements placed in local newspapers. A total of 318 community-dwelling older individuals (mean age, 78.9 [7.3] years) participated in this study. The exclusion criteria ensured that none of the participants had any indications of the following clinical conditions: (i) serious visual impairment, (ii) inability to ambulate independently (those individuals requiring the assistance of a walking frame were excluded), (iii) a score of <7 on the Rapid Dementia Screening Test [13], (iv) symptomatic cardiovascular disease, (v) Parkinson's disease or stroke, (vi) peripheral neuropathy of the lower extremities or (vii) severe arthritis. Written informed consent was obtained from each subject in accordance with the guidelines approved by the Kyoto University Graduate School of Medicine and the Declaration of Human Rights, Helsinki, 1975. Each participant was categorised as either a high-risk (HR) or low-risk (LR) elderly individual on the basis of whether they had experienced at least one fall within the past year (self-reported). A fall was defined as any event that led to unplanned, unexpected contact with a supporting surface during walking. On the basis of this classification, the participants were divided into HR ($n = 90$) and LR ($n = 228$) groups (Table 1).

Smartphone data collection

The Android-based Smartphone Android Dev Phone 2 (HTC Corp., Taiwan) was used as a measurement device. Android is a popular operating system for Smartphones. The phone is lightweight (123 g with battery) and has

Table 1. Characteristics of the participants in the GR and LR groups

Characteristic	HR ($n = 90$) Mean (SD)	LR ($n = 228$) Mean (SD)	P-value	Effect size	95%CI
Age	79.1 (7.4)	78.8 (7.2)	0.733	0.04	−1.41 to 2.00
Height, cm	153.3 (6.7)	153.6 (6.4)	0.703	0.05	−1.81 to 1.22
Weight, (kg)	53.7 (10.2)	54.2 (9.8)	0.695	0.05	−2.78 to 1.86
Gender, female, n (%)	62 (56.3%)	146 (64.0%)	0.435		
ST walking time, s	13.3 (5.3)	11.6 (4.3)	0.001*	0.34	0.70 to 2.87
DT walking time, s	27.8 (28.2)	20.9 (22.9)	0.019*	0.24	1.14 to 12.67
ST android, score	39.7 (14.5)	36.9 (12.5)	0.081	−0.23	−0.35 to 6.09
DT android, score	29.5 (12.4)	34.8 (9.5)	<0.001*	0.56	−7.78 to −2.84
DT time lag, %	52.2 (35.1)	39.4 (32.4)	0.001*	0.36	5.00 to 20.49
DT point lag, %	34.8 (46.4)	3.8 (34.1)	<0.001*	0.67	21.89 to 39.97
DT total lag, %	86.9 (52.6)	42.9 (47.7)	<0.001*	0.84	32.51 to 55.54
TUG, s	15.8 (12.6)	11.8 (5.3)	0.000*	0.32	2.01 to 6.03
One leg standing, s	7.5 (12.8)	10.4 (11.4)	0.046*	0.25	−5.74 to −0.05
FR, cm	21.5 (8.2)	24.5 (9.5)	0.006*	0.32	−5.12 to −0.89
Five-chair stand test, s	12.9 (6.9)	10.7 (4.5)	0.001*	0.34	1.03 to 3.59

*Indicates statistical significance, Student's t-test, $P < 0.05$.

CI, confidence interval; DT, dual-task; ST, single task; DT time lag (%) = 100 * (DT walking time − ST walking time)/ST walking time. DT point lag (%) = 100 * (DT Android score − ST Android score)/ST Android score. DT total lag (%) = DT point lag + DT time lag. TUG, time up and go.

triaxial accelerometers. The use of Android-based applications is advantageous because they are free to develop, offer flexible design options, and can be easily and rapidly distributed over the Internet. The author (K.O.) developed an Android application (RollingBall) for the assessment of fall risk (available for download at http://www.kuhp.kyoto-u.ac.jp/~kazuya/RollingBall.apk) in which a small blue ball (1.5 cm in diameter) is moved on a large white circle (4 cm in diameter) by tilting the phone. The inclination of the phone is determined by the triaxial accelerometers (Figure 1). The Android application also calculates a score based on coordinate data of the ball on the circle; higher scores indicate that the blue ball is nearer to the centre of the circle. The application was based on the 'walking while carrying a ball on a tray' task, previously demonstrated to be a good predictor of falling (Yamada M., unpublished data).

Participants used the application in single- (ST) and dual-task conditions. In the ST condition, participants used the application for 15 s while stationary (ST Android test). The instructions were as follows: 'Using your left hand (or the hand without a cane), please control the Smartphone to keep the blue ball in the centre of the white circle'. The score calculated by the application was recorded as a variable. In the DT condition, the participants walked 15 m at a comfortable speed while using the Android application. The participants were instructed as follows: (i) They should walk at a comfortable speed while positioning and maintaining the blue ball at the centre of the white circle with the left hand (or the hand without a cane). (ii) It was not necessary to constantly look at the Smartphone screen. (iii) The exercise should be performed safely to ensure that no accidents, such as falls, occurred. The score calculated by the application and the time taken to walk 15 m were recorded as variables. Before the tests were carried out, a trained evaluator gave standardised verbal instructions regarding the test procedure and a visual demonstration of the tests. The test–retest reliability, determined using the inter-class correlation coefficient (ICC [1.1]), was 0.976. The tests were performed in a random order. The score under each condition was calculated as an average of the scores obtained from the two trials. The reduction in performance due to walking, the DT lag, was calculated as follows for both the application score (DT point lag) and

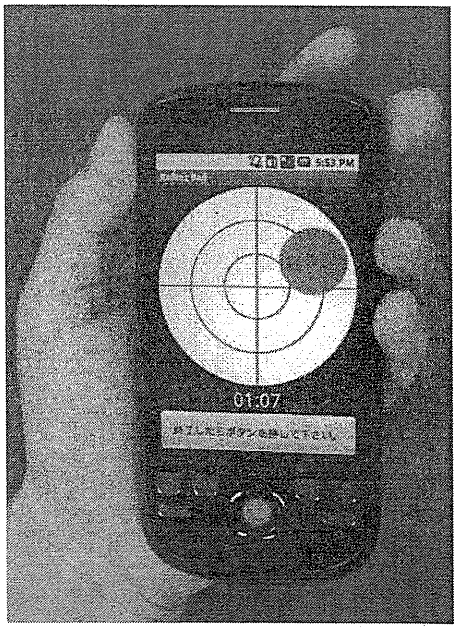

Figure 1. The developed Android application allowed users to control the position of a small blue circle (1.5 cm in diameter) on a large white circle (4 cm in diameter). The score was automatically calculated on the basis of the coordinate tracking data of the blue circle.

walking time (DT time lag) variables [14]:

$$\text{DT lag}(\%) = 100 * \frac{(\text{DT condition} - \text{ST condition})}{\text{ST condition}}$$

The DT total lag was then calculated using the following equation:

$$\text{DT total lag }(\%) = \text{DT point lag} + \text{DT time lag}$$

Data collection for other physical performance tests

In addition to DT walking, the participants were subjected to five other physical performance tests that are widely used to identify HR elderly adults: 10 m walk under an ST condition (ST walking) [15], timed up and go (TUG) test [16], functional reach (FR) [17], one-leg stand [18] and five-chair stand tests [19]. The tests were performed in random order. For each performance task, the participants performed two trials and an average score was calculated.

Statistical analysis

Differences in the physical performance variables between the HR and LR groups were analysed using a Student's *t*-test. To compare physical performance in the two groups, effect sizes were determined. The effect size was calculated as: (HR mean − LR mean)/standard deviation. The relationship between the scores from the Smartphone test and the five previously validated tests was assessed using Pearson's correlation coefficient. All data analysis was carried out in the Statistical Package for Social Science (Windows version 11.0). A *P*-value of <0.05 was considered statistically significant for all analyses.

Results

Descriptive statistics for patient characteristics in the two fall risk groups are summarised in Table 1. Participants in the HR and LR groups were comparable and well-matched in terms of their age, height, weight and gender. With the exception of the ST Android, DT walking time, one-leg standing and FR test results ($P > 0.05$), all physical performance tests demonstrated that the elderly participants in the LR group had significantly better scores than those in the HR group. The largest effect size was the DT total lag in all physical performance tests. The results for DT total lag were weakly, but significantly, correlated with those for ST walking time ($r = 0.267$, $P < 0.001$) and those for the TUG ($r = 0.194$, $P = 0.001$), one-leg standing ($r = -0.195$, $P = 0.001$), FR ($r = -0.202$, $P < 0.001$) and five-chair stand ($r = 0.161$, $P = 0.005$) tests.

Discussion

This is the first study to examine the use of a Smartphone device for DT-based fall risk assessment. The present findings support the conclusion of previous experimental studies that measurement of changes in gait while dual tasking is an effective tool in the clinical assessment of fall risk [7–12]. Several characteristics of the Smartphone application developed here are considered to contribute to increasing the demands on the attention of HR elderly participants during DT walking. First, the application represents a simple manual task (i.e. maintaining a small circle in a central position on a large circle) that participants can easily understand and perform. Second, the application provides the ability to measure performance in both the principal and secondary tasks. This constitutes an improvement over previous DT-related reports, which did not sufficiently evaluate the participants' performance in secondary tasks [7–12]. Changes in physical performance during dual tasking are considered to be due to the competing demands for the participant's attention required to successfully complete both tasks [20, 21]. Therefore, performance in both the principal and secondary tasks needs to be evaluated. The results for DT total lag weakly correlated with those from previously validated physical performance tests. Our results reveal that the Smartphone test evaluates the risk of falls by using a different parameter from that used in previously validated physical performance tests.

In addition to the benefits of the developed Smartphone application as a clinical assessment tool, we assessed whether this application could be used as tool for public health promotion. The Smartphone application has a number of advantages over conventional DT-based fall risk assessment tests. First, it is able to measure performance in both principal and secondary tasks. Second, because the application is downloadable from the Internet, it can be readily accessed and distributed throughout the world. Third, the simplicity and portability of the application permits self-assessment of fall risk by concerned individuals in non-clinical settings. However, there is a serious limitation in this study. The developed Smartphone application could not predict falling in older adults as this study was based on the participants having experienced falls in the previous year.

Key points

- A Smartphone-based application was used to assess dual-tasking ability as a measure of the risk of falls.
- The results for DT total lag weakly correlated with those for previously validated physical performance tests.
- This is the first study to examine the use of a Smartphone device for the assessment of the risk of falling.

Conflicts of interest

None declared.

Minoru Yamada*, Tomoki Aoyama, Kazuya Okamoto,
Koutatsu Nagai, Buichi Tanaka, Tadamasa Takemura
Department of Human Health Sciences, Graduate School of Medicine, Kyoto University, 53, Kawaharcho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan
Tel: (+81) 75 751 3909; Fax: (+81) 75 751 3964.
Email: yamada@hs.med.kyoto-u.ac.jp
**To whom correspondence should be addressed*

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Long-term effect on mortality of a multicomponent cognitive behavioural group intervention to reduce fear of falling in older adults: a randomised controlled trial

SIR—Fear of falling and avoidance of activity due to fear of falling are common in older people. Prevalence rates for fear of falling in community-living older persons range from 20 to 60% [1–8] and for avoidance of activity due to fear of falling from 15 to 55% [1, 6, 7, 9–11]. Fear of falling and related avoidance of activity may lead to adverse consequences, like functional decline [8, 12, 13], restriction of social participation [9], decreased quality of life [2, 8, 12], increased risk of falling [8, 10, 13] and institutionalisation [12]. Indeed, fear of falling is suggested to be a potential health problem of equal importance to a fall [12].

Several interventions showed to reduce fear of falling or to improve confidence regarding performing activities without falling [14]. Particularly two multicomponent cognitive behavioural group interventions explicitly aimed at reducing excessive fall-related fear and unnecessary avoidance of activity showed beneficial outcomes in randomised controlled trials in community-living older people [15, 16]. In the first study confidence in performing activities without falling and mobility range were improved directly and 12 months after a multicomponent cognitive