Effects of walking on falls among community-dwelling older adults

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Effects of walking on falls among community-dwelling older adults

by

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ABSTRACT

Background: Although walking often plays a key role in health promotion programs, the association between habitual walking and falls in previous studies has been inconsistent. The level of frailty or risk of falling of the study participants is hypothesized as an effect modifier in the association between walking and falls. This doctoral thesis consists of findings from four studies that examined the effects of habitual walking on falls among community-dwelling older adults, considering the risk of falling.

Methods: [Study 1] A cross-sectional study with 708 community-dwelling older adults aged 60-91 years (72.3 ± 6.6 yr, 233 men and 475 women). [Study 2] A longitudinal study among 535 community-dwelling older adults aged 60-91 years (73.1 ± 6.6 yr, 157 men and 378 women), with a mean follow-up period of 1.7 (1-5) years. [Study 3] An intervention study among 90 community-dwelling older adults aged 65-79 years. The walking group attended a brisk walking program, and the balance group attended a tai chi, balance, and strength training program, once per week for twelve weeks supplemented by home exercises, and were assessed for physical and psychological fall-related factors. [Study 4] The same 90 participants were monitored for 16 months of fall occurrences, and assessed for fall rate accounting for the amount of exposure to environmental hazards (physically active person-days, person-steps)

Results: [Study 1] Habitual walking was significantly associated with fewer fall history (odds ratio (OR): 0.44, 95% confidence interval (CI): 0.20-0.97) among the lower-risk group, but significantly associated with greater falls (OR: 4.61, 95% CI: 1.32-16.09) among the higher-risk group. [Study 2] Habitual walking was not significantly associated with falls (Hazard ratio (HR): 1.00, 95% CI: 0.53-1.89) among the lower-risk group but that it was significantly associated with increased falls (HR: 2.17, 95% CI: 1.16-4.04) among the higher-risk group. [Study 3] In both groups, significant improvements ($P < 0.05$) over the 12-week intervention were observed in usual/maximum gait speed, timed up and go, 10-m walk over obstacles, 6-minute walk, functional reach, 30-s chair stand, and isometric knee extension force. Only the walking group showed significant increases in the fall self-efficacy (+3.1 ± 8.0 points) and daily step counts (+3366.4 ± 3212.5 steps/day) ($P < 0.05$). [Study 4] The walking group demonstrated a significant reduction in fall risk when evaluated as falls per physically active person-day (rate ratio (RR): 0.38, 95% CI: 0.19-0.77) and falls per person-step (RR: 0.47, 95% CI: 0.26-0.85) compared to the balance group. In contrast, trips significantly increased with walking, even when evaluated as trips per physically active person-day (RR: 1.50, 95% CI: 1.12-2.00).

Conclusion: The findings from this thesis can be summarized as follows: 1) habitual walking significantly increases the risk of falling only among high-risk older adults, 2)

habitual walking can be as effective as traditional strength and balance training in reducing the risk of falling and incidence of falls. A hybrid-type fall prevention program, with population-based approach for the general community-dwelling older people using habitual walking, and high-risk approach using strength and balance exercises may be effective.

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LIST OF ABBREVIATIONS

ADL	Activity of daily living
ANCOVA	Analysis of variance
CI	Confidence interval
HR	Hazard ratio
IADL	Instrumental activity of daily living
ICC	Intraclass correlation coefficient
IR	Incidence ratio
OR	Odds ratio
RCT	Randomized controlled trial
RR	Rate ratio
SD	Standard deviation

CHAPTER 1

INTRODUCTION

1.1. Background

Approximately 30% of the community-dwelling older population experience falls each year (Niino et al., 2003; Tinetti et al., 1988). Falls and fractures are the fifth greatest cause of functional dependency among older adults in Japan (Japanese Ministry of Health, Labour and Welfare, 2010). The fall-related functional dependency are caused by bone fractures (Schwartz et al., 2005), fear of falling (Niino et al., 2000), and restricted activity (Murphy and Isaacs, 1982). In the rapidly aging society in Japan, approximately one in four people are now 65 years old or older (Japanese Ministry of Health, Labour and Welfare, 2013). The number of falls is expected to increase in magnitude as the number of older adults is continued to increase in Japan and worldwide (World Health Organization, 2008). Therefore, effective fall prevention programs that can be implemented on a wide older population are urgently needed.

The Japanese Ministry of Health, Welfare, and Labor (2000) has proposed the nation-wide goal of daily steps (6700 steps for older men, 5900 steps for older women) to promote physical activity and health of older adults in Japan. Walking, which can be implemented regardless of time, location, previous sports experience, or the presence of instructors, is the most prevalent type of exercise (Japanese Ministry of Education, Culture, Sports Science and Technology, 2013; Morris and Hardman, 1997). The

Japanese Cabinet Office (2006) reported that among 3,000 Japanese adults, 44.2% of the respondents had been engaged in at least 30 minutes of walking for twice per week in the previous year.

Since gait deficit has been reported as a predictor of future falls (Suzuki et al., 1999), habitual walking among older adults may prevent future falls by maintaining gait function. However, the reports regarding the effectiveness of walking on fall prevention is limited (Gregg et al., 2000). Rather, a systematic review and meta-analysis of 44 randomized, controlled trials (RCTs) of fall prevention programs reported that inclusion of a walking program had resulted in increased risk of falling among the participants (Sherrington et al., 2008). In fact, the majority of falls in community-dwelling older adults occurred during walking (Berg et al., 1997; Niino et al., 2003). In this regard, Otaka et al. (2003) even called falling as a “side effect” of physical activity such as walking.

Faber et al. (2006) conducted an RCT to provide a walking related exercise intervention and reported a significant increase of falls among the older participants. However, in the subgroup analysis stratified by a frailty index, the significant increase of falls was only observed among the “frail” subgroup, in contrast to a significant fall reduction effect found in the “pre-frail” subgroup (Faber et al., 2006). This study indicates that the walking program for fall prevention can be useful only when the participants are not physically frail and susceptible to falling. However, the walking-related exercise program (e.g., heel/toe stands and walk, walking along a straight line forward and backward) under supervision of experts is distinctly different from habitual walking among community-dwelling older adults. It is important to clarify the effects of habitual walking regularly conducted by the large number of community-dwelling older adults (Japanese Cabinet Office, 2006), and to determine the specific population who would be benefitted by the habitual walking. This knowledge would yield to an important reference for the health promotion and fall prevention strategies using walking as a key component. However, the effects of habitual walking on falls among community-dwelling older adults have not been adequately examined.

1.2. Literature review

1.2.1. Epidemiology of falls

Fractures in the femoral neck (hip fracture) are the most serious consequences of nonfatal falls in older population. The incidence rate of hip fractures increases dramatically in their 70^{s}, especially in postmenopausal women who accompany sudden decline in estrogen and bone mineral density (Figure 1) (Orishige and Kiyomi, 2004). Among those who hospitalized for hip fractures, approximately 25% lost their ability to walk independently (Kikuchi, 1992). The one-year mortality rates of the older adults who suffered hip fractures were 12.7% in the community (Aharonoff et al., 1997) and 58.3% in the institution (Rapp et al., 2008; Schnell et al., 2010).

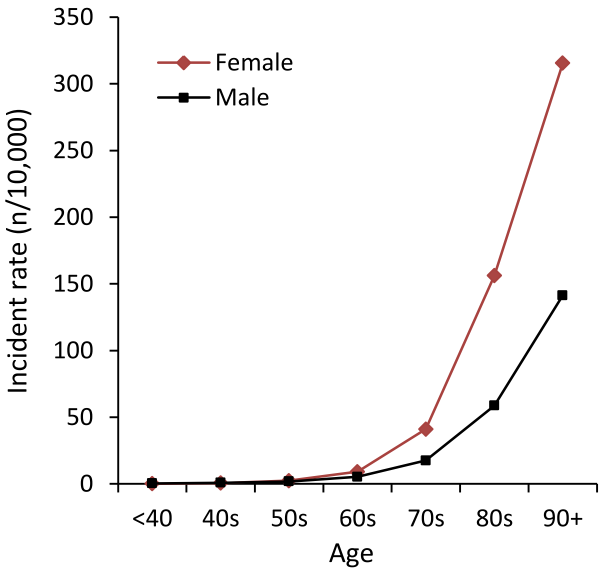

Figure 1. Incidence rate of hip fractures according stratified by gender and age class

Orishige H, Kiyomi S. 2004. The results of the fourth national survey of hip fractures: the estimate of new incidence patients in 2002 and change in 15 years. (article in Japanese) Japan Medical Journal 4180: 25-30.

Siris et al. (2004), investigated the bone mineral density of 149,524 postmenopausal women in the United States, and reported that 6.4% who had baseline T scores of −2.5 or less which correspondent to the World Health Organization definition for osteoporosis. Although fracture rates were highest in these high-risk osteoporotic women, they experienced only 18% of the osteoporotic fractures (Figure 2) and 26% of the entire hip fractures (Siris et al., 2004). The result showed that the majority of fractures occurred among the lower-risk, general older population, and fractures in the high-risk population was limited. It suggested a need of population-wide approaches among the general population, in addition to high-risk approaches.

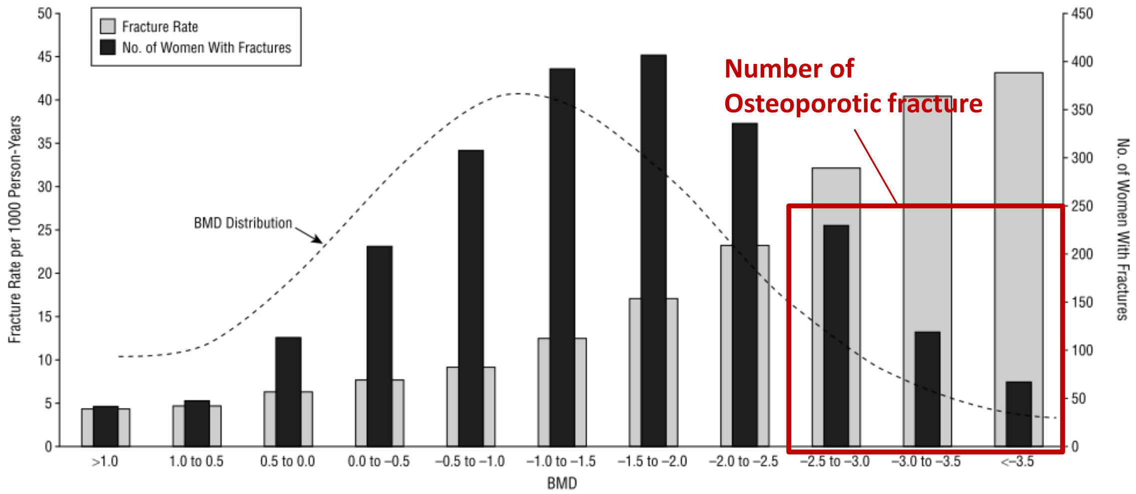

Figure 2. Bone mineral density, fracture rate, and number of women with fractures.
Siris ES, Chen YT, Abbott TA, Barrett-Connor E, Miller PD, Wehren LE, Berger ML. 2004. Bone mineral density thresholds for pharmacological intervention to prevent fractures. Arch Intern Med 164: 1108-12.

Murphy and Isaacs (1982) reported a case of the "post-fall syndrome" of which a patient who experience a fall without injuries as fractures but became unable to walk without support, and became bedridden in hospitals or died within four months after the initial falls. Suzuki (2003) explained the two major pathways which a fall could lead to a bedridden state; (1) directly losing the physical ability by serious injuries as hip fractures, (2) excessive fear of falling leads to restricted daily physical activities, activity of daily living (ADL) and mobility limitation, and physical frailty (Figure 3).

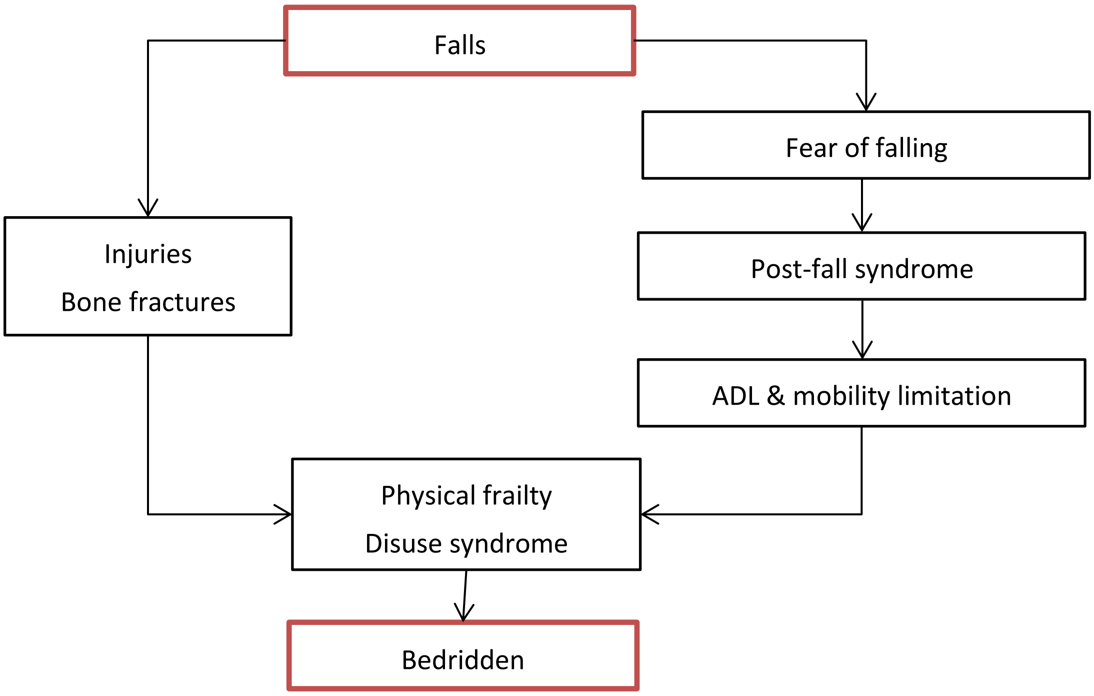

Figure 3. Consequences of falls in older people
Suzuki T. 2003. Epidemiology and implications of falling among the elderly (article in Japanese). Nippon Ronen Igakkai Zasshi 40: 85-94.

Chu et al. (2006) reported that a history of fall was an independent predictor of functional decline in ADL, instrumental activity of daily living (IADL), gait speed, and mobility.

1.2.1. Gait characteristics in older adults

Murray et al. (1969) illustrated the walking postures of older and younger adults (Figure 4). The walking patterns of older adults are characterized as a shortened step length, increased step width, bending hip and knee joints, small arm swing, unsmooth turning, gait initiation, easiness to stagger, and slow gait speed (Murray et al., 1969). The slow gait speed is considered as a consequence of the decreased step length and pace (number of steps per minute). The decreased toe elevation or sliding feet, as a consequence of weakening of the iliopsoas and tibialis anterior muscles were considered to be the major cause of trips (Kaneko, 1990).

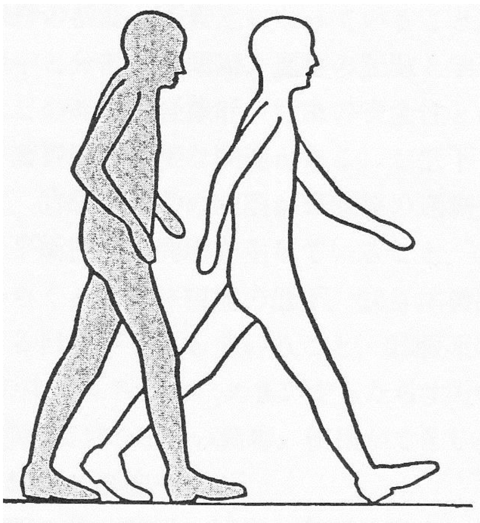

Figure 4. Walking postures of older (left) and younger (right) adults
Murray et al: Walking patterns in healthy old men. J Gerontol 24: 169-178, 1969

1.2.2. Observational studies on falls and walking/physical activity

The association between falls and walking (including general physical activity) has been reported in inconsistent manner in the previous observational studies. Sorock and Labiner (1992) reported that participants who walked 15 blocks (approximately 3 km) or more had 40% non-significantly fewer falls compared to those who walking less than 15 blocks. Several other studies reported significant reduction of falls with physical activity (Graafmans et al., 1996; Tinetti et al., 1995; Tinetti et al., 1988). For instance, O'Loughlin et al. (1993) reported significant reduction of falls with high physical activity. Tinetti et al. (1988) and O'Loughlin et al. (1993) reported the variety of physical activity types were associated with reduction of falls. In contrast, Graafmans et al. (1996) reported that the association between physical activity and falls were vanished after adjusted for mobility limitation. Gregg et al., (2000) in their excellent review, pointed out that the inconsistency of these studies could be regarded to inconsistent definition of physical activity (e.g., subjective assessment, no data of duration). Moreover, even in the studies found significant reduction of falls with physical activity, none of them classified participants into three or more groups, leaving a question regarding the dose-response relationship. Gregg et al. (2000) warned that the association between physical activity and falls should be interpreted with caution because some of those were not adjusted for potential confounding factors such as heavy body weight, medication use, medical history, mobility limitation.

More recently, the quality of the observational studies has been improved in terms of definition of physical activity, grouping, sample size, multivariable analysis. Heesch et al. (2008) classified 8,188 older women into five groups with weekly amount of physical activity, and followed-up for 3-6 years. Heesch et al. (2008) reported that 36% reduction of falls (adjusted odds ratio: (aOR): 0.64, 95% confidence interval (CI): 0.43-0.96) and 47% reduction of fractures (aOR: 0.53, 95% CI: 0.34-0.83) along with moderate-to-vigorous intensity physical activity. Mertz et al. (2010) conducted a longitudinal study with 10,615 adults aged 20-87 years, with classification of four groups of physical activity, and reported that the group with the lowest physical activity level had 70% increase of falls (aOR: 1.7, 95% CI: 1.1-2.7). Although it is important to accumulate these well-designed studies and their evidence, the question still exists regarding the inconsistency of previous findings about the association between falls and walking or physical activity.

Stevens et al. (1997) and Faulkner et al. (2010), in their studies on the association between fractures and physical activity, reported a potential clue to solve the question. Stevens et al. (1997) reported that among older participants without difficulty in ADL, high physical activity was significantly associated with low risk of fractures (aOR: 0.6, 95% CI: 0.5-0.8) but among those with difficulty in ADL, high physical activity was significantly associated with high risk of fractures (aOR: 3.2 ,95% CI: 1.1-9.8) (Stevens et al., 1997). Faulkner et al. (2010) reported that among older women with difficulty in instrumental ADL (IADL), the high physical activity was not associated with falls (RR: 1.06, 95% CI: 0.97-1.16). In contrast, among those with difficulty in IADL, high physical activity was significantly associated with falls (RR: 1.31, 95% CI: 1.14-1.52). In addition, a significant interaction between the high physical activity and difficulty in IADL was reported ($P \leq 0.05$). These results indicated the need to consider the frailty or different levels of risk of falling of the study participants when examining the association between falls and walking or physical activity.

1.2.3. Intervention studies with walking components aiming at fall prevention

In 2008, Sherrington et al. systematically reviewed 44 RCTs (a total of 9,603 participants) to examine the effective components of interventions aiming at fall prevention and conducted a meta-analysis. Sherrington et al. (2008) reported that a challenging balance training, a higher dose of exercise (50 ≥ hours), and not including walking program were the significant factors for the effective fall prevention interventions. In this meta-analysis, inclusion of walking programs significantly increased the falls (pooled rate of rate ratio: 1.32, 95% CI: 1.11-1.58). The results of the included RCTs with a walking program are summarized in Table 1.

However, Karinkanta et al. (2010) argued against the Sherrington's conclusion not to include walking in fall prevention interventions with the following reasons. First, in the meta-analysis by Sherrington et al. (2008), the studies in which older people were exclusively encouraged to walk outside were pooled with studies in which systematic, expert-supervised walking training was used. Second, walking was a more common exercise among the older adults at risk of falls than in the general population. Third, as falls occur mostly during periods of movement, such as walking, running or other physical activities (Nachreiner et al., 2007), training of mobility skills should be emphasized.

Table 1. Results of randomized controlled trials that a walking program or practice was specifically mentioned

First author, year,	Control group falls/ person-year or % Who fell during follow-up period	Data extracted	Sample size at randomization	Follow-up (months)	Estimate of fall rate ratio (95% CI)
Barnett, 2003	0.97	IRR	163	12	0.60 (0.36–0.99)*
Bunout, 2005	0.18	F/PY	298	12	1.22 (0.70–2.14)
Campbell, 1997	1.34	HR-4	233	12	0.68 (0.52–0.90)*
Campbell, 1999	0.97	HR-M	93	10	0.87 (0.36–2.09)
Campbell, 2005	1.13	IRR	391	12	1.15 (0.82–1.61)
Cerny, 1998	0.46	F/PY	28	6	0.87 (0.17–4.29)
Ebrahim, 1997	0.55	F/PY	165	24	1.29 (0.90–1.83)
Faber, 2006	2.5	FR	278	12	1.32 (1.03–1.69)*
Green, 2002	31%	Risk ratio	170	9	1.34 (0.87–2.07)
Hauer, 2001	60%	Risk ratio	57	6	0.75 (0.46–1.25)
Korpelainen, 2006	0.53	F/PY	160	30	0.79 (0.59–1.05)
Lin, 2007	0.88	FR	150	6	0.67 (0.32–1.41)
Lord, 1995	0.63	F/PY	197	12	0.85 (0.57–1.27)
Lord, 2003	0.85	IRR (cl)	551	12	0.78 (0.62–0.99)*
Luukinen, 2007	1.23	HR-M	486	16	0.93 (0.80–1.09)
Madureira, 2007	0.9	FR	66	12	0.48 (0.25–0.93)*
Means, 2005	1.18	FR	338	6	0.41 (0.21–0.77)*
Mulrow, 1994	2.05	F/PY	194	4	1.26 (0.90–1.76)
Nowalk, 2001	75%	Risk ratio	112	24	0.96 (0.63–1.46)
Protas, 2005	37.6	F/PY	18	0.5	0.62 (0.26–1.48)
Resnick, 2002	0.56	FR	20	6	0.71 (0.04–11.58)
Robertson, 2001	1.01	IRR	240	12	0.54 (0.32–0.91)*
Rubenstein, 2000	2.25	F/PY	59	3	0.90 (0.42–1.91)
Schoenfelder, 2000	3.43	F/PY	16	6	3.06 (1.61–5.82)*
Schnelle, 2003	0.69	F/PY	190	8	0.62 (0.38–0.98)*
Toulotte, 2003	1.95	F/PY	20	4	0.08 (0.00–1.37)

IRR = incidence rate ratios from analysis with negative binomial models from trial reports; F/PY = Falls per person-year (by group) were used to calculate rate ratio; rate ratio = rate ratio from trial reports ; FR = fall rates (by group) were used to calculate rate ratios; HR = hazard ratio from Cox models or survival analyses considering time to first fall in trial reports; HR-M = hazard ratio from extensions to Cox models that allow for multiple events from trial reports; HR-4 = hazard ratio from extensions to Cox models that allow for up to four events from trial reports; Risk ratio = risk ratio was calculated from the proportion of fallers in each group; cl = cluster randomized trials.

Sherrington C, Whitney JC, Lord SR, Herbert RD, Cumming RG, Close JC. Effective exercise for the prevention of falls: a systematic review and meta-analysis. J Am Geriatr Soc 56 (12): 2234-2243, 2008.

In 2011, Sherrington et al. (2011) conducted an update of the meta-analysis with 10 additional RCTs, and reported that although the model without walking programs was the most effective in fall reduction, inclusion of walking programs did not significantly increase the risk of falls. In this new version, Sherrington et al. (2011) wrote that walking could be included in fall prevention program if the participants were not high risk of falling.

Otaka et al. (2003) expressed the importance of considering the combination of intervention programs and characteristics of the participants. Of the 44 RCTs which were pooled in the meta-analysis by Sherrington et al. (2011), 29 RCTs recruited participants who were high risk of falling at baseline (e.g., aged care facility residents, aged ≥ 75, impaired strength or balance, previous falls). The majority of the participants included in the meta-analysis were “high–risk” participants such as frail nursing home residents (Mulrow et al., 1994), patients with Parkinson's disease (Protas et al., 2005), osteoporosis (Madureira et al., 2007), stroke (Green et al., 2002), or patients with a recent history of fractures (Ebrahim et al., 1997). Therefore, the high-risk characteristics of those included participants might have modified the effects of walking on falls.

As mentioned above, the association between walking or physical activity and falls had not been consistent. In this doctoral thesis, a hypothesis "Habitual walking increases falls among higher-risk community-dwelling older adults, but prevents falls among general community-dwelling older adults" was made. If this hypothesis was verified, the inconsistency and question from the previous studies would be solved and shed light into a new knowledge in the field of fall prevention.

1.3. Purpose

The purpose of the study was to verify the hypothesis "Habitual walking increases falls among higher-risk community-dwelling older adults, but prevent falls among general community-dwelling older adults."

In order to fulfill this purpose, (1) a cross-sectional and (2) longitudinal study to examine the association between habitual walking and falls among community-dwelling older adults were conducted, considering the different risk levels of the participants. (3) An intervention study to examine the effects of walking on fall-related physical and psychological risk factors among general community-dwelling older adults was conducted. (4) Finally, a year-long follow-up survey for the general community-dwelling older adults to examine the effects of walking on falls was conducted.

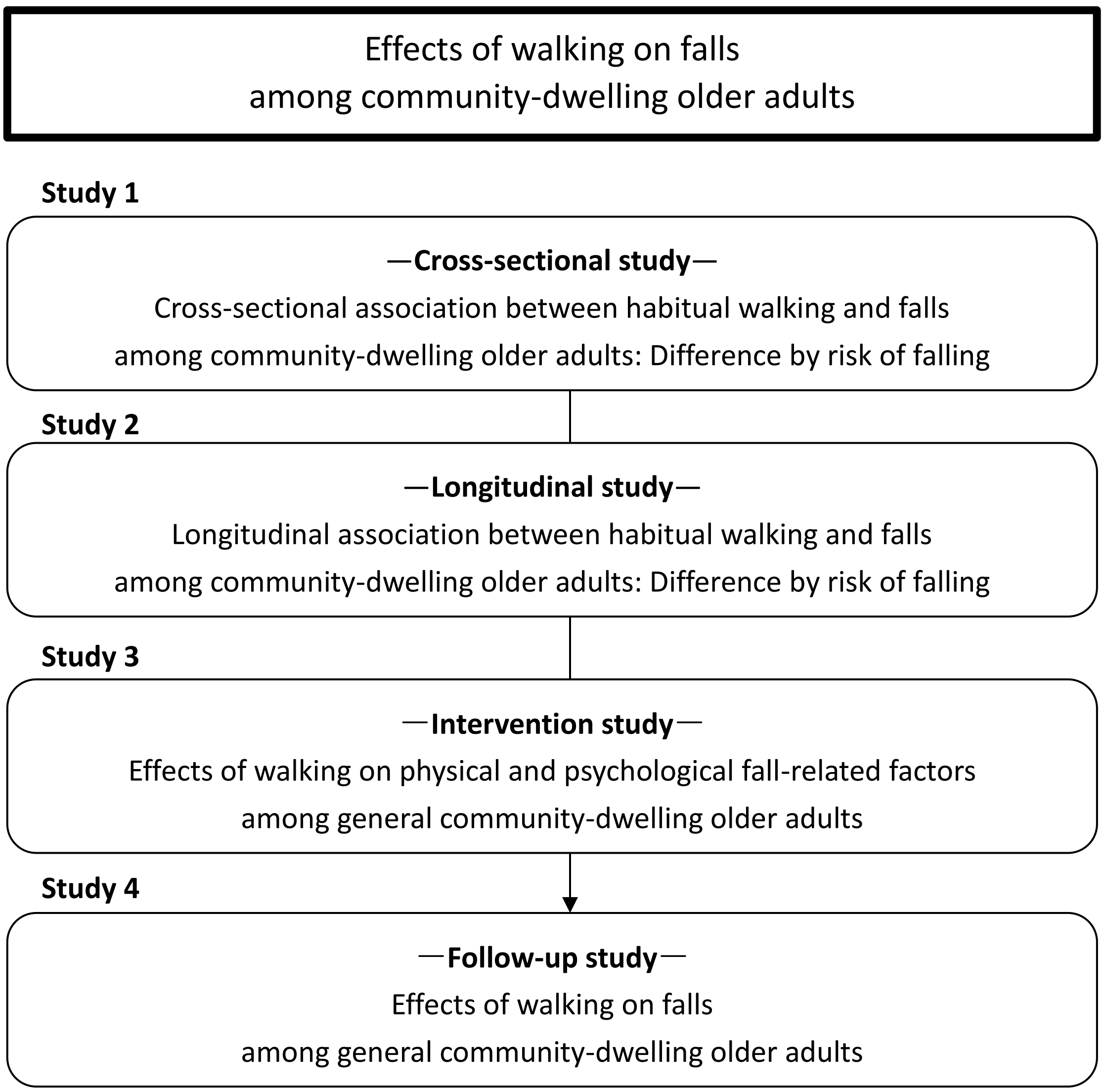

Figure 5. Flow of the studies in the doctoral thesis

1.4. Significance

This thesis would challenge to explain the reason of the inconsistency regarding the association between walking and falls among the previous studies (Gregg et al., 2000; Sherrington et al., 2008) from the perspective of the risk level of the study participants. This would help the progress of the fall prevention research.

Moreover, it is possible to propose walking as fall prevention exercise which can be disseminated in a wide range of general older population. With the baby-boom generation reaching retirement age, the general older population is expected to increase, population-wide strategy will be increasingly important, as well as high-risk strategy which are underway (e.g., secondary prevention policy) (Hayashi and Kondo, 2011; Sherrington et al., 2011). There have been a couple of attempts for nation-wide (Campbell and Robertson, 2010) and community-wide (McClure et al., 2005; Tinetti et al., 2008) fall prevention strategies in overseas. With this in mind, fall prevention strategy using walking, which is the most popular form of exercise, will become more important.

1.5. Definition of terms

1.5.1. Older adults

The World Health Organization (1984) traditionally defined age of 65 years or older as older adults. Most developed countries, including Japan and the United States, have accepted the chronological age of 65 years or older as a definition of elderly or older person. However, there is no consistency among studies as to what demographic group constitutes older adults. The term is used for age-groups starting from as low as 50 years (in countries with relatively short longevity). In Japan, a significant proportion of people retire from their work at the age of 60 years and start a new lifestyle as older population. It is not unusual that health promotion programs for older population held by municipalities accept participants aged 60 years or older. The United Nations stated that "there is no United Nations standard numerical criterion, but the UN agreed cutoff is 60+ years to refer to the older population" (World Health Organization, 2014). Moreover, the Cochran systematic review and meta-analysis of interventions for preventing falls among community-dwelling older adults used the cutoff of 60 years (Gillespie et al., 2012). Therefore, this doctoral thesis operationally defined older adults as people aged 60 years or older.

It should be noted, the term "elderly" had been commonly used interchangeably with older adults in previous literature. However, it is sometimes referred to as an ageism term stereotyping older adults as sick, frail, and physically dependent (Avers et al., 2011). Therefore, use of the term “older adults” was preferred in this doctoral thesis.

1.5.2. Community-dwelling

Community-dwelling means living in one’s home or not being institutionalized. The living environment, functional status, and fall risk factors of community-dwelling older adults are considerably different from those of institutionalized older adults. It is a standard to study community-dwelling (Gillespie et al., 2012) and institutionalized (Cameron et al., 2012) older adults differently. Since, community-dwelling older adults are the target population of primary prevention of functional disability, this doctoral thesis focused on community-dwelling older adults.

1.5.3. Falls

This doctoral thesis defined a fall as “unintentionally coming to rest on the ground, floor, or other lower level due to reasons other than sudden-onset paralysis, epileptic seizures, or overwhelming external forces” (Gibson, 1990). In order to examine the effects of walking on falls, falls during bicycling were excluded.

1.5.4. Risk of falling

A number of studies have identified various risk factors for falling (American Geriatrics Society et al., 2001; Berg et al., 1997; Campbell et al., 1989; Tinetti et al., 1988). These can be categorized into intrinsic (e.g., lower-extremity weakness, poor grip strength, balance disorder, functional and cognitive impairment, visual deficits), extrinsic (e.g., polypharmacy [i.e., four or more prescribed medications]), behavioral (e.g., hurrying too much), and environmental (e.g., poor lighting, loose carpets, and lack of bathroom safety equipment) factors. As people become older, the intrinsic risk factors play more dominant role than the extrinsic risk factors in occurrence of falls (Nickens, 1985; Rubenstein et al., 1994). Therefore, this doctoral thesis focused mainly on the intrinsic risk factors when assessing the risk of falling among older adults.

Although, the strength of association with falls differs among the various types of fall risk factors, it was reported that duplication or co-existence of multiple fall risk factors increases the risk of falling in greater extent (Graafmans et al., 1996; Nevitt et al., 1989; Tinetti et al., 1988; Tinetti et al., 1986). Therefore, in this doctoral thesis, the number of risk factors within an older individual was used to evaluate the different levels of risk of falling.

CHAPTER 2

GENERAL METHODS

2.1. Observational studies

In the Studies 1 and 2, cross-sectional and longitudinal studies were conducted to observe the association between habitual walking, falls, and risk of falling among community-dwelling older adults.

2.1.1. Ethical consideration

We conducted these studies in accordance with the guidelines proposed in the Declaration of Helsinki, and the study protocol was approved by the Ethics Committee of the University of Tsukuba, Japan. The older adults participated in a health check-up with their own will. All participants were explained verbally and by document, regarding the purpose of the study and physical fitness tests, contents of the questionnaire survey, handling of the data including anonymity. It was also clarified that their consent was based on free will and could be withdrawn any time without disadvantage. Confirming these points, the participants provided written informed consent.

2.1.2. Funding

These studies were funded by the Japan Society for the Promotion of Science (Tanaka K., A comprehensive guideline of a primary care physical activity program in older

adults [19200047]).

2.1.3. Settings and participants

Study participants included community-dwelling older adults who participated in a health check-up. These check-ups were organized by municipalities as part of a nursing-care prevention (geriatric health promotion) program in Ibaraki, Chiba, and Fukushima prefectures. The Study 1 was conducted in 2008 and 2009 and the Study 2 was conducted in 2008 to 2012 with follow-ups in 2009 to 2013. Almost all of the participants were recruited through local advertisements and flyers. The eligibility criteria were as follows: (1) community residents aged 60 years or older and (2) individuals who were able to understand the instructions on the performance tests and questionnaires.

2.1.4. Sample size

This sample size calculation was conducted after completion of the Study 1 to determine the number of participants required in the Study 2. To detect significant differences in fall incidences between the walkers and non-walkers (lower-risk: 7.5% and 15%; higher-risk: 25% and 16%) (Okubo et al., 2011, Study 1) with a 5% alpha level and 80% power, a total of 610 person-years (lower-risk: 280 person-years; higher-risk: 330 person-years) was computed as the required sample size.

2.1.5. Measurements

2.1.5.1. Habitual walking

The presence of habitual walking and its duration (min), frequency (times/week), and number of years practiced were ascertained in an interview. The participants were classified as walkers if, for over a year, they walked at least 30 minutes a day twice a week (Japanese Ministry of Health, Labour and Welfare, 2012). Those who walked for shorter periods of time were classified as non-walkers.

2.1.5.2. Fall risk factors

The six items to evaluate fall risk factors were chosen from those in the health check-up, according to the fall prevention guideline (American Geriatrics Society, 2001), and considering the “feasibility” in community and home and “modifiability” by interventions. The fall risk factors chosen were (1) poor balance, (2) mobility limitation, (3) knee pain, (4) depressive symptoms, (5) use of assistive device, and (6) polypharmacy. In the Study 2, (7) previous fall history was added as another fall risk factor. Each fall risk factors were measured in the following methods.

2.1.5.2.1. Poor balance

One-leg stance with eyes opened (Vellas et al., 1997): The participants were instructed to stand with their feet together, placing both hands on their waist, lift their preferred leg from the floor, and keep their balance for a maximum of 60 seconds. The measurement ended until the supporting foot moved, a hand left the waist, or body parts other than supporting foot landed on the floor. The average time recorded to the nearest 0.1 s in two trials was used in analysis. The participants who had an average time of less than 10 seconds were classified as having poor balance.

2.1.5.2.2. Mobility limitation

Difficulty in climbing stairs: The participants who reported difficulty in climbing 10 steps without resting were defined as having a mobility limitation (Guralnik et al., 1993; Seino et al., 2010).

2.1.5.2.3. Knee pain

The participants who experienced knee pain or underwent treatment for knee pain were defined as having knee pain.

2.1.5.2.4. Depressive symptom

Depressive symptoms: The participants who reported "I felt everything I did was an effort" or "I could not get going" during the past week, in The Center for Epidemiological Studies-Depression scale (CES-D), were defined as having depressive symptoms (Fried et al., 2001; Radloff, 1977).

2.1.5.2.5. Use of assistive device

The participants who regularly used a walking cane, walker, or wheelchair were defined as requiring an assistive device.

2.1.5.2.6. Polypharmacy

Participants who were taking four or more medications were defined as polypharmacy (Robbins et al., 1989). The medications included those prescribed by a doctor, and an OTC (over-the-counter) drug, an unregulated drug, and supplement which could be purchased at drugstores were excluded.

2.1.5.2.7. Previous fall history

The participants who experienced an injurious fall or multiple falls within a year prior to the baseline were defined as having a previous fall history (Delbaere et al., 2010b; Okubo et al., 2011).

2.1.5.3. Other measurements

Socio-demographics, anthropometrics, physical performances, lifestyle and psychological factors, and functional status were assessed to describe the characteristics of the walkers and non-walkers. The participants completed self-reported health status questionnaires and received an interview by a staff to confirm the information. The performance tests were measured by trained researchers after the participant's physical conditions were ascertained.

2.1.5.3.1. Socio-demographics and anthropometrics

Age and gender were ascertained during the interview. Body height (cm) and weight (kg) were measured in light clothing without shoes, and body mass index (BMI, kg/m^2) was calculated. The presence of scoliosis was ascertained when measuring the body height.

2.1.5.3.2. Performance tests

2.1.5.3.2.1. Hand-grip strength

Hand-grip strength was measured using a hand-held dynamometer (GRIP-D, T.K.K 5401; Takei Scientific Instruments, Tokyo, Japan). Participants were in a standing position with their arms hanging naturally at their sides. They were instructed and verbally encouraged to squeeze the hand-grip as hard as they could. Grip size was adjusted to a comfortable level for the participant. Participants performed two trials with each hand alternately, and the results were average to the nearest 0.1 kg.

2.1.5.3.2.2. One-leg balance with eyes open

Participants were asked to stand on their preferred leg for a maximum of 60 s, during which they could maintain a one-legged stance with their eyes open in a standard position. The average time recorded to the nearest 0.1 s in two trials was used in analysis.

2.1.5.3.2.3. Tandem balance

Participants stood with the heel of one foot directly in front of the toes of the other foot for a maximum of 30 s. The end point occurred when the participants shifted from the tandem position lifted or replaced a foot, moved a foot on the floor, or touched any object with their hands to maintain their balance (Rossiter-Fornoff et al., 1995). Participants performed two trials with the results averaged to the nearest 0.01 s.

2.1.5.3.2.4. Sit and reach

Participants sat on the flower with their back touching a walk, legs placed forward. The participants placed their palms on the measuring device (T.K.K.5112; Takei Scientific Instruments, Tokyo, Japan), with their elbows and knees being kept straight, and reached forward as fur as possible. The distance was recorded to the nearest 0.5 cm and the average of two trails was used in the analysis.

2.1.5.3.2.5. Functional reach

Participants were asked to stand with their shoulder adjacent to a measuring scale attached to a wall. The participants stood by the wall with their feet apart in their shoulder width, raised their arms to the horizontal line (starting position), reached forward while keeping their arms straight and horizontal (ending position). The distance from the starting position to the ending position of the tips of their middle fingers was measured. The distance was recorded to the nearest 1 cm and the average of two trials was used in the analysis.

2.1.5.3.2.6. Five-repetition chair stand

The chair stand test measures the time to move from a sitting to a standing position 5 times without using the arms. Participants were asked to stand up and sit down on a straight-backed chair 46 cm high as quickly as possible. The time was measured from the initial sitting position to the final fully erect position at the end of the fifth stand (Guralnik et al., 1994). Participants performed two trials, and the results were averaged to the nearest 0.01 s.

2.1.5.3.2.7. Alternate step

Participants were asked to step with alternate legs onto a raised platform. The time it took to place each leg alternately onto a 19-cm high step 8 times was measured (Menz and Lord, 2001). Participants performed two trials, and the results were averaged to the nearest 0.01 s.

2.1.5.3.2.8. Timed up and go

Participants were asked to raise from a 46-cm high chair, walk forward 3 m as quickly as possible, turn 180 degrees, walk back to the chair, and sit down (Podsiadlo and Richardson, 1991). Participants performed two trials with the results averaged to the nearest 0.01 s.

2.1.5.3.2.9. Five-meter usual gait

Participants were instructed to stand with their feet behind and just touching a starting line marked with tape at 0 m and, on receiving the tester’s command, to start walking at their normal pace along a 7-m course. The actual walking speed was measured over 5 m starting with the first footfall past the 1-m mark and ending with the first footfall after the 6-m mark. Participants performed two trials with results averaged to the nearest 0.01 s (Shinkai et al., 2000).

2.1.5.3.2.10. Three-meter tandem walk

The dynamic balance was assessed using the timed forward tandem walk test over a 3-m course that was 5-cm wide (Nevitt et al., 1989). The participants were instructed to place one foot in front of the other, ensuring that with each step the heel of one foot was directly in front of the toes of the other foot. The participants were instructed to walk forward as fast as possible without falling or making a mistake. The time was recorded to the nearest 0.01 s and the average of two trials was used in the analysis. In addition, the number of mistakes was recorded. A composite measure was calculated by summing the time and number of mistakes, with higher scores indicating a worse performance.

2.1.5.3.3. Lifestyle factors

Frequency of field work (day/week), house work (day/week), and outings (day/week) were ascertained during the interview. All behavior to go out of one's home regardless of the purpose or duration was considered as an outing.

2.1.5.3.4. Psychological factors

Fear of falling was ascertained by the question "Are you afraid of falling?" Self-rated health was ascertained by the question "How is your health condition?" in the Japanese version of the 36-item short-form health survey (SF-36) (Fukuhara et al., 1998). The question "In general, would you say your health is ---" and response categories (1) excellent, (2) very good, (3) good, (4) fair, and (5) poor" were used. The responses (1) to (3) were rated as "good" in the analysis.

2.1.5.3.5. Functional status

Tokyo Metropolitan Institute of Gerontology index of competence (TMIG-IC) (Koyano et al., 1991) which consisted of three domains of functional status, instrumental self-maintenance, intellectual activity, and social role, were ascertained during interview.

2.1.5.3.6. Medical history in one year

Medical history for the previous one year including stroke, hypertension, diabetes, heart diseases (e.g., arrhythmia, heart failure, and ischemic heart disease), osteoporosis, and glaucoma/cataract were ascertained during the interview.

2.2. Intervention studies

2.2.1. Study design

In the Studies 3 and 4, intervention and follow-up studies were conducted to examine the short-term (physical and psychological fall-related factors) and long-term (incidence rate of falls and trips) effects of habitual walking among community-dwelling older adults. The study design was a 2-armed intervention trial with a follow-up survey (Figure 6). In an attempt to accomplish both our research purposes and the ethical satisfaction of the study participants (Tanaka and Shigematsu, 2010), an active control group was arranged. The active control group, namely a balance group, received a common fall prevention program (Gillespie et al., 2012) that was substantially different from walking, namely without increasing exposure to environmental hazards. No blinding was applied in study procedure.

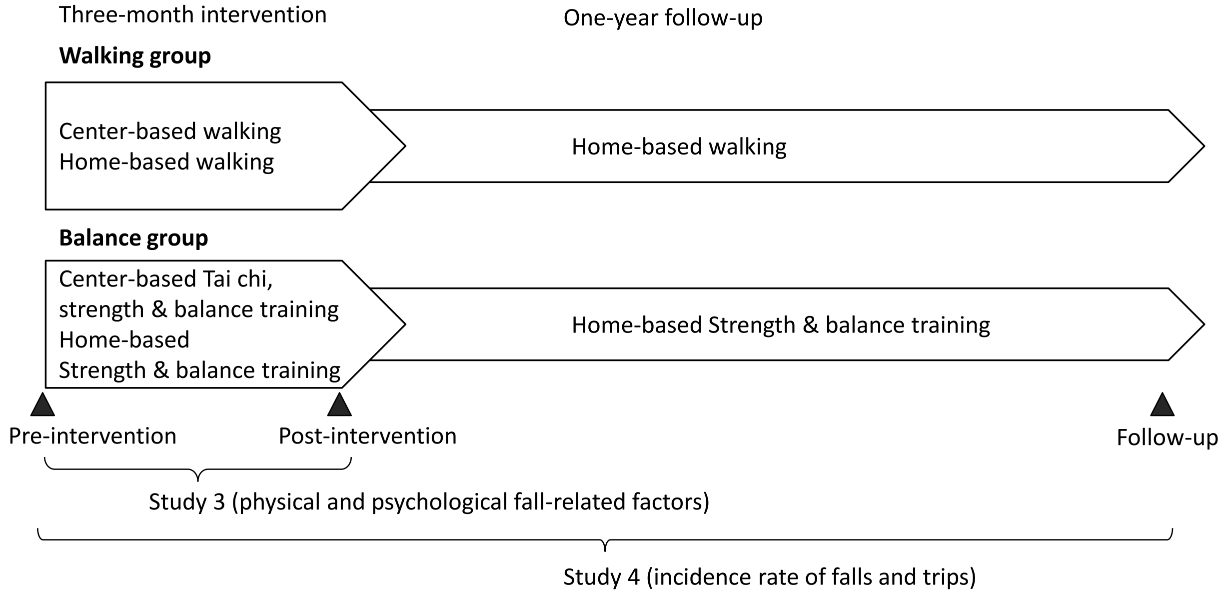

Figure 6. Overall design of the intervention studies

2.2.2. Ethical consideration

The study protocol was developed in accordance with the guidelines proposed in the Declaration of Helsinki and was approved by the Research Ethics Committee of the Faculty of Health and Sport Sciences of the University of Tsukuba, Japan (TAI23-42). The study protocol was registered with the UMIN Clinical Trials Registry (UMIN000012058).

2.2.3. Funding

These studies were funded by the Japan Society for the Promotion of Science (Okubo Y., Examination of fall prevention effects of habitual walking among lower-risk community-dwelling older adults [12J01824]).

2.2.4. Settings and participants

The trial was conducted in the University of Tsukuba, twice from September to December 2012 and from April to July in 2013. Study participants were recruited through advertisements in a community newspaper. The eligibility criteria were as follows: aged between 65 to 79 years; not care-dependent or support-dependent on a Japanese long-term care insurance system; not restricted from exercising by a doctor; and without regular exercise habits. Participants were excluded if they were at a high risk of falling (two or more of the following: using a walking aid; knee pain; using four or more medications; and a history of recurrent falls/fractures in the previous year) (Okubo et al., 2011, Study 1; Okubo et al., 2015, Study 2), were unable to participate in either of the two intervention groups, or had participated in another clinical trial during the previous year (Figure 13). The remaining participants were then assigned to one of the two study arms using computer-generated random numbers. The participants were ranked in order of the computer-generated random numbers; the top 20^{th} (in 2012) or 25^{th} (in 2013) ranks were assigned to the balance group and the remaining to the walking group. The numbers of participants were decided according to the capacity and safety of the program. Age and gender equality between the two groups was confirmed. If a participant was informed of his/her group allocation and was unable to participate in the allocated group, he/she was excluded from the study and considered to be dropped out. We then held an explanatory meeting for the included study participants and obtained written informed consent.

2.2.5. Sample size

This sample size calculation was for the Study 4 (fall incidence as main outcome) which would require greater number of participants than the Study 3 (continuous variables as main outcome). To detect a significant (0.70) relative fall risk among the walking group with a 3.0 base incidence rate, 80% power, and 5% alpha error, 100 participants were needed.

2.2.6. Intervention programs

2.2.6.1. Common features of exercise classes

The intervention programs consisted of 12 2-h sessions held at the university once per week for 12 weeks. A session consisted of lectures (20 min), a warm-up (10-15 min), recreational activity (0-10 min), the main exercise (30-50 min), and a cool-down (10-15 min). The lectures included the following topics: fall prevention, the benefits of and tips for regular exercise, training mechanisms, etc. Heart rate (HR) was measured during the main exercise with a heart rate monitor (RS400, Polar Electro Japan, Tokyo, Japan).

Percent HRmax was calculated using the following formula: HR/age expected HRmax (220 – age (years)) × 100. All of the programs, except for the main and home exercise components, were the same in both groups.

2.2.6.2. Walking group

Brisk walking on a pedestrian road was the main exercise for the walking group. Proper walking technique and advice for purchasing suitable walking shoes were provided to the participants. In order to maintain a good applicability in wide range of community-dwelling older adults, a strict walking protocol (pre-determined walking duration, speed, and distance) was not provided in this study. However, the participants were instructed to walk more quickly than their usual pace, but between “Light (11)” and “Somewhat hard (13)” on the rating of the perceived exhaustion scale (Borg, 1982). According to the participant’s walking ability and condition, they chose one of five groups of different walking paces, each led by a trained instructor. The duration (min), distance (km), and pace (m/min) in each group were recorded by instructors. The duration of walking was extended from 30 min during the 1st week to 50 min by the 12th week. The walking distance and pace of the groups were gradually increased by the participants, with guidance of instructors, within both the above timeframe and the perceived exhaustion of the participants (the 1st week: 2.3 ± 0.2 km, 78.4 ± 3.6 m/min, the 12th week: 4.5 ± 0.6 km, 96.2 ± 12.6 m/min) (Figure 7). When walking outside was not feasible due to rain (twice in 2012, once in 2013), a walking-related exercise (Shigematsu et al., 2008) was conducted indoors. Walking for 30 to 50 min, 3 to 5 days per week, was also recommended for home exercise (American College of Sports Medicine, 2009). The participants received pedometers (Lifecorder PLUS, Suzuken Inc., Aichi, Japan) to wear every day, and they recorded their step counts and walking durations in their exercise diaries for self-monitoring.

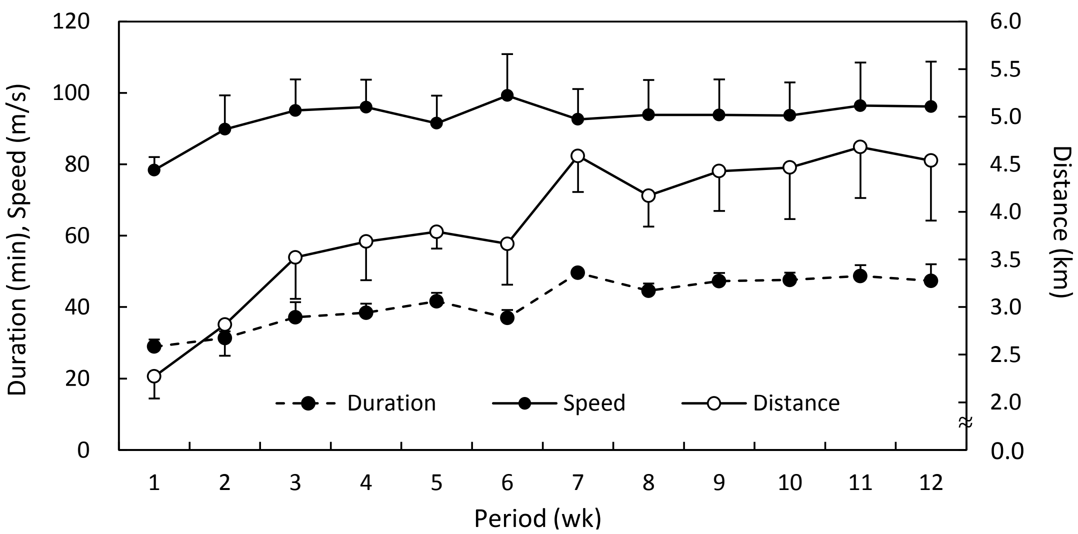

Figure 7. Self-selected walking speed, duration, and distance within exercise classes over 3-month intervention period (n = 50)

2.2.6.3. Balance group

Balance training, muscle strengthening of the legs (15-20 min), and tai chi (30-40 min) were the main exercises for the balance group. Beginner's tai chi (8 forms) and 24-form tai chi were taught by a professional tai chi instructor. The strength and balance program was based on the Otago Exercise Program, of which an individual could choose one of four levels of difficulty and intensity. All participants started from level one and were recommended to increase the level or perform multiple sets as they got used to the level (Gardner et al., 2001). Balance training included a one-leg stance with the eyes opened/closed, with decreasing support of the upper limbs (Sherrington et al., 2008). Muscle strengthening consisted of ankle dorsiflexors and plantar flexors, knee extensors, knee flexors, hip abductors, squats, and lunges at increasing levels of difficulty and dose (10-20 repetitions) (Gardner et al., 2001). Balance and muscle strengthening training were also recommended for home exercise, to be done 3 to 5 days per week. The participants recorded the home training in their exercise diaries.

Table 2. Levels and number of repetitions for the strength and balance training

	Level[1]			
Exercise	1	2	3	4
Strength training				
Ankle dorsiflexors (back on heels)	Seated position, 10 repetitions for both legs together	Seated position, 15 repetitions for both legs together	Seated position, 20 repetitions for both legs together	Standing position, 20 repetitions for both legs together
Ankle plantarflexors (up on toes)	Standing position, 10 repetitions for both legs together	Standing position, 10 repetitions for each leg	Standing position, 15 repetitions for each leg	Standing position, 20 repetitions for each leg
Knee extensor	Seated position, 10 repetitions for each leg	Seated position, 10 repetitions for both legs together		
Knee flexor	Standing position, 10 repetitions for each leg			
High knee		Standing position, 10 repetitions for each leg	Standing position, 15 repetitions for each leg	Standing position, 15 repetitions for each leg
Hip abductor			Standing position, 10 repetitions for each leg	Standing position, 15 repetitions for each leg
Squats	Half, 10 repetitions	Deep, 10 repetitions		
Lunges			10 repetitions, alternating legs	15 repetitions, alternating legs

Balance training[2]				
One leg stance with eyes opened	30-60 seconds for each leg	40-60 seconds for each leg		
One leg stance with eyes closed			Hold support, 20-30 seconds for each leg	No support, 10-20 seconds for each leg

[1] All participants started from the level 1, and stepped up as they mastered the trainings and feel easier to perform. [2] Holding support were recommended when a participant was not able or confident to perform the balance training, and then gradually decreasing the support. The least support to achieve the required time was recommended.

2.2.7. Measurements

At baseline, information regarding gender, medication use, history of cataract/glaucoma, lumbar pain, knee pain, fear of falling, and history of falling over the past year was collected. Body weight and height were measured.

Items and methods of measurements used to assess the effects of the interventions were described here after. Since, a non-exercise control group was not available in these studies, reliability of the measurements were assessed by calculating intraclass correlation coefficients (ICC) and 95% CIs.

2.2.7.1. Usual and maximal gait speeds

According to the previously described method, 5-m usual gait time on a 7-m course was measured with a verbal command "Please walk at your usual pace such as when you walk in your home." Maximal gait time was also measured with a verbal command "Please walk as fast as you can such as when you are in hurry." Usual and maximal gait speeds (m/s) were calculated by dividing 5 (m) by the usual and maximal gait times (s). The speed was recorded to the nearest 0.01 m/s and the average of two trials was used in the analysis. The reliability of the two trials in usual and maximal gait speed was excellent with ICCs (95% CIs) of 0.94 (0.91-0.96) and 0.96 (0.93-0.97), respectively.

2.2.7.2. Ten-meter walk over obstacles

Six urethane-made obstacles (height: 20 cm, length: 100-cm, depth: 10 cm) were placed in 2-m interval on a 10-m course. Participants were instructed to stand with their feet behind and just touching a starting line and, on receiving the tester’s command, to start walking at their fastest pace along a 10-m course stepping over the obstacles. The time was recorded to the nearest 0.01 s and the average of two trials was used in the analysis. The reliability of the two trials in 10-m walk over obstacles was excellent with an ICC (95% CI) of 0.97 (0.96-0.98).

2.2.7.3. Six-minute walk

Participants were instructed to walk as far as possible in 6 minutes, in 50-meter course. The distance they covered in 6 minutes was recorded in meters. If participants felt difficult to continue walking for 6 minutes, they were allowed to quit and the distance they covered until the termination was recorded. The distance was recorded to the nearest 1 m in one trial (because the second trial was likely to be affected by fatigue) and was used in the analysis. Although the reliability of six-m walk was not able to examine, excellent reliability with ICCs of 0.98-0.99 have been reported previously (Hesseberg et al., 2014; Kervio et al., 2004).

2.2.7.4. One-legged stance with eyes closed

Participants were asked to stand on their preferred leg for a maximum of 60 s, during which they could maintain a one-legged stance with their eyes closed in a standard position. The measurement ended until the supporting foot moved, a hand left the waist, eyes opened, or body parts other than supporting foot landed on the floor. The reliability of the two trials in one-legged stance with eyes closed was poor with an ICC (95% CI) of 0.32 (-0.03-0.55).

2.2.7.5. Timed up and go

According to the previously described method, the time taken to rise from a chair, walk forward 3 m as quickly as possible, turn 180 degrees, walk back to the chair, and sit was measured. The reliability of the two trials in timed up and go was excellent with an ICC (95% CI) of 0.95 (0.93-0.97).

2.2.7.6. Functional reach

According to the previously described method, the maximal distance to reach forward was measured. The reliability of the two trials in functional reach was excellent with an ICC (95% CI) of 0.93 (0.89-0.95).

2.2.7.7. Thirty-second chair stand test

This test counts the repetition to stand from a sitting position in 30 seconds without using their arms (Jones et al., 1999). Participants were asked to stand up and sit down on a straight-backed chair (they sit on a chair that was 46-cm high) as quickly as possible. The repetition to form the initial siting position to the final fully erect position was counted for 30 seconds. The repetition was recorded in only one trial (because the second trial was likely to be affected by fatigue) and was used in the analysis. Although the reliability of 30-s chair stand was not able to examine from the data, Jones et al. (1999) reported excellent reliability with an ICC of 0.95 (0.84-0.97) for this test.

2.2.7.8. Knee extension force

Knee extension force was measured using a dynamometer (Biodex system 3, Biodex Medical, New York, USA). Maximum isometric contractions were held with knees at 60° for three seconds, with a five-second rest period between three repetitions in each trial. The knee extension force (torque) was recorded to the nearest 0.01 Nm, and the maximal values of the tree trials in both legs were averaged to be used in the analysis. The reliability of the tree trials in knee extension force was excellent, with an ICC (95% CI) of 0.96 (0.95-0.97).

2.2.7.9. Fall self-efficacy

The fall self-efficacy scale for older Japanese (Takenaka et al., 2002), which ascertains confidence in performing 15 activities of daily living that are common in Japan (e.g., reaching up to a high shelf) without falling, was used. The sum of the items (15 to 75 points) was used in the analysis. The reliability (test and retest within two weeks) of falls self-efficacy has been reported as acceptable with a correlation coefficient of 0.74 (Takenaka et al., 2002).

2.2.7.10. Daily step counts

Daily step counts were measured with a pedometer (Life-coder PLUS, Suzuken Inc., Japan), used by the participants for at least 12 hours per day for one week. The reliability of the daily step counts over 5 consecutive days has been reported as good with Cronbach's α of 0.84 to 0.87 (Strycker et al., 2007).

CHAPTER 3

STUDY 1:

Cross-sectional association between habitual walking and falls among community-dwelling older adults: Difference by risk of falling

Related publication

Okubo et al., Association between habitual walking and multiple or injurious falls among community-dwelling older adults: Difference by risk of falling (article in Japanese). Jpn J Phys Fitness Sports Med 2011, 60(2):239-248.

3.1. Purpose

The purpose of this study was to examine the association between habitual walking and falls among community-dwelling older adults, stratified by the different risk of falling.

3.2. Methods

3.2.1. Study design

The study design was a cross-sectional study. However, the reverse-causation was unlikely to happen because we extracted only habitual walking continued for one year or longer, which prior to the fall events in the past one year.

3.2.2. Participants

Study participants were recruited through a method described previously (see 2.1.3, in page 23). Out of 823 participants of the health check-ups in 2008 to 2009, participants who duplicated (n = 77), younger than 60 years (n = 26), and had missing data for fall status (n = 12) were excluded. A total of 708 participants (233 men, 475 women) were included in the subsequent analyses.

3.2.3. Measurements

According to the methods described previously (2.1.5 Measurements, page 24), the presence of habitual walking, fall risk factors, socio-demographics, anthropometrics, physical performances, lifestyle and psychological factors, and functional status were measured.

3.2.3.1. Fall history

The fall frequency for the past year and sustained injuries (e.g., contusion, incised wound, abrasion, bone fracture) were ascertained at the annual health check-up. When the participants reported falls, the activities being performed when falls occurred and the causes of falls were recorded for the most injurious falls. Since previous studies have reported that single fallers are similar to non-fallers (Nevitt et al., 1989), the outcome variable “fallers” was defined as participants who suffered multiple falls and participants who suffered a fall with injury within a previous one year (Delbaere et al., 2010b; Okubo et al., 2011). The participants who suffered single fall without injury or did not suffer a fall were classified as non-fallers.

3.2.4. Statistical analyses

In order to examine the association between habitual walking and falls considering the different risk of falling, the following two subgroup analyses were conducted.

3.2.4.1. Subgroup analysis Ⅰ

To examine the point at which the association between habitual walking and falls was modified, the participants were first classified into five different risk levels for falling (R0, R1, R2, R3, and R4+) according to the numerical value of the positive score for the fall risk factors. The prevalence of fall history of the walkers and non-walkers was calculated according to the five risk levels for falling. χ-square test was applied to examine the statistical significance of prevalence of fall history between the walkers and non-walkers stratified by the five levels of falling risks.

3.2.4.2. Subgroup analysis Ⅱ

Then, groups R0, R1, and R2 were defined as the lower-risk (R < 3) group, and groups R3 and R4+ were defined as the higher-risk (R ≥ 3) group. An analysis of covariance (ANCOVA) was applied to examine the statistical significance of difference in characteristics among the lower- and higher-risk groups, adjusted for age and gender. χ-square test was applied to examine the statistical significance of categorical variables of the characteristics among the lower- and higher-risk groups. The same methods were applied to examine the statistical significance of difference in characteristics among the walkers and non-walkers stratified by the higher- and lower-risk groups. Multivariable logistic regression analysis was applied, to calculate odds ratios (ORs) and 95% CIs with fall history as a dependent variable, habitual walking as an independent variable, gender, age, depressive symptoms, poor balance, polypharmacy, use of assistive device, knee pain, and mobility limitation as covariates. The multivariable logistic regression analysis was conducted stratified by the higher- and lower-risk groups.

3.2.4.3. Analysis of an interaction

To examine the statistical significance of interaction between habitual walking and fall history, multivariable logistic regression analysis was applied, with fall history as a dependent variable, "being higher-risk ($R \geq 3$) and doing habitual walking (yes)" as an independent variable, gender, age, habitual walking, higher-risk, depressive symptoms, poor balance, polypharmacy, use of assistive device, knee pain, and mobility limitation as covariates. The age was entered as a continuous variable and other items were entered as categorical variables.

P-values of less than 0.05 were considered statistically significant. IBM SPSS Statistics 19 was used for the statistical analysis.

3.3. Results

3.3.1. Socio-demographics

The age of the study participants were 72.3 ± 6.6 (60-91) years (men: 72.5 ± 6.5 years; women: 72 ± 6.7 years). The mean duration of walking, frequency of walking, weekly amount of walking, and number of years practicing walking were 48.1 ± 20.3 (30-180) min/day, 5.3 ± 2.0 (2-14) times/day, 256.9 ± 157.2 (60-1260) min/week, and 7.6 ± 6.5 (1-36) years.

Table 3 represents the prevalence of walkers and fallers according to gender and age category. The prevalence of walkers was 36.1% in men and 23.8% in women. The prevalence of fallers was 6.4% in men and 13.1% in women.

Table 3. Prevalence of walkers and fallers according to gender and age category (n = 708)

Age	n	Walkers n (%)	Fallers n (%)
Men			
60-64	21	6 (28.6)	1 (1.4)
65-69	63	24 (38.1)	1 (4.1)
70-74	64	24 (37.5)	5 (7.8)
75-79	47	19 (40.4)	6 (12.8)
80+	38	11 (28.9)	2 (5.3)
Total	233	84 (36.1)	15 (6.4)
Women			
60-64	64	19 (29.7)	4 (6.3)
65-69	116	30 (25.9)	16 (13.8)
70-74	118	33 (28.0)	15 (12.7)
75-79	105	23 (21.9)	12 (11.4)
80+	72	8 (11.1)	15 (20.8)
Total	475	113 (23.8)	62 (13.1)

Fallers: participants who experienced multiple falls (≥ 2) or suffered an injurious fall (≥ 1) in the previous one year.

Table 4 represents the prevalence of fall risk factors and previous fall status among the walkers and non-walkers. The prevalence of poor balance, mobility limitation, knee pain, and use of assistive device were significantly lower among the walkers than those of the non-walkers. The mean number of fall risk factors among the walkers (0.99 ± 1.09) was significantly lower than that of the non-walkers (1.32 ± 1.35). The prevalence of at least one fall was significantly lower among the walkers than that of the non-walkers. However, the prevalence of multiple or injurious falls were 7.6% among the walkers and 12.1% among the non-walkers, and no statistically significant difference was observed.

Table 4. Prevalence of fall risk factors and previous fall status among the walkers and non-walkers (n = 708)

Variables	Non-walkers (n = 511)		Walkers (n = 197)		
Fall risk factors					
Poor balance, yes	143	(28.4)	41	(20.9)	*
Mobility limitation, yes	133	(26.0)	30	(15.2)	*
Knee pain, yes	81	(15.9)	15	(7.6)	*
Depressive symptoms, yes	182	(35.8)	70	(35.5)	
Assistive device, use	35	(6.8)	5	(2.5)	*
Polypharmacy, yes	100	(19.6)	34	(17.3)	
Number of fall risk factors					
0	170	(33.3)	82	(41.6)	*
1	168	(32.9)	61	(31.0)	
2	72	(14.1)	36	(30.1)	
3	59	(11.5)	12	(6.1)	*
4+	42	(8.2)	6	(3.0)	*
Fall status in previous one year					
Any falls (≥ 1), yes	90	(17.6)	22	(11.2)	*
Multiple falls (≥ 2), yes	30	(5.9)	7	(3.6)	
Injurious (≥ 1) falls, yes	51	(10.0)	17	(8.6)	
Multiple or injurious falls, yes	62	(12.1)	15	(7.6)	

* $P < 0.05$ vs the non-walkers. n (%)

3.3.2. The subgroup analysis Ⅰ

Figure 8 represents the prevalence of falls among the walkers and non-walkers, stratified by the five levels of fall risk. The prevalence of fallers among the walkers compared to the non-walkers was significantly lower in the group R2, and non-significantly lower in the groups R0 and R1. In contrast, the prevalence of fallers among the walkers compared to the non-walkers was non-significantly higher in the R3 and R4+. With this results, the groups R0, R1, R2 (n = 589) were combined as the lower-risk group, and the groups R3 and R4+ were combined as the higher-risk group (n = 119) for the subsequent subgroup analysis Ⅱ.

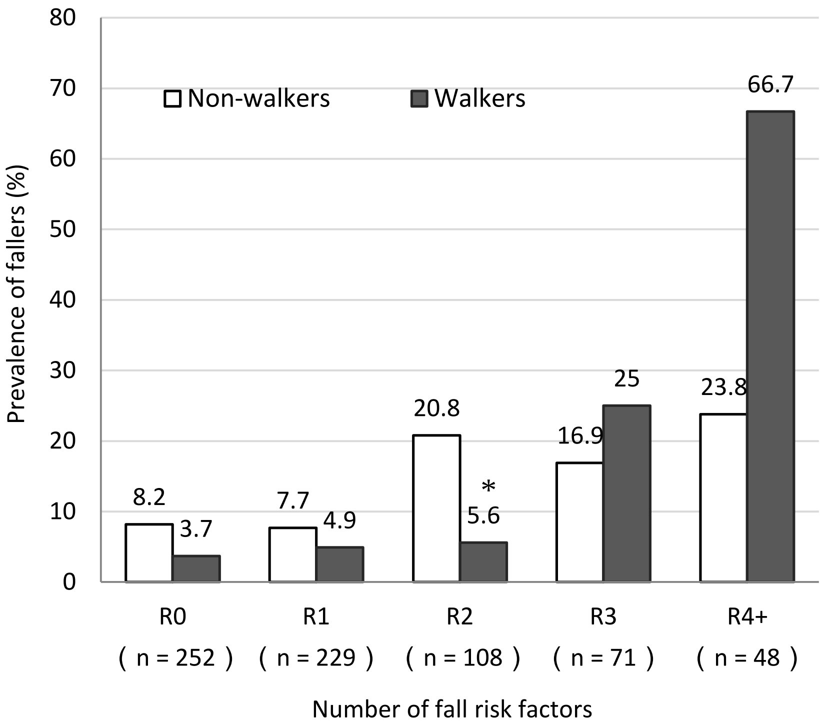

Figure 8. Prevalence of fallers among the walkers and non-walkers, stratified by the five levels of fall risk (n = 708)

* $P < 0.05$ vs the non-walkers

R: number of fall risk factors (poor balance, mobility limitation, knee pain, depressive symptoms, use of assistive device, and polypharmacy)

3.3.3. The subgroup analysis Ⅱ

Figure 9 represents the histogram of the participants, stratified by the age category and the lower- and higher-risk groups. The histogram showed that the lower-risk participants were distributed around 65-74 years. On the other hand, the higher-risk participants were distributed around 75-84 years.

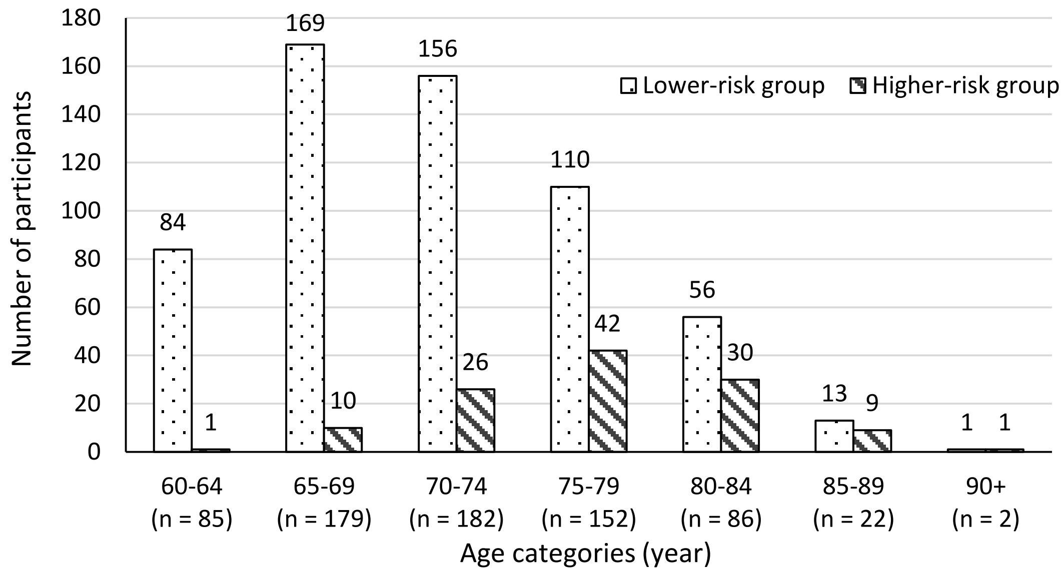

Figure 9. Histogram of participants among the lower- and higher-risk groups (n = 708)

Table 5 represents the characteristics of the walkers and non-walkers, stratified by the higher- and lower-risk groups. In the socio-demographics, the prevalence of women among the walkers was significantly higher than that of the non-walkers in the lower-risk group. However, the difference in the prevalence of women was not observed in the higher-risk group. In the physical performance, no difference was observed between the walkers and non-walkers in either higher- and lower-risk groups. In the comparison between the higher- and lower-risk groups, all variables were significantly better (younger, taller, lighter in weight, stronger, faster, and longer in maintaining balance) in the lower-risk group than higher-risk group.

Table 5. Socio-demographics and physical performances of the walkers and non-walkers, stratified by the higher- and lower-risk groups (n = 708)[1]

Variables	Lower-risk group (R < 3) (n = 589)					Higher-risk group (R ≥ 3) (n = 119)				
	Non-walkers (n = 410)		Walkers (n = 179)			Non-walkers (n = 101)		Walkers (n = 18)		
Socio-demographics & Anthropometrics										
Age, years	71.5	± 0.3	71.2	± 0.5		77.2	± 0.6	77.0	± 1.4	†
Gender, female	282	(68.8)	102	(57.0)	*	80	(79.2)	11	(61.1)	†
Body height, cm	153.2	± 0.3	153.7	± 0.4		148.5	± 0.5	148.9	± 1.2	†
Body weight, kg	54.9	± 0.4	54.6	± 0.6		54.1	± 1.2	58.3	± 2.1	†
BMI, kg/m^2	23.4	± 0.2	23.1	± 0.2		24.8	± 0.4	26.3	± 0.9	†
Spinal curvature, yes	21	(5.1)	5	(2.8)		19	(18.8)	4	(22.2)	†
Physical performance										
+ One-leg balance with eyes opened, s	36.6	± 1.0	39.4	± 1.5		8.6	± 1.1	9.3	± 2.5	†
+ Tandem balance, s	28.3	± 0.2	28.6	± 0.4		23.8	± 0.9	21.3	± 2.0	†
+ Functional reach, cm	27.3	± 0.3	27.8	± 0.4		22.8	± 0.7	21.4	± 1.4	†
- Five-chair stance, s	7.0	± 0.1	6.8	± 0.1		9.5	± 0.3	8.3	± 0.6	†
- Alternate step, s	4.2	± 0.0	4.2	± 0.1		5.8	± 0.2	5.2	± 0.5	†
- Timed up & go, s	6.2	± 0.1	6.2	± 0.1		8.9	± 0.3	8.0	± 0.7	†
- 5-m usual gait, s	3.7	± 0.0	3.7	± 0.1		5.1	± 0.2	4.7	± 0.4	†
- Tandem walk, s	11.6	± 0.2	11.4	± 0.3		16.6	± 0.6	15.4	± 1.3	†

N (%) or adjusted mean ± standard error, R: number of fall risk factors (poor balance, mobility limitation, knee pain, depressive symptoms, use of assistive device, and polypharmacy)

† $P < 0.05$ vs the lower-risk group, * $P < 0.05$ vs the non-walkers

Analysis of covariance (ANCOVA); continuous variables were adjusted by gender and age (age was adjusted only by gender) [1] Less than 10% missing data.

BMI: body mass index, + : higher values denote good performance, - : lower values denote good performance

Table 6 represents the lifestyle, psychological factors, functional status, and medical history of the walkers and non-walkers, stratified by the higher- and lower-risk groups. In the psychological factor, the fear of falling among the walkers was significantly lower than that of the non-walkers in the higher-risk group. In the medical history, the walkers had significantly higher prevalence of diabetes mellitus than that of the non-walkers in the higher-risk group, but no other differences were observed between the walkers and non-walkers. The lower-risk group was significantly better than the higher-risk group in all variables except for field work.

Table 6. Lifestyle, psychological factors, functional status, and medical history of the walkers and non-walkers, stratified by the higher- and lower-risk groups (n = 708)[1]

Variables	Lower-risk group (R < 3) (n = 589)					Higher-risk group (R ≥ 3) (n = 119)					
	Non-walkers (n = 410)		Walkers (n = 179)			Non-walkers (n = 101)		Walkers (n = 18)			
Lifestyle factors											
Field work, day/week	3.6	± 0.1	3.1	± 0.2		3.5	± 0.3	3.9	± 0.8		
House work, day/week	5.3	± 0.1	5.4	± 0.2		5.4	± 0.2	4.4	± 0.6		
Frequency of outings, day/week	6.5	± 0.1	6.6	± 0.1		5.8	± 0.2	6.1	± 0.5		†
Psychological factors											
Fear of falling, yes	144	(35.1)	61	(34.3)		74	(73.3)	8	(44.4)	*	†
Self-rated health, good	358	(87.7)	165	(92.2)		57	(58.2)	15	(83.3)		†
Functional status											
+TMIG-IC, 0-13	10.4	± 0.1	10.5	± 0.2		9.8	± 0.3	9.4	± 0.6		†
Medical history in one year											
Stroke, yes	5	(1.2)	5	(2.8)		7	(6.9)	0	(0.0)		†
Hypertension, yes	142	(34.6)	74	(41.3)		56	(55.4)	9	(50.0)		†
Diabetes, yes	23	(5.6)	19	(10.6)	*	16	(15.8)	1	(5.6)		†
Heart disease, yes	33	(8.0)	12	(6.7)		21	(20.8)	4	(22.2)		†
Osteoporosis, yes	23	(5.6)	6	(3.4)		17	(16.8)	2	(11.1)		†
Glaucoma/cataract, yes	9	(2.2)	4	(2.2)		7	(6.9)	1	(5.6)		†

N (%) or adjusted mean ± standard error, R: number of fall risk factors (poor balance, mobility limitation, knee pain, depressive symptoms, use of assistive device, and polypharmacy)

† *P* < 0.05 vs the lower-risk group, * *P* < 0.05 vs the non-walkers

Analysis of covariance (ANCOVA); continuous variables were adjusted by gender and age [1] Less than 10% missing data.

TMIG-IC: Tokyo Metropolitan Institute of Gerontology-Index of Competence

Table 7 represents the ORs and 95% CIs of habitual walking for fall history, stratified by the higher- and lower-risk groups. Among the lower-risk group, habitual walking was significantly associated with fewer fall history (OR: 0.44, 95% CI: 0.20-0.96). In contrast, among the higher-risk group, habitual walking was significantly associated with greater fall history (OR: 3.42, 95% CI: 1.08–10.81). Among the lower-risk group, the association between habitual walking and fewer fall history was significant even after adjusted for age, gender, and all six fall risk factors (OR: 0.44, 95% CI: 0.20-0.97). Among the higher-risk group, the association between habitual walking and greater fall history was significant even after adjusted for age, gender, and all six fall risk factors (OR:4.61, 95% CI: 1.32-16.09).

Table 7. Odds ratios and 95% CIs of habitual walking for fall history, stratified by the higher- and lower-risk groups.

	Lower-risk group (R < 3) (n = 585[a)])			Higher-risk group (R ≥ 3) (n = 111[a)])		
Habitual walking	No	Yes		No	Yes	
Model1	1.00 (reference)	0.44 (0.20-0.96)	*	1.00 (reference)	3.42 (1.08-10.81)	*
Model2	1.00 (reference)	0.44 (0.20-0.97)	*	1.00 (reference)	3.41 (1.07-10.78)	*
Model3	1.00 (reference)	0.43 (0.19-0.94)	*	1.00 (reference)	4.18 (1.22-14.32)	*
Model4	1.00 (reference)	0.44 (0.20-0.97)	*	1.00 (reference)	4.61 (1.32-16.09)	*

* $P < 0.05$
Model1: Adjusted for gender
Model2: Model1 adjusted for age
Model3：Model2 adjusted for poor balance, depressive symptoms, and polypharmacy
Model4：Model3 adjusted for knee pain, mobility limitation, and use of assistive device
R: number of fall risk factors (poor balance, mobility limitation, knee pain, depressive symptoms, use of assistive device, and polypharmacy)
a) 4 participants in the lower-risk group, 8 participants in the higher-risk group were excluded from the analysis for missing data

In the multivariable logistic regression analysis with all participants, a significant interaction between habitual walking and higher-risk, adjusted for all covariates, was observed ($P < 0.01$).

3.4. Discussion

3.4.1. Habitual walking and fall history among the lower-risk older adults

The results of the current study suggest that habitual walking continued one year or longer (7.6 ± 6.5 years) was related with fewer fall history in past one year among the lower-risk community-dwelling older adults. The interaction between habitual walking and higher-risk indicates that the relationship between habitual walking and fall history was significantly modified by the high-risk characteristics of the study participants. To our best knowledge, this was the first study which suggested that high-risk characteristics of the community-dwelling older adults were the effect modifier in the association between habitual walking and fall history.

Although this was a cross-sectional study, a few possible reasons for the observed beneficial association among the lower-risk participants were speculated. Gait deficit or decline in walking ability has been reported as one of the major fall risk factors in many previous studies (American Geriatrics Society, 2001; Suzuki et al., 1999). Suzuki et al. (2004) described that walking might be effective in preventing falls through maintaining the walking ability of older adults. However, in the current study, the physical performance tests related to walking ability such as timed up & go and 5-m habitual walk did not show significant difference between the walkers and non-walkers among the lower-risk group. This may have been due to the fact that some of the non-walkers in the current study were engaged in other forms of habitual exercise such as golf, ground golf, calisthenics, and ball games (e.g., tennis, volley ball). It was possible that the participants with other forms of habitual exercise had high physical performance and masked the difference between the walkers and non-walkers. However, it should be noted that even if the effects of walking on physical performance did not differ from other forms of exercise, walking was significantly and specifically associated with fewer fall history. Habitual walking in the outside environments with various hazards for one year or longer might have been contributed to obtaining the ability to detect hazardous situations for falling and recover the balance when tripped or slipped.

In the medical history, the prevalence of diabetes mellitus was significantly higher in the walkers than the non-walkers. Several previous studies have reported the association between diabetes mellitus and falls among community-dwelling older adults (Hanlon et al., 2002; Maurer et al., 2005; Seino et al., 2010). On the other hand, exercise is known to improve the blood sugar and insulin resistance (Zisser et al., 2011). The walkers in the lower-risk community-dwelling older adults might have been walking in order to improve the blood sugar status.

3.4.2. Habitual walking and fall history among the higher-risk older adults

The results of the current study indicate that habitual walking among the higher-risk community-dwelling older adults is associated with greater fall history. The association between habitual walking and greater fall history remained significant even after adjusted for age, gender, and all six fall risk factors (Table 7, page 61).

Although, this was a cross-sectional study, a few possible reasons for the observed association could be speculated. Delbaere et al. (2010a) reported that one third of community-dwelling older adults had either overestimated or underestimated fear of falling compared to their physiological fall risk status. Soyano and Kamioka (2001) described that older adults with actual high risk (being physically frail) and had confidence in fall prevention were in the danger of falling during exercises. The higher-risk walkers showed significantly lower prevalence of fear of falling than the higher-risk non-walkers despite of the fact that the higher-risk walkers were not better than the higher-risk non-walkers in the physical performance such as walking and balance ability. The greater fall history among the higher-risk walkers might have been due to the inappropriately low fear of falling or lack of proper attention. Kamioka and

Okada (2008) described that the exercise with greater danger of falling was effective because movements which accompanies loss of balance would train older adults to maintain and recover their body balance. Walking is one form of exercise which accompanies the danger of falling because the center of gravity precedes the base of support during fast walking. However, in the higher-risk older adults who need assistive device, have knee pain, or difficulty in climbing stairs, the danger of falling immanent in the walking behavior and greater opportunity of encountering trips and slips might exceed the merit of walking such as improvement of physical function.

Figure 8 (page 55) suggests that the point at which the association between habitual walking and falls was modified was three risk factors of falling. An RCT by Faber et al. (2006) reported that the negative effects of walking-related exercise program were observed among the participants with three or more risk factors of frailty. If habitual walking was to be recommended as an exercise in a health promotion strategy for community-dwelling older adults, a criterion of three or more fall risk factors could be proposed for screening the participants who could safely and effectively walk for their health and fall prevention. For higher-risk community-dwelling older adults, safer forms of exercise such as strength and balance training, which traditionally known as effective fall prevention exercises, can be recommended (Sherrington et al., 2008; Wijlhuizen et al., 2007).

3.4.3. The interaction between habitual walking and higher-risk of falling

The statistically significant interaction between habitual walking and higher-risk of falling was observed (*P* < 0.01). In other ward, the effect of walking on fall history was reversed in the lower- and higher-risk characteristics of the study participants.

Large cohort studies in the United States also suggested the effects of high physical activity was modified by the presence of difficulty in ADL (Stevens et al., 1997) or IADL (Faulkner et al., 2009). Therefore, the interaction or modification effect found in the current study could possibly be generalized in other population. To our best knowledge, this was the first study which showed the significant interaction between habitual walking naturally conducted by older adults and higher-risk of falling. However, because habitual walking and high physical activity can be correlated, examination of confounding is warranted.

3.4.4. Strengths and limitations

Strengths of the current study include the original subgroup analyses in different levels of objectively assessed risk of falling, and relatively large sample size (n = 708) to allow the analyses.

On the other hand, our study has several limitations. First, the study participants were limited to relatively healthy community-dwelling older adults who voluntarily participated in the health check-up. Second, there is the potential for unmeasured confounding variables that we could not assess, such as total physical activity, cognitive function, and risk-taking behavior. Third, although the reliability of a retrospective fall survey in Japanese community-dwelling older individuals has been confirmed (Haga et al., 1996), prospective surveillance using a monthly fall calendar will be more reliable.

3.4.5. Conclusion of the Study 1

In conclusion, this cross-sectional study suggests that the association between habitual walking and history of multiple or injurious falls among community-dwelling older adults are significantly modified by the presence of risk factors for falling. Habitual walking continued one year or longer was related with fewer fall history in past one year among the lower-risk community-dwelling older adults. However, habitual walking was related with greater fall history among the higher-risk community-dwelling older adults with three or more risk factors for falling.

Further longitudinal study is warranted to examine the cause-effect relationship suggested by this cross-sectional study.

CHAPTER 4

STUDY 2:

Longitudinal association between habitual walking and falls among community-dwelling older adults: Difference by risk of falling

Related publication
Okubo et al., Longitudinal association between habitual walking and fall occurrences among community-dwelling older adults: analyzing the different risks of falling. Arch Gerontol Geriatr 2015, 60(1):45-51. (in press)

4.1. Purpose

The results of the Study 1 are based on the cross-sectional analyses and not able to show the cause-effect relationship. Therefore, the purpose of this Study 2 was to examine the association between habitual walking and falls among community-dwelling older adults, stratified by the different levels of risk of falling.

4.2. Methods

4.2.1. Participants

Study participants were recruited using a method described previously (see 2.1.3, in page 23). In total, 1474 individuals (448 men and 1026 women) aged 60-91 participated in the health check-up in 2008 to 2012. We excluded 773 individuals (247 men and 526 women) from the analysis due to incomplete follow-up health check-ups from 2009 to 2013. We also excluded 49 individuals (12 men and 37 women) who were under the age of 60 and 117 individuals (32 men and 85 women) with incomplete data. A total of 535 individuals (157 men and 378 women) were thus enrolled in the present study.

4.2.2. Baseline measurements

At baseline, according to the methods described previously (2.1.5, page 24), the presence of habitual walking, fall risk factors, socio-demographics, anthropometrics, physical performances, lifestyle and psychological factors, and functional status were measured.

4.2.3. Follow-up surveillance and end point determination

The fall frequency for the past year and sustained injuries (e.g., contusion, incised wound, abrasion, bone fracture) were ascertained at the annual health check-up. The activities being performed when falls occurred and the causes of falls were also recorded (only for the most serious fall for multiple fallers). Previous studies have reported that single fallers were more similar to non-fallers than multiple fallers when comparing a range of medical, physical, and psychological risk factors (Nevitt et al., 1989). In the current study, the outcome variable “fallers” was defined as participants who suffered multiple falls within a year during the follow-up period and participants who suffered a fall with injury, as single fallers should not be categorized as non-fallers when an injury occurs (Delbaere et al., 2010b). The participants were followed with an annual health check-up until an injurious fall occurred, multiple falls occurred, the participant missed the annual health check-up, or the end of 2013.

4.2.4. Statistical analyses

In order to examine the association between habitual walking and falls considering the different risk of falling, the following two subgroup analyses were conducted.

4.2.4.1. Subgroup analysis Ⅰ

To examine the point at which the association between habitual walking and falls was modified, the participants were first classified into five different risk levels for falling (R0, R1, R2, R3, and R4+) according to the numerical value of the positive score for the fall risk factors. The incidence of falls (n/100 person-years) of the walkers and non-walkers was calculated according to the five risk levels for falling. An unadjusted Cox proportional hazard model was used to examine the statistical significance of fall incidence between the walkers and non-walkers, stratified by the five levels of falling risks.

4.2.4.2. Subgroup analysis Ⅱ

Then, groups R0 and R1 were grouped as the lower-risk ($R < 2$) group, and groups R2, R3, and R4+ were grouped as the higher-risk ($R \geq 2$) group. The ANCOVA adjusted for gender and age (60-64, 65-69, 70-74, 75-79, and 80+ years) was used for the continuous variables, and a χ-square test was used for the binomial variables to examine the statistical significance of the difference in the baseline characteristics between the walkers and non-walkers stratified in the lower- and higher-risk groups. The same methods were applied to examine the statistical significance of the difference between the lower- and higher-risk groups. The Logrank test was used to examine the difference in time to the falls among the walkers and non-walkers in the lower- and higher-risk groups. The hazard ratios (HRs) of falls, with their corresponding 95% CIs of habitual walking, were calculated using the Cox proportional hazards regression model. This analysis was conducted as a subgroup analysis that was stratified by the risk of falling (lower/higher). The covariates included baseline age, depressive symptoms (yes/no), poor balance (yes/no), polypharmacy (yes/no), assistive device (yes/no), mobility limitation (yes/no), and previous fall history (yes/no). These covariates were chosen because they were related to falls (American Geriatrics Society, 2001).

4.2.4.3. Analysis of an interaction

The interaction between habitual walking (yes) and a higher-risk of falling (yes) was examined using the Cox proportional hazards regression model adjusted for the above covariates plus habitual walking (yes/no) and risk of falling (lower/higher).

P-values of less than 0.05 were considered statistically significant. All statistical analyses were conducted using SAS version 9.2 (SAS Institute, Cary, NC, USA).

4.3. Results

4.3.1. Socio-demographics

At baseline, the age of the study participants was 73.1 ± 6.6 years (range, 60-91) (men: 73.2 ± 6.2 years, women: 73 ± 6.7 years). The median (interquartile range) duration of walking, frequency of walking, and number of years practicing walking were 40 (30-60) min, 6 (3.5-7) days/week, and 5 (3-10) years, respectively. The weekly total amount of walking was 210 (120-300) min/week. Compared with the participants who were followed up, those who were not followed up were significantly younger (71.6 ± 6.9 years) and had fewer risk factors for falling (1.1 ± 1.2); however, no significant differences were observed in gender, prevalence of walkers, or fall history.

4.3.2. Fall status

Table 8 shows the prevalence of walkers at baseline and the incidence rate of fallers in the follow-up period. The prevalence of habitual walking was 30.6% in men and 18.5% in women. During the follow-up, which lasted through 2013 and represented a mean period of 1.7 (1-5) years (1.9 years in men and 1.6 years in women), a total of 916 person-years (295 person-years in men and 621 person-years in women) and 112 fall cases (26 men and 86 women) among 535 older adults (157 men and 378 women) were observed. The incidence of fallers was 8.8% in men and 13.8% in women. The activities when falls occurred were walking (58.3%), descending stairs (7.1%), ascending stairs (2.4%), standing up (2.4%), standing (1.2%), running (1.2%), playing sports (1.2%), bicycling (13.1%), and doing other tasks (13.1%). The causes of falls were tripping (48.5%), slipping (21.1%), misstepping (12.4%), staggering (3.1%), dizziness (2.1%), and other reasons (10.8%).

Table 8. Prevalence of walkers at baseline and incidence of multiple (≥ 2) or injurious (≥ 1) falls in the follow-up period (n = 535)

Age (years)	n	Walkers n (%)	Multiple or injurious falls n (n/100 person-years)
Men			
60-64	12	3 (25.0)	0 (0.0)
65-69	37	11 (29.7)	3 (3.8)
70-74	38	15 (39.5)	4 (6.3)
75-79	42	11 (26.2)	9 (12.7)
80+	28	8 (28.6)	10 (18.2)
Total	157	48 (30.6)	26 (8.8)
Women			
60-64	40	8 (20.0)	7 (10.1)
65-69	89	20 (22.5)	19 (12.9)
70-74	89	20 (22.5)	27 (19.0)
75-79	89	15 (16.9)	16 (11.7)
80+	71	7 (9.9)	17 (13.5)
Total	378	70 (18.5)	86 (13.8)

Table 9 shows the prevalence of positive scores for risk factors, the number of risk factors for falling at baseline and the fall status during the follow-up period among the walkers and non-walkers. The prevalence of mobility limitation and R0 was significantly higher in the non-walkers than in the walkers. In contrast, the prevalence of R4+ was significantly lower in the walkers than in the non-walkers. The mean number of fall risk factors among the walkers (1.02 ± 1.35) was significantly lower than that of the non-walkers (1.43 ± 1.46). The incidence of multiple or injurious falls was 13.5% in the walkers compared with 11.8% in the non-walkers, and no significant difference was observed.

Table 9. Prevalence of positive scores for risk factors, number of risk factors for falling at baseline, and fall status during the follow-up period among walkers and non-walkers (n = 535)

Variables	Non-walkers (n = 417)		Walkers (n = 118)	
Risk factors for falling				
Poor balance, yes	117	(28.1)	26	(22.0)
Mobility limitation, yes	140	(33.6)	20	(16.9)**
Knee pain, yes	108	(25.9)	30	(25.4)
Depressive symptoms, yes	45	(10.8)	7	(5.9)
Use of assistive device, yes	33	(7.9)	8	(6.8)
Polypharmacy, yes	94	(22.5)	20	(16.9)
Previous fall history, yes	60	(14.4)	9	(7.6)
Number of risk factors for falling				
0	144	(34.5)	55	(46.6)*
1	103	(24.7)	34	(28.8)
2	81	(19.4)	15	(12.7)
3	46	(11.0)	6	(5.1)
4+	43	(10.3)	8	(6.8)
Fall status during the follow-up period				
Any falls (≥ 1), yes	130	(19.5)	39	(19.3)
Multiple falls (≥ 2), yes	38	(5.1)	18	(8.0)
Injurious falls (≥ 1), yes	71	(9.8)	21	(9.9)
Multiple or injurious falls, yes	84	(11.8)	28	(13.5)

* $P < 0.05$, ** $P < 0.01$ versus non-walkers

n (%), n (n/100 person-years) for fall status

4.3.3. The subgroup analysis Ⅰ

Figure 10 shows the incidence of falls during the follow-up period using the five falling risk levels and the presence of habitual walking. The incidence of falls did not differ significantly between the walkers and non-walkers in R0 and R1 or between the walkers and non-walkers in R2 and R3; however, it was significantly higher in walkers in R4+

compared with non-walkers. Despite the lack of statistical significance, the direction of the differences in the incidence of falls (i.e., lower among walkers in R0 and R1 but higher among walkers in R2, R3, and R4+) led to the grouping of these five categories into two groups. According to these results, R0 and R1 were grouped as a lower-risk group (n = 336, 594 person-years), and R2, R3, and R4+ were grouped as a higher-risk group (n = 199, 322 person-years) for the subsequent subgroup analyses.

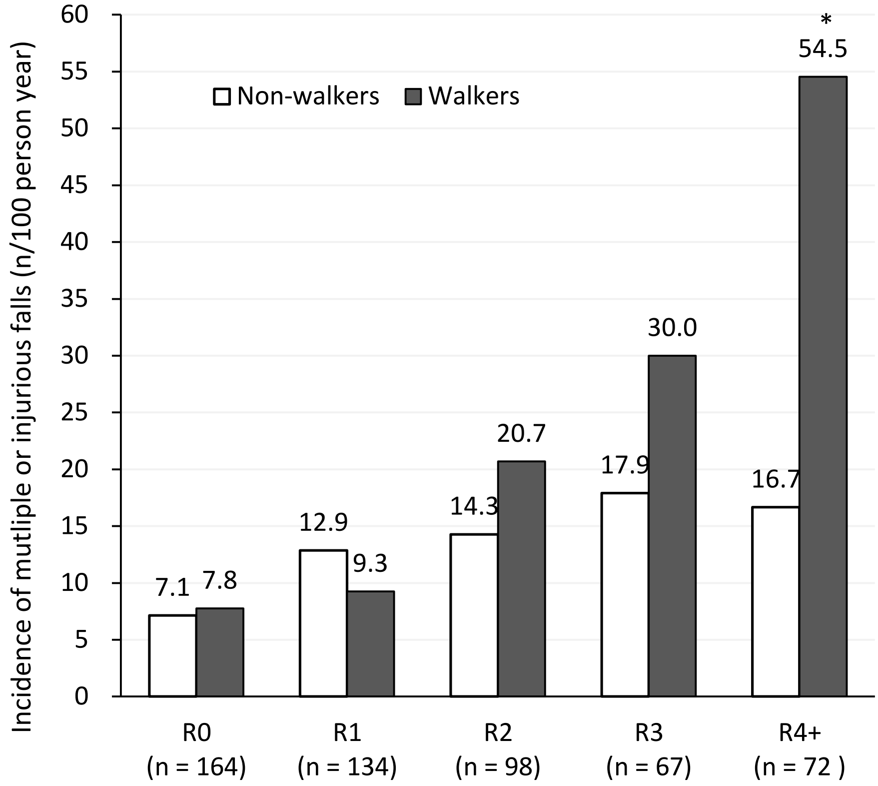

Figure 10. Incidence of multiple (≥ 2 falls) or injurious (≥ 1 fall) falls in the follow-up period, by 5 levels of risk of falling and presence of habitual walking (n = 535)

* $P < 0.05$ versus Non-walkers

R = number of risk factors for falling. The risk factors are depressive symptom, poor balance, polypharmacy, use of assistive device, knee pain, mobility limitation, and previous fall history.

4.3.4. The subgroup analysis Ⅱ

Figure 11 represents the histogram of the participants, stratified by the age category and the lower- and higher-risk groups. The histogram showed that the lower-risk participants were distributed around 65-74 years. On the other hand, the higher-risk participants were distributed around 75-84 years.

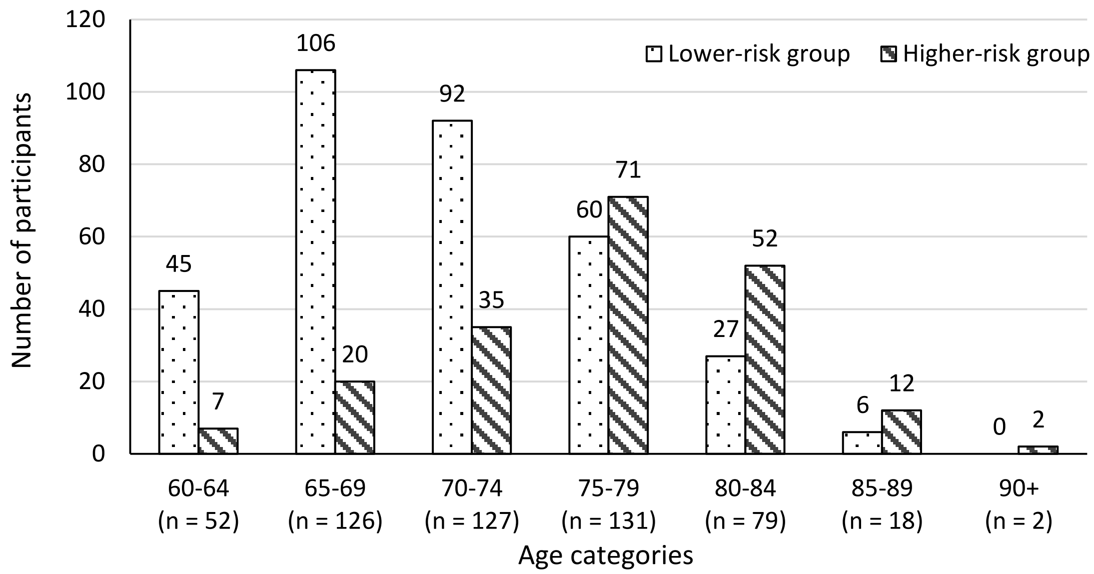

Figure 11. Histogram of participants among the lower- and higher-risk groups (n = 535)

Table 10 and Table 11 shows the baseline characteristics of the walkers and non-walkers in the lower- and higher-risk groups. Among the lower-risk group, the walkers showed significantly better performance in the one-leg balance test with eyes open and alternate step and a higher prevalence of diabetes than the non-walkers. Among the higher-risk group, the walkers showed significantly higher weights and BMIs than did the non-walkers. The lower-risk group showed significantly better values (younger, taller, lighter in weight, stronger, faster, and longer in maintaining balance) in all variables except gender, field work, TMIG-IC, frequency of outings, and the prevalence of diabetes compared with the higher-risk group.

Table 10. Socio-demographics and physical performances of the walkers and non-walkers, stratified by the higher- and lower-risk groups (n = 535)[1]

Variables	Lower-risk (R < 2) (n = 336)					Higher-risk (R ≥ 2) (n = 199)				
	Non-walkers (n = 247)		Walkers (n = 89)			Non-walkers (n = 170)		Walkers (n = 29)		
Socio-demographics & Anthropometrics										
Age, year	71.1	± 0.4	70.8	± 0.6		76.7	± 0.5	76.6	± 1.1	††
Gender, female	178	(72.1)	54	(60.7)	*	130	(76.5)	16	(55.2)	
Body height, cm	152.4	± 0.3	153.5	± 0.5		149.2	± 0.4	149.7	± 1.0	†
Body weight, kg	53.7	± 0.5	55.1	± 0.8		53.8	± 0.6	57.0	± 1.5	††
BMI, kg/m^2	23.1	± 0.2	23.3	± 0.3		24.1	± 0.3	25.4	± 0.7	††
Scoliosis, yes	11	(4.5)	1	(1.1)		24	(14.1)	4	(13.8)	††
Performance tests										
+ One-leg balance with eyes open, s	39.4	± 1.2	44.5	± 1.9	*	15.8	± 1.2	15.8	± 3.0	††
+ Tandem stance, s	28.5	± 0.3	28.7	± 0.4		23.6	± 0.7	22.1	± 1.7	††
+ Functional reach, cm	28.1	± 0.3	28.2	± 0.5		24.4	± 0.5	25.0	± 1.2	††
- 5-repetition chair stand, s	6.9	± 0.1	6.6	± 0.2		9.6	± 0.3	9.6	± 0.6	††
- Alternate step, s	4.4	± 0.1	4.1	± 0.1	*	5.7	± 0.2	5.8	± 0.4	††
- Timed up & go, s	6.1	± 0.1	5.9	± 0.1		8.6	± 0.2	8.6	± 0.6	††
- 5-m habitual walk, s	3.8	± 0.1	3.5	± 0.2		5.0	± 0.2	5.0	± 0.4	††
- Tandem walk, s	11.6	± 0.2	11.0	± 0.3		15.4	± 0.4	17.2	± 1.1	††

N (%) or adjusted mean ± standard error. R = number of risk factors for falling.
† $P < 0.05$, †† $P < 0.01$ versus lower-risk. * $P < 0.05$, ** $P < 0.01$ versus non-walkers. Analysis of covariance (ANCOVA); continuous variables were adjusted by age and gender (age was adjusted only by gender). BMI = body mass index. [1] Less than 5% missing data. +: Higher values signify better performance, -: Lower values signify better performance

Table 11. Lifestyle, psychological factors, functional status, and medical history of the walkers and non-walkers, stratified by the higher- and lower-risk groups (n = 535)[1]

Variables	Lower-risk (R < 2) (n = 336)					Higher-risk (R ≥ 2) (n = 199)					
	Non-walkers (n = 247)		Walkers (n = 89)			Non-walkers (n = 170)		Walkers (n = 29)			
Lifestyle factors											
Field work, day/week	4.2	± 0.2	3.9	± 0.4		3.9	± 0.2	2.8	± 0.6		
House work, day/week	6.0	± 0.2	5.9	± 0.3		4.8	± 0.2	2.8	± 0.6	*	††
Frequency of outings, day/week	6.4	± 0.1	6.5	± 0.2		5.9	± 0.1	6.1	± 0.4		
Psychological factors											
Fear of falling, yes	76	(30.9)	21	(23.6)		104	(61.2)	16	(55.2)		††
Self-rated health, good	224	(90.7)	84	(94.4)		120	(70.6)	26	(89.7)	*	††
Functional status											
+TMIG-IC[2], 0-13	10.9	± 0.2	10.9	± 0.3		10.8	± 0.2	11.0	± 0.4		
Medical history in 1 year											
Stroke, yes	3	(1.2)	1	(1.1)		10	(5.9)	4	(13.8)		††
Hypertension, yes	87	(35.4)	35	(39.3)		86	(50.6)	15	(51.7)		††
Diabetes, yes	9	(3.7)	12	(13.5)	**	13	(7.7)	3	(10.3)		
Heart disease, yes	23	(9.4)	4	(4.5)		27	(15.9)	8	(27.6)		†
Osteoporosis, yes	15	(6.1)	4	(4.5)		23	(13.5)	3	(10.3)		††
Glaucoma/cataract, yes	9	(3.7)	6	(6.7)		19	(11.2)	4	(13.8)		†

N (%) or adjusted mean ± standard error. R = number of risk factors for falling.
† *P* < 0.05, †† *P* < 0.01 versus lower-risk. * *P* < 0.05, ** *P* < 0.01 versus non-walkers. Analysis of covariance (ANCOVA); continuous variables were adjusted by age and gender. [1] Less than 5% missing data, except in the categories of field work (n = 328) and house work (n = 325). [2] Tokyo Metropolitan Institute of Gerontology Index of Competence. +: Higher values signify better performance

Figure 12 shows the Kaplan-Meier curve illustrating the incidence of falls among the walkers and non-walkers in the lower and higher-risk groups. A significant difference in at least one of the four groups was observed ($P < 0.0001$).

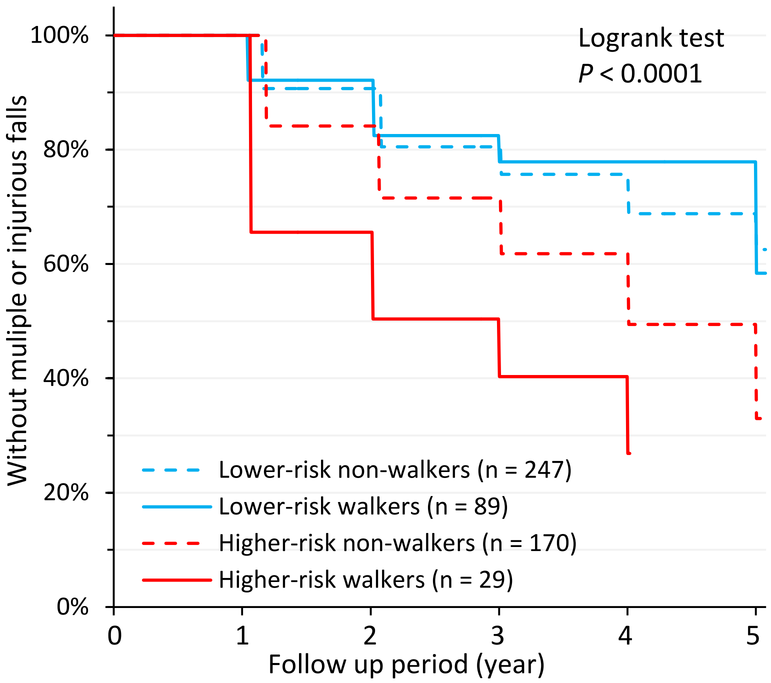

Figure 12. Kaplan-Meier curve on the appearance of multiple (≥ 2) or injurious (≥ 1) falls among the walkers and non-walkers in the lower and higher-risk groups (n = 535)

Table 12 shows the HRs (95% CIs) of habitual walking for falls during the follow-up period, stratified by the lower- and higher-risk groups. In the lower-risk group, no significant associations between habitual walking and falls were observed (HR: 1.00, 95% CI: 0.53-1.87). In the higher-risk group, a significant positive association between habitual walking and falls was observed (HR: 1.89, 95% CI: 1.04-3.43). In model 5, which was adjusted for all covariates, no associations between habitual walking and falls were observed in the lower-risk group (HR: 1.00, 95% CI: 0.53-1.89). In the higher-risk group, the significant positive association between habitual walking and falls remained consistent (HR: 2.17, 95% CI: 1.16-4.04).

Table 12. Hazard ratios and 95% CIs of habitual walking for multiple (≥ 2) or injurious (≥ 1) falls during the follow-up period in the lower- and higher-risk groups (n = 535)

	Lower-risk (R < 2)		Higher-risk (R ≥ 2)		
	Non-walkers (n = 247)	Walkers (n = 89)	Non-walkers (n = 170)	Walkers (n = 29)	
Model 1	1.00 (reference)	1.00 (0.53-1.87)	1.00 (reference)	1.89 (1.04-3.43)	*
Model 2	1.00 (reference)	0.98 (0.52-1.86)	1.00 (reference)	1.89 (1.04-3.44)	*
Model 3	1.00 (reference)	0.97 (0.52-1.83)	1.00 (reference)	1.90 (1.04-3.47)	*
Model 4	1.00 (reference)	0.98 (0.52-1.84)	1.00 (reference)	1.90 (1.03-3.50)	*
Model 5	1.00 (reference)	1.00 (0.53-1.89)	1.00 (reference)	2.17 (1.16-4.04)	*

* $P < 0.05$
Model 1: adjusted by gender
Model 2: model 1 adjusted by age
Model 3: model 2 adjusted by depressive symptoms, poor balance, polypharmacy
Model 4: model 3 adjusted by use of assistive device, knee pain, mobility limitation
Model 5: model 4 adjusted by previous fall history
R = number of risk factors for falling. The risk factors are depressive symptoms, poor balance, polypharmacy, use of an assistive device, knee pain, mobility limitation, and previous fall history

4.3.5. The analysis of the Interaction

A statistical interaction between habitual walking and higher-risk (R ≥ 2) was observed in the Cox proportional hazard model adjusted for all covariates ($P < 0.05$).

4.4. Discussion

4.4.1. Habitual walking and fall incidence among the higher-risk older adults

The results of this longitudinal study showed that habitual walking significantly contributed to an increase of the incidence of falls by two-fold among higher-risk community-dwelling older adults (HR: 2.17, 95% CI: 1.16-4.04). This result is consistent with the results of the previous cross-sectional study (Study 1) (Okubo et al., 2011), which showed that habitual walking among higher-risk community-dwelling older adults was significantly associated with an increased history of falls (adjusted OR: 4.61, 95% CI: 1.32-16.09). The results were also consistent with the meta-analysis of 44 RCTs of fall prevention programs (Sherrington et al., 2008), which reported that the inclusion of a walking program significantly increased the fall incidence (fall rate ratio: 1.32, 95% CI: 1.11-1.58). In that meta-analysis, 29 (59%) of the 44 RCTs examined recruited higher-risk populations such as aged care facility residents.

The higher-risk participants in our study scored significantly worse in all of their physical performance characteristics, such as dynamic and static balance, strength, gait, and agility, compared with the lower-risk participants. The walking pattern of the older adults was characterized by decreases in the step length, range of motion in hip flexion and extension, dorsiflexion of the ankle, and toe elevation during the swing phase (Murray et al., 1969). The decrease in toe elevation during the swing phase increases the risk of stumbling over obstacles (Kaneko et al., 1991). Trips were the most prevalent cause of falls that occurred while walking (Berg et al., 1997) and accounted for 48.5% of the total number of falls in this study. Older adults tend to reduce their level of physical activity as they become afraid of falling (Wijlhuizen et al., 2007), and the decrease in physical activity (e.g., avoiding hazards) in older adults can generally be interpreted as a behavioral response to perceived difficulty in controlling balance (Etman et al., 2012). If higher-risk walkers have a vulnerable walking pattern, they may have a greater chance of trips and falling. On the other hand, while the majority of falls (58.3%) occurred during walking (which was not necessarily intended as exercise), accidental falls that were likely unrelated to the participants' habitual walking were included. In this regard, habitual walking by the high-risk older adults might have been related to other factors such as risk-taking behaviors in their activities of daily living (Kloseck et al., 2008).

4.4.2. The interaction between habitual walking and higher-risk of falling

The significant interaction between habitual walking and the risk of falling found in this study suggested that the effect of habitual walking on falls was modified when individuals have two or more risk factors for falling. This result suggested that when individuals have two or more risk factors for falling, caution is warranted when recommending habitual walking because walking may put these individuals at greater risk of multiple or injurious falls. Similar modification effects were reported with habitual walking (Study 1) (Okubo et al., 2011) and high physical activity (Faulkner et al., 2009; Stevens et al., 1997). In a case-control study (Stevens et al., 1997), high physical activity (exercise, heavy housecleaning, other hard labor) was associated with a reduction in the number of fractures occurring in participants with no ADL limitation (OR: 0.6, 95% CI: 0.5-0.8) but also with more fractures in participants with at least one ADL limitation (OR: 3.2, 95% CI: 1.1-9.8). A more comprehensive examination to explore which types of physical activity, including habitual walking, are strongly associated with falls is needed.

4.4.3. Habitual walking and fall incidence among the lower-risk older adults

In this longitudinal study, the habitual walking observed among 336 lower-risk participants was not significantly associated with reduction of falls (HR: 1.00, 95% CI:

0.53-1.89). This result did not account for the cause-effect relationship of the previous cross-sectional analysis in the Study 1 (Okubo et al., 2011), in which habitual walking for at least 30 minutes twice per week for one year was associated with 56% fewer falls among 585 lower-risk participants, which was a significant reduction (adjusted OR: 0.44, 95% CI: 0.20-0.97). The plausible explanations for the non-significant results are as follows. First, although the sample size goal based on the previous results in the Study 1 (Okubo et al., 2011) was fulfilled (goal: 280 person-years; analyzed data: 594 person-years), the statistical power may not be sufficient to detect a smaller difference. Second, because we did not collect data related to walking intensity, the inclusion of moderate-to-vigorous intensity walkers and older adults who merely walk for leisure might have weakened the association. However, in Table 10 (page 80), the lower-risk walkers presented significantly better performance in one-leg balance (static balance) and alternate step (stepping agility) than did the lower-risk non-walkers. Walking has been characterized as a "continuous process of recovery from a loss of balance" (Murray et al., 1969). Habitual walking may be effective in maintaining balance if it is continued with sufficient intensity for a long period of time; indeed, Brown and Holloszy (1993) reported that endurance training consisting of brisk walking, cycling, and jogging significantly improved one-leg balance at month 15. Because the effects of walking on falls have been inconclusive for many years (Gregg et al., 2000), a larger cohort and an RCT to re-examine the effects of habitual walking on falls in the non-high-risk population are needed (Voukelatos et al., 2011).

4.4.4. Strengths and limitations

Strengths of the current study include the longitudinal design to allow examination of the cause-effect relationship, and the original sub-group analysis with different levels of risk of falling. The results of the longitudinal association between habitual walking and future incidence of falls among the higher-risk older adults were robust, because it was significant even when adjusted for the strong risk factors such as previous fall history.

However, our study has several limitations. First, this study may not be widely generalizable for the following reasons: (1) the follow-up rate was not high (36.3%), and the mean follow-up period was relatively short (1.7 years) because the participants were free to participate in the annual health check-up, and a one-time absence was sufficient to terminate the follow-up; and (2) the study participants were limited to relatively healthy community-dwelling older adults who voluntarily participated in the health check-up. Second, there is the potential for unmeasured confounding variables that we could not assess, such as total physical activity, cognitive function, and risk-taking behavior. Third, although the reliability of a retrospective fall survey in Japanese community-dwelling older individuals has been confirmed (Haga et al., 1996), prospective surveillance using a monthly fall calendar will be more reliable.

4.4.5. Conclusion of the Study 2

In conclusion, this longitudinal study showed that the effects of walking on multiple or injurious falls are modified by the presence of risk factors for falling. When individuals have two or more risk factors for falling, caution is warranted when recommending walking because walking increases these individuals' risk of multiple or injurious falls. Further research should focus on safer walking programs for higher-risk, community-dwelling older adults and on the positive effects of habitual walking among the lower-risk, general community-dwelling older adults.

CHAPTER 5

STUDY 3:

Effects of walking on physical and psychological fall-related factors among general community-dwelling older adults

Related publication

Okubo et al., The effects of walking on physical and psychological fall-related factors in community-dwelling older adults: A walking versus balance program. J Phys Fitness Sports Med, 3(5): 515-524, 2014.

5.1. Background and purpose

Contrary to the negative previous reports regarding the effects of walking on falls (Sherringtion et al., 2008), the results of the Studies 1 and 2 indicated a beneficial and non-harmful effect of walking regarding fall prevention among the lower-risk general community-dwelling older adults.

Primary fall prevention strategies for the general population of community-dwelling older adults who are not yet at high-risk are potentially important because, among this population, approximately 20% experience falls each year (Mertz et al., 2010). This 20% of the older population is likely to transition to a high-risk for future falls because previous fall experience is consistently found to be one of the strongest predictors of future falls in various studies (American Geriatrics Society, 2001). Moreover, all older adults have the possibility of developing a high-risk of falling in the future; we do not need to wait for that to happen to prevent or at least slow down the development of this risk.

Exercise interventions can be safer and more effective when older adults are physically fit and cognitively intact (Uemura et al., 2013). Although walking was reported to be less effective than strength and balance training among high-risk older adults (Sherrington et al., 2008), greater effects on physical function may be obtained among general older adults who can walk with a higher intensity and longer duration. The question remains whether regular walking is effective in improving lower-extremity muscle strength or balance or overcoming the fear of falling, and further, whether walking is comparable to strength and balance training which are the most common types of exercise for fall prevention (Gillespie et al., 2012). Therefore, the purpose of the study 3 was to examine the effects of walking on physical and psychological fall-related factors compared to strength and balance training among general, community-dwelling older adults.

5.2. Methods

5.2.1. Study design

The study was a 2-armed intervention trial. The current research focused on examining the short-term effects of walking compared to a strength and balance program over a 12-week intervention.

5.2.2. Settings and participants

The study participants were recruited through the methods described previously (see 2.2.4, in page 34). Of 243 applicants, 105 individuals were allocated to the walking (n =

60) or balance (n = 45) groups. A total of 90 participants who remained in the study until the post-intervention assessment (n = 50 in the walking group, n = 40 in the balance group) were included in the final analysis.

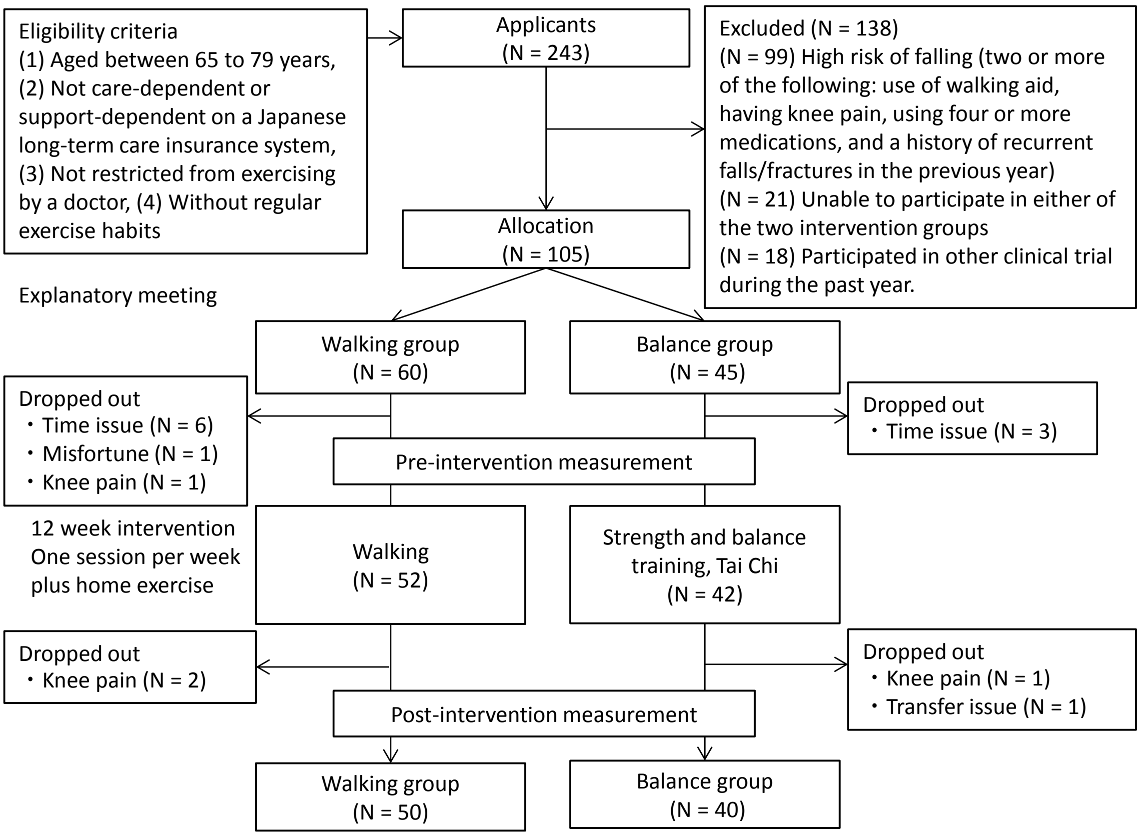

Figure 13. Flow chart of the study participants

5.2.3. Intervention

The detail information on intervention programs for the walking and balance groups has been described previously (see 2.2.6 Intervention programs, in page 35).

5.2.4. Main outcome measurements

Physical and psychological functional measurements that have been reported to be fall-related factors (American Geriatrics Society, 2001) and to be associated with functional dependence (Shinkai et al., 2000) were measured at baseline and after the 12-week intervention. The detail methods of each measurement has been described previously (see 2.2.7, in page 41)

Gait was assessed using usual and maximal gait speeds, 10-meter walk over obstacles, and 6-minute walk. Balance was assessed using one-legged stance with eyes closed, timed up and go test, and functional reach. Strength was assessed using 30-second chair stand test and knee extension force. Fall-related psychological function was assessed using fall self-efficacy scale for older Japanese (Takenaka et al., 2002).

5.2.5. Secondary outcome measurements

The numbers of falls and trips were recorded at the beginning of each weekly session throughout the 12-week intervention period. Participants were also asked whether they suffered any injuries as a result of the fall, such as bruises, lacerations, or fractures. A trip was defined as “the act of stumbling over an object without landing on any part of the body" (Shigematsu et al., 2008).

Daily step counts were measured using a pedometer (see 2.2.7.10, in page 45).

5.2.6. Statistical analysis

All the participants who remained in the study until the post-intervention measurement, regardless of attendance and exercise participation, were included in all the analyses. The participants with missing data (two variables, one case each) were included with the last observation carried forward (LOCF) methods, assuming no change. The unpaired *t* test or χ-square test was used to examine the statistical significance of between-group differences at baseline. The paired-*t* test or Wilcoxon's signed-rank test was used to examine the statistical significance of improvements after the 12-week intervention. Two-way analysis of variance was used to examine the statistical significance of between-group interactions of the main effects (changes between pre- and post-intervention). In order to address imbalances between baseline values and gender, analysis of covariance was also used to examine the between-group difference of the changes of outcome measurements pre-and post-intervention, adjusted for baseline values and gender. Negative binomial regression analysis was used to examine the statistical significance of between-group differences in fall status.

The data were analyzed using IBM SPSS Statistics software, version 21 (SPSS Inc., Chicago, IL, USA), with the level of statistical significance set at 5%.

5.3. Results

5.3.1. Characteristics of the participants, attendance, and dropouts

Of the 90 participants who remained in the final analysis (Figure 13, page 93), the average age was 70.1 ± 3.8 years old, and 62.2% were women. No significant between-group differences were observed in the participant characteristics (Table 13, page 97) and outcome measures at baseline, except for the fall self-efficacy scale (Table 15, page 100). The individual attendance rates were 95.0% for the walking group and 94.2% for the balance group. Adherence to the home exercises (an average of 3 days/week or more) was 96.0% for walking group and 95.0% for the balance group. Ten participants in the walking group (16.6%) and 5 participants in the balance group (11.1%) dropped out of the study (Figure 13, page 93). No significant differences in age and gender were observed between the participants who did or did not drop out.

Table 13. Baseline characteristics of the study participants (n = 90)

Variables	Total (n = 90)		Walking group (n = 50)		Balance group (n = 40)		*P* for difference
Age, year	70.1	± 3.8	70.3	± 3.9	70.0	± 3.7	0.686
Gender, female	62.2		60.0		65.0		0.667
Height, cm	157.4	± 7.7	157.6	± 7.8	157.1	± 7.5	0.750
Weight, kg	56.1	± 9.8	56.1	± 9.2	56.1	± 10.6	0.983
BMI, kg/m^2	22.6	± 3.6	22.5	± 2.7	22.8	± 4.5	0.737
Body fat, %	24.8	± 9.2	24.2	± 8.3	25.5	± 10.3	0.505
Medication use, n	0.9	± 1.4	1.1	± 1.7	0.7	± 1.1	0.505
Hypertension, yes	15.6		20.0		10.0		0.248
Diabetes mellitus, yes	11.1		14.0		7.5		0.502
Heat disease, yes	1.1		0.0		2.5		0.444
Hyperlipidemia, yes	8.9		4.0		1.5		0.132
Cataract/glaucoma, yes	22.2		22.0		22.5		1.000
Lumbar pain, yes	17.8		16.0		20.0		0.782
Knee pain, yes	7.8		6.0		10.0		0.695
Fear of falling, yes	24.4		32.0		15.0		0.085
TMIG-IC, score	12.4	± 1.0	12.4	± 1.2	12.5	± 0.8	0.727

Mean ± standard deviation or %. TMIG-IC: Tokyo Metropolitan Institute of Gerontology Index of competence. *P* values were calculated using an unpaired *t* test for the continuous variables or a χ-square test for the categorical variables.

5.3.2. Exercise components during the interventions

The average speed and distance of walking in a session were 93.2 ± 7.9 m/s and 3.9 ± 0.3 km, respectively (Table 14). The %HRmax values of the walking and balance groups (tai chi, strength and balance training) were 77.0 ± 9.6% and 55.1 ± 8.7% ($P < 0.01$), respectively.

Table 14. Exercise components during the 12-week intervention in the walking and balance groups (n = 90)

Variables	Walking group (n = 50)		Balance group (n = 40)	
Home exercise				
Frequency (days/week)	5.5	± 1.2	5.8	± 1.4
Walking				
Duration (min/day)	45.8	± 22.8	NA	
Amount (min/week)	262.8	± 166.5	NA	
Strength training (sets/day)	NA		1.7	± 0.8
Supervised exercise				
RPE (6-20)	11.6	± 0.9	12.3	± 1.0**
HR (b/min)	115.2	± 13.5	82.5	± 12.8**
%HRmax (%)	77.0	± 9.6	55.0	± 8.8**
Walking				
Distance (km)	3.9	± 0.3	NA	
Duration (min)	41.4	± 2.1	NA	
Speed (m/min)	93.2	± 7.9	NA	

Mean ± standard deviation. NA: not applicable, HR: heart rate, RPE: rating of perceived exertion. ** P < 0.01 vs the walking group.

5.3.3. Main outcome

Table 15 represents fall-related physical and psychological functions and physical activity over the 12-week intervention among the walking and balance groups. Significant improvements in both groups over the 12-week intervention were observed in usual/maximum gait speed, timed up and go, 10-m walk over obstacles, 6-minute walk, functional reach, 30-s chair stand test, and isometric knee extension force (Table 15, page 100). However, the knee extension force in the balance group (+4.9 ± 6.1 kg) showed significantly greater improvement than that in the walking group (+2.5 ± 4.7 kg) (*P* for interaction = 0.042). One-legged balance with eyes closed was significantly improved only in the balance group. The fall self-efficacy scale significantly improved in the walking group (+3.1 ± 8.0 points), but significantly decreased in the balance group (-2.6 ± 8.0 points) (*P* for interaction = 0.001).

Table 15. Fall-related physical and psychological functions and physical activity over the 12-week intervention among the walking (n = 50) and balance (n = 40) groups.

Variables	Group	Baseline		Post-intervention		*P* for difference	*P* for interaction
Usual gait speed, m/s	W	1.37	± 0.20	1.54	± 0.18	< 0.001	0.337
	B	1.40	± 0.19	1.54	± 0.20	< 0.001	
Maximum gait speed, s	W	2.05	± 0.29	2.15	± 0.28	0.005	0.803
	B	2.05	± 0.26	2.17	± 0.30	< 0.001	
Timed up & go, s	W	6.3	± 0.9	5.7	± 0.8	< 0.001	0.548
	B	6.2	± 0.7	5.7	± 0.8	< 0.001	
Obstacle avoiding walk, s	W	7.8	± 1.7	7.1	± 1.2	< 0.001	0.830
	B	7.6	± 1.2	7.0	± 1.0	< 0.001	
Six-minute walk, m	W	558.3	± 57.9	609.7	± 61.2	< 0.001	0.069
	B	569.6	± 88.1	603.8	± 75.4	< 0.001	
One-leg stance with eyes opened, s	W	38.8	± 21.3	40.1	± 21.4	0.569	0.474
	B	38.9	± 21.1	42.8	± 18.5	0.207	
One-leg stance with eyes closed, s	W	4.9	± 3.8	6.3	± 9.3	0.250	0.092
	B	5.7	± 4.8	10.5	± 10.4	0.004	
Functional reach, cm	W	28.4	± 5.0	31.0	± 5.0	< 0.001	0.674
	B	28.9	± 5.1	31.2	± 4.4	0.004	
Chair stand, n/30s	W	21.2	± 4.2	22.8	± 4.5	0.003	0.240
	B	20.8	± 4.7	23.3	± 5.0	< 0.001	
Knee extension force, Nm[1]	W	103.6	± 36.1	111.1	± 33.6	< 0.001	0.042
	B	91.8	± 31.4	105.9	± 34.3	< 0.001	
Fall self-efficacy, point	W	54.5	± 12.0*	57.6	± 11.5	0.008	< 0.001
	B	60.6	± 9.0	58.0	± 10.6	0.045	
Daily step counts, n/day[2]	W	6156.7	±3046.1	9448.6	± 3324.6	< 0.001	0.001
	B	6121.9	± 3284.3	6545.3	± 2798.3	0.167	

Mean ± standard deviation. * $P < 0.05$ vs the balance group at baseline. The last observation carried forward method was applied to [1] one missing datum in the balance group [2] and one missing datum in the walking group.

Figure 14 (page 101) represents the between-group comparisons of the changes of outcomes over the 12-week intervention, adjusted for each baseline value and gender. Significant difference was observed in the fall self-efficacy scale ($P < 0.05$). No significant differences were observed in other outcome measures.

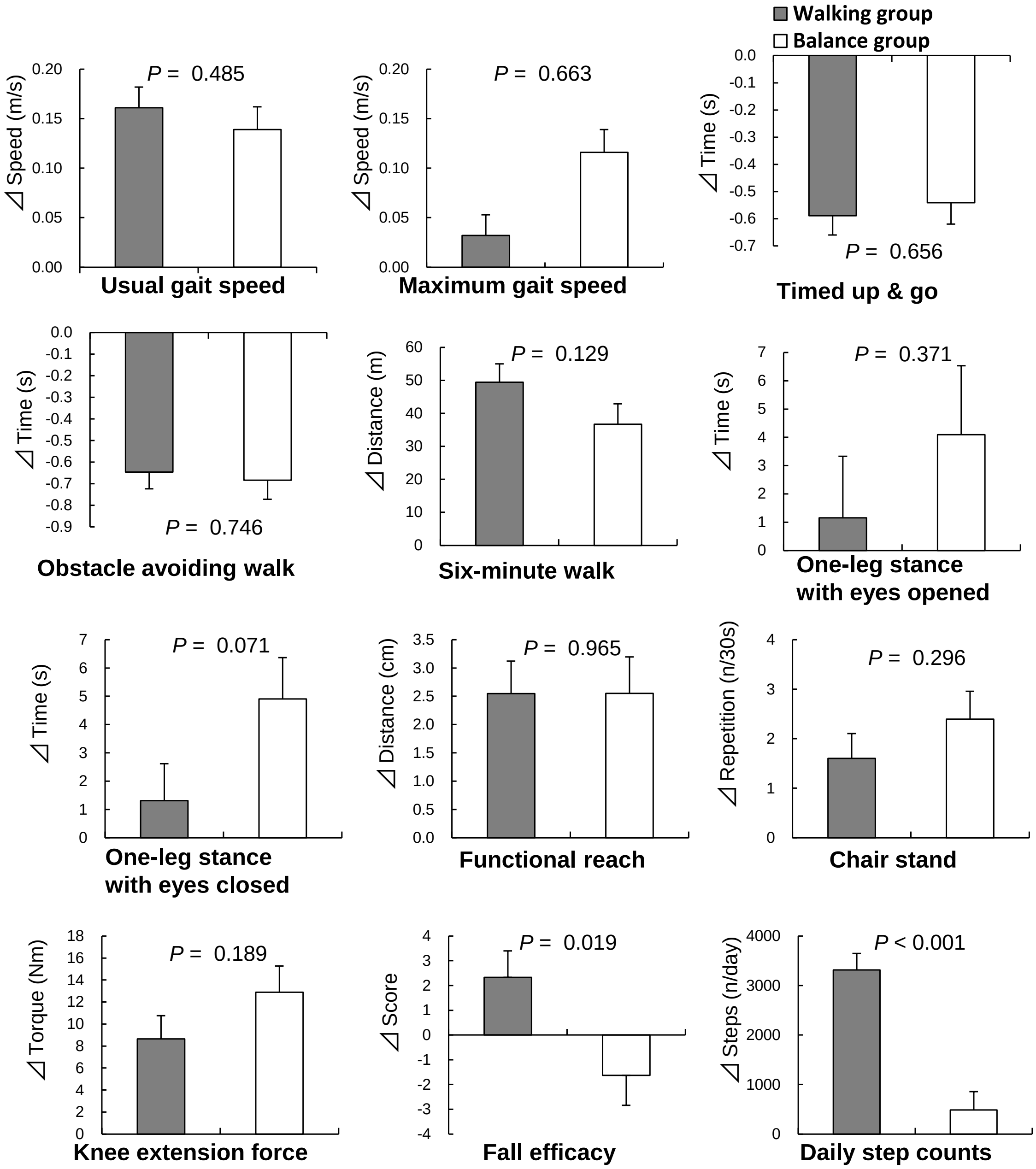

Figure 14. Comparisons of changes in fall-related physical and psychological functions and physical activity over the 12-week intervention between the walking (n = 50) and balance (n = 40) groups.

5.3.4. Secondary outcome

Daily step counts were significantly improved only in the walking group (+3366.4 ± 3212.5 steps/day) (P for interaction < 0.001) (Table 15, page 100). A significant difference was also observed in daily step counts after adjusting for the baseline value and gender ($P < 0.05$).

The incidence rates (number of incidences per 100 person-months) of trips (Walking: 32.0, Balance: 25.8, P = 0.674), falls (Walking: 5.3, Balance: 9.2, P = 0.312), and injurious falls (Walking: 3.3, Balance: 3.3, P = 0.708) did not differ significantly between the two groups.

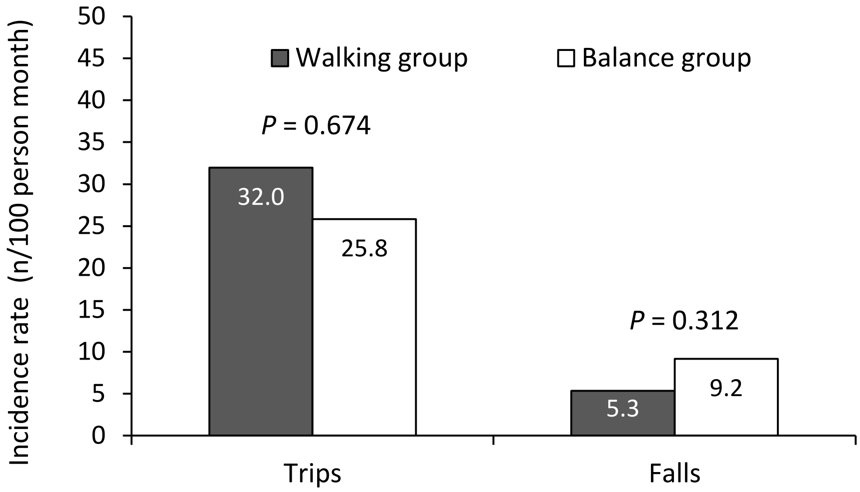

Figure 15. Incidence rates of falls and trips during 12-week intervention period among the walking (n = 50) and balance (n = 40) groups.

5.4. Discussion

Walking has previously been reported not to be effective for fall prevention (Sherrington et al., 2008). However, this study suggested that walking, which is the most common exercise, was also effective among general community-dwelling older adults in improving physical fall-related factors (American Geriatrics Society, 2001) — gait, dynamic balance, and the strength of the lower extremities — compared to the balance and strength program. Moreover, this was the first study that showed the particular effectiveness of walking in improving fall self-efficacy, a psychological fall-related factor.

5.4.1. Main outcome: physical and psychological fall-related factors

5.4.1.1. Gait

As expected, 12 weeks of walking improved usual and maximum gait speeds by 12% and 4.9%, respectively. Figure 14 indicated that the effects of walking on usual gait speed were equal to those of the strength and balance training, but were slightly smaller with regard to maximum gait speed. Buchner et al. (1997a) examined groups engaging in stationary cycling, walking, aerobic movement, or no exercise (controls), and only the walking group significantly improved in usual gait speed, by 5%. Because slow walking speed was a strong risk factor for falling (American Geriatrics Society, 2001), it is argued that walking is effective in improving this fall-related physical function.

5.4.1.2. Strength

Nemoto et al. (2007) reported that among middle-aged and older participants aged 63 ± 6 years, high-intensity interval walking (40% to 70% of peak aerobic capacity) for 4.5 days/week for 5 months significantly improved isometric knee extension force by 13%. However, Kubo et al. (2008) reported that a self-selected, comfortable pace of walking for 40 min, 4 days/week for 6 months, did not improve the isometric knee extension force. Nemoto et al. (2007) also reported that moderate-intensity walking, 4.5 days/week for 5 months, did not improve the isometric knee extension force. In the current study, brisk walking, at an average pace of 93.2 m/s and %HRmax of 77.0% for 12 weeks, significantly improved the isometric knee extension force by 7%. Morris and Hardman (1997) suggested that walking faster than a customary pace and regularly, in sufficient quantities, in the “training zone” of more than 70% of the maximal heart rate was required to develop and sustain physical fitness. Rooks et al. (1997) reported that among community-dwelling older adults aged 65-95, self-paced strength training done 3 days/week for 10 months resulted in a significant 65% increase in knee extension strength (1RM), but that self-paced walking for 45 min, 3 days/week for 10 months, resulted in a non-significant decrease. In the current study, although, the difference did not reach statistical significance in the gender- and baseline-adjusted model, the effects of strength training (+16%) on the isometric knee extension force were greater than those from walking (+7%). Moreover, a learning effect of repeated measurements should be carefully taken into account in the values. Therefore, the short-term effect of brisk walking on isometric or maximal knee extension force among the general community-dwelling older adults may exist but its magnitude may be small compared to the strength training.

On the other hand, the effect of walking on dynamic strength of the lower extremities (30-s chair stand test) was similar to that of the balance and strength program. Dynamic strength, which is more closely related to movements in daily activities, may be related to fall prevention because most falls occur during dynamic activities such as walking, turning, and reaching (Judge et al., 1996).

5.4.1.3. Balance

Walking was equally effective for improving dynamic balance (functional reach and timed up and go tests) as the strength and balance program, but not as effective for static balance (one-legged balance with eyes closed). Paillard et al. (2004) also reported that brisk walking, done 5 days/week for 12 weeks, significantly improved dynamic balance (body sway on unstable platform), but not static balance (body sway on stable ground).

Walking has been characterized as a “continuous process of recovery from a loss of balance” (Murray et al., 1969) and thus as a factor contributing to the maintenance of dynamic balance. Walking might be effective for static balance if continued for a longer period of time; Brown and Holloszy (1993) reported that endurance training consisting of brisk walking, cycling, and jogging for one year significantly improved one-leg balance at month 15, but not at month 3. With regard to the comparison with the strength and balance program, although the difference of the gender- and baseline-adjusted change in one leg stance with eyes closed was not significant (P = 0.071), a significant difference would likely be observed with a greater sample size. Rooks et al. (1997) reported that self-paced walking significantly improved one-leg balance at month 10, but that a greater improvement was achieved by strength training. On the other hand, Rooks et al. (1997) also reported that tandem walking, as an indicator of dynamic balance, was significantly improved in the walking group but not in the strength training group. Future research should examine which of the static and dynamic balance improvements are more closely related to the prevention of falls.

5.4.1.4. Fall self-efficacy

Fall self-efficacy, or the confidence of an individual in his ability to perform daily activities without falling (Tinetti et al., 1990), is important in maintaining an active lifestyle and physical function, as activity restriction due to loss of confidence or fear of falling can lead to future functional decline and a consequent increased risk of falling (Deshpande et al., 2008). In the current study, fall self-efficacy was significantly increased only in the walking group and significantly decreased in the balance group. Yoo et al. (2010) reported that among women of average age 70.9 ± 2.7 years old walking with ankle weights, 3 days/week for 12 weeks, resulted in a significantly decreased fear of falling. The Study 1 (Okubo et al. 2011) also revealed that high-risk walkers aged 78.5 ± 2.7 years old had a significantly lower fear of falling (44.4%) than high-risk non-walkers (73.3%). Although the mechanism of how the fall self-efficacy is increased by walking remains uncertain, a possible explanation is that the walking group experienced a greater chance of falling, along with the 56% increased daily step counts, than the balance group, without actually falling at a greater rate. This experience of avoiding falling in an outside environment in the walking group might have increased the fall self-efficacy of the participants. While the walking group spent most of their exercise time outside, all of the strength and balance training was conducted inside of a building. While this way of improving fall self-efficacy requires increased caution for high-risk older adults due to increased environmental hazards, it is clearly desirable for general community-dwelling older adults to maintain a high level of physical activity.

5.4.2. Secondary outcomes: fall status and physical activity during the intervention period

5.4.2.1. Fall status & physical activity

The recent meta-analysis by Sherrington et al. (2011) re-examined the effects of walking on falls and suggested that walking can be included in fall prevention programs, if the participants are not at high risk for falling. The results of the Study 3 partially supported this recommendation, because increased physical activity among general community-dwelling walkers did not result in a greater fall incidence over the 12-week intervention. The results were also consistent with the cross-sectional analysis in the Study 1 (Okubo et al., 2011), which showed that among general community-dwelling older adults, habitual walking for 48.1 ± 20.3 min, 5.3 ± 2.0 days/week for 7.6 ± 6.5 years, was significantly correlated with a history of fewer falls over the previous year. The participants in the current study improved obstacle avoidance, dynamic balance, and lower-extremity muscle strength, as well as succeeded in preventing falls and trips. The fall prevention lectures about fall-prone situations, walking patterns, and the importance of paying proper attention might have played a role in the improvements observed in the walking group, as these participants encountered greater exposure to environmental hazards. We clarified to the participants that although slow gait speed and a short stride were key characteristics of fall-prone older people (Luukinen et al., 1995b), a fast walking speed and wide stride rendered participants vulnerable to falling after trips (Pavol et al., 2001) and to slipping (Espy et al., 2010), respectively. In contrast to the walking group, almost no increase in physical activity was observed among the balance group. This may have contributed to the previous success of reducing falls by balance training without a walking component (Sherrington et al., 2011). However, if the final goal of fall prevention is to allow older populations to safely and freely walk and maintain a good quality of life, an intervention that maintains or improves physical and psychological factors to the extent that older adults can sustain exposure to increased environmental hazards is required.

5.4.3. Strengths and limitations

The high feasibility of this protocol as a health promotion program in communities is a strength of the current study; the dropout rate was low (14.3%) and the attendance rate was high (94%).

In contrast, there were several limitations in the current study. First, the generalizability of the study may not be high because the participants were limited to an age range of 65 to 79 years old. Certainly, there are populations older than 80 years of age that would benefit from regularly walking outside. Second, the sample size (n = 90) may be insufficient to detect between-group differences for some outcome variables (effect size < 0.3). The between-group difference in changes for one-leg stance with eyes closed and knee extension force might be better detected with a bigger sample size (effect size: 0.15-2.0, α error: 0.05, β error: 0.8, sample size: 200-380). The non-significant differences in falls and trips between the groups might also have been due to an insufficient sample size and the short follow-up duration. Third, the reliability of measurements was excellent (except for one-leg balance with eyes closed) (see 2.2.7, in page 41), a learning effect of repeated measurements could not be ruled out in the study design a without a non-exercise control group.

5.4.4. Conclusion of the Study 3

In conclusion, the results of the current study suggest that walking has specific effects in improving psychological fall-related factors, as well as similar effects as the balance and strength training program in improving fall-related physical factors such as gait, dynamic balance, and the dynamic strength of the lower extremities, without increased falls over the 12-week intervention. Therefore, walking is suggested to be a useful type of exercise to maintain the physical and psychological fall-related factors among general community-dwelling older adults.

CHAPTER 6

STUDY 4:

Effects of walking on falls among general community-dwelling older adults

Related publication

Okubo et al., Walking can be more effective than balance training in fall prevention among community-dwelling, older adults. Geriatr Gerontol Int. (in press)

6.1. Purpose

Although the study 3 indicated the positive physical and psychological effects along with the walking intervention, the previous studies reported that increased physical activity led to increased exposure to environmental hazards, and consequent high incidence of falling (Ebrahim et al., 1997; Sherrington et al., 2008). The problematic nature of a walking intervention aiming at fall prevention is that along with the improvements in physical and psychological functions, it is also accompanied by an increased exposure to environmental hazards (e.g., a greater chance of trips while walking). Wijlhuizen et al. (2010) developed the FAlls risk by Exposure (FARE), in which 1000 physically active person-days and the number of fallers over ten months are computed to evaluate the risk of falling. FARE was able to reveal the high relative risk of falls among participants with balance control difficulties, which could not be observed with a normal fall risk indicator by 1000 person-years. To the best of our knowledge, no previous intervention studies have evaluated the effects of walking on falls while also accounting for exposure (the numbers of physically active days and step counts). Therefore, the purpose of this Study 4 was to examine the effects of walking on falls and evaluate these effects by both time period and exposure among the general community-dwelling older adults.

6.2. Methods

6.2.1. Design and participants

This study was an extension of the previously reported 3-month controlled trial in the Study 3 (Okubo et al., 2014a) with an additional 13-month follow-up survey (clinical trials registry: UMIN000012058). The flow of the participants was shown in Figure 16 (page 115). The 90 participants who completed the Study 3 (n = 50 in the walking group and n = 40 in the balance group) were included in the fall analyses. A total of 75 participants who attended the follow-up assessment (n = 42 in the walking group and n = 33 in the balance group) were included in the analysis of secondary outcomes.

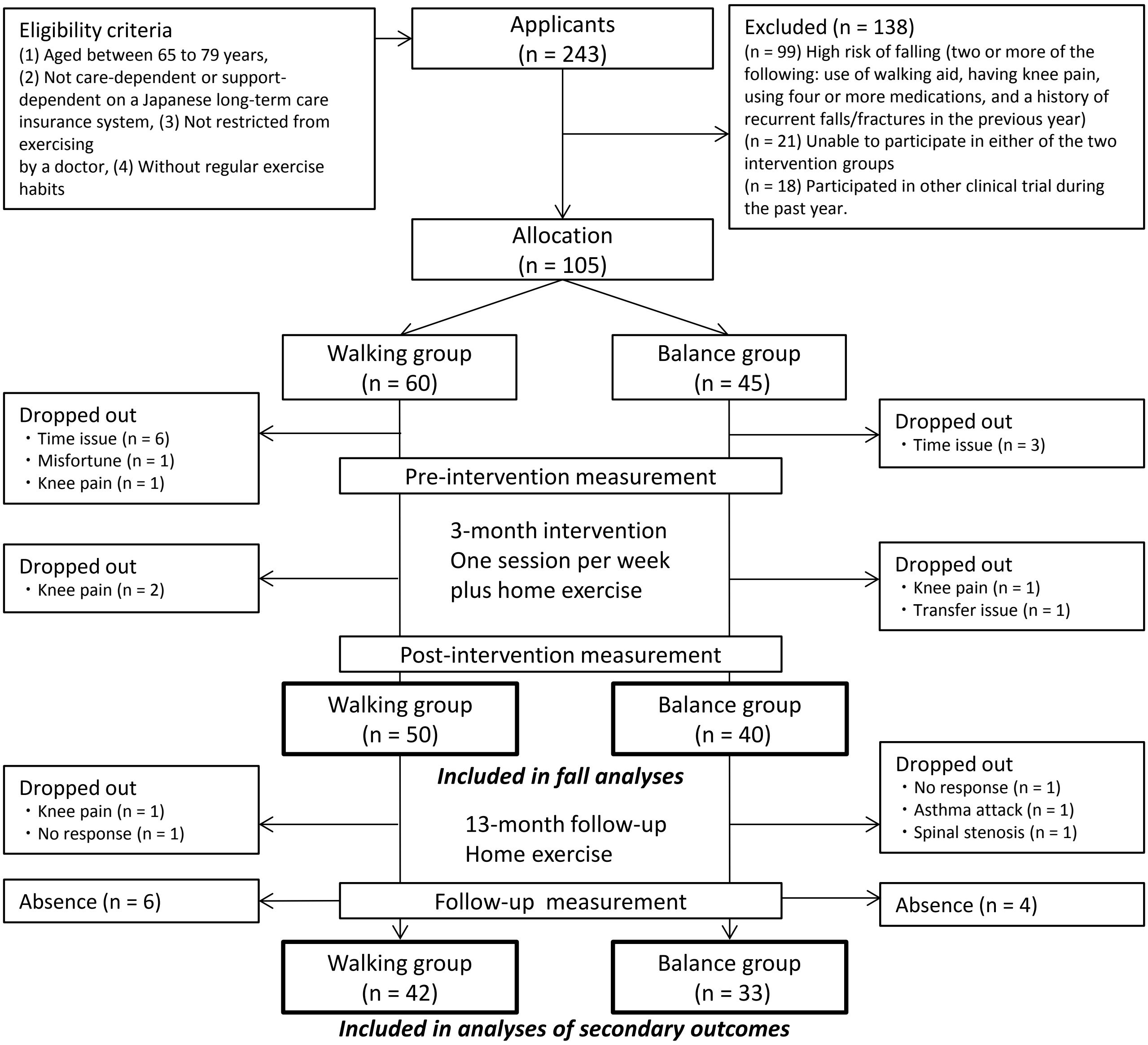

Figure 16. Flow chart of the study participants

6.2.2. Measurements

6.2.2.1. Main outcomes: Falls and trips

In order to collect reliable and valid data during the follow-up period (Lamb et al., 2005) , the participants were asked to record numbers of falls and trips each day in a fall and exercise calendar, and send it to the university at the end of each month. Telephone calls were made to chase missing data and to ascertain further details of falls as required. The definitions of a fall (see 1.5.3, page 19) and trip (see 5.4.2.1, page 108) have been described previously.

6.2.2.2. Time and exposure variables

The number of months for which the participants were followed-up was used in the analysis. At the end of the intervention, the number of physically active days was ascertained by a question: “How many days in a month have you been physically active - walking for at least 30 minutes? (Wijlhuizen et al., 2010)” Daily step counts were also measured with accelerometers (Life-coder PLUS, Suzuken Inc., Japan), which were used by the participants for one week.

6.2.2.3. Secondary outcomes

As fall-related physical and psychological functions (American Geriatrics Society, 2001), we chose to assess gait, balance, fall-efficacy, and physical activity at baseline, immediately after the 3-month intervention, and at the 1-year follow-up. *Gait* was assessed with an obstacle avoidance walk and a 6-minute walk. *Balance* was assessed with a one-legged stance with the eyes closed. *Fall self-efficacy* was assessed with the fall self-efficacy scale for older Japanese. *Physical activity* was assessed as daily step counts (see 2.2.7, in page 41).

6.2.3. Statistical analyses

The baseline characteristics of the walking and balance groups were compared with an unpaired *t*-test and χ-square test. A Poisson regression analysis was used to calculate the adjusted rate ratio (RR) and 95% CIs with the number of falls or trips as dependent variables, the gender and baseline fall history (yes/no) as covariates, and the groups as independent variables. The offset variables included the time period (followed months), physically active days (followed months*physically active days/10), or steps (followed months*daily steps/100,000). Within-group changes and between-group interactions of the secondary outcome measurements between both groups at baseline, post intervention, and follow-up were examined by a two-way analysis of variance (ANOVA) with the Bonferroni correction. These analyses were conducted using IBM SPSS Statistics software, version 21 (SPSS Inc., Chicago, IL, USA), and the level of significance was set at 5%.

6.3. Results

Of the 90 participants who remained in the fall analyses (Figure 16, page 115), the average age was 70.1 ± 3.8 years old. No significant between-group differences were observed in the participant characteristics at baseline (Table 16). During the 16-month study period, an average of 1.4 ± 0.5 sets/day were performed for 4.6 ± 2.0 days/week in the balance group, and an average of 45.2 ± 24.5 minutes/day of walking for 4.3 ± 1.7 days/week (231.4 ± 179.3 minutes/week) were performed in the walking group.

Table 16. Baseline characteristics of the study participants (n = 90)

Variables	Walking group (n = 50)		Balance group (n = 40)		*P*-value
Age, year	70.3	± 3.9	70.0	± 3.7	0.686
Gender, female	60.0		65.0		0.667
Body height, cm	157.6	± 7.8	157.1	± 7.5	0.750
Body weight, kg	56.1	± 9.2	56.1	± 10.6	0.983
Medication use, n	1.1	± 1.7	0.7	± 1.1	0.505
Cataract/glaucoma, yes	22.0		22.5		1.000
Lumbar pain, yes	16.0		20.0		0.782
Knee pain, yes	6.0		10.0		0.695
Fear of falling, yes	32.0		15.0		0.085
Fall history in a past year, yes	18.0		30.0		0.215

Mean ± standard deviation or prevalence (%)

During the follow-up period, which had an average ± standard deviation (SD) of 15.5 ± 2.2 (range: 5-16) months (in a total of 116 person-years), 53 falls were observed in both groups (0.46 falls per person-year).

Table 17 presents the circumstances of falls during the study period among the walking and balance groups. The falls in the walking group (68.2%) were significantly more likely to be occurred while walking than the balance group (37.9%). No significant differences were observed among the two groups. The major causes of falls among the walking and balance groups were trip (68.2% and 48.3%) and slip (22.7% and 20.7%). The major injury suffered by fallers in the walking and balance groups was abrasion (40.9% and 37.9%). Two fallers in the balance groups suffered fracture in front tooth or ankle.

Table 17. Circumstances of falls among the walking and balance groups (n = 53)

Variables	Walking group (23 falls)[1]		Balance group (29 falls)		*P*-value
Actions when falls occurred					
Walking	68.2	(15)*	37.9	(11)	0.032
Running	0	(0)	3.4	(1)	0.569
Using stairs	9.1	(2)	17.2	(5)	0.341
Getting up/down	4.5	(1)	17.2	(5)	0.171
Standing/reaching	9.1	(2)	10.3	(3)	0.632
Playing sports	4.5	(1)	3.4	(1)	0.682
Other tasks	4.5	(1)	13.8	(4)	0.273
Causes of falls					
Trip	68.2	(15)	48.3	(17)	0.484
Slip	22.7	(5)	20.7	(6)	0.563
Dizziness	0.0	(0)	0.0	(0)	-
Miss one's footing on something	4.5	(1)	10.3	(3)	0.417
Clash	4.5	(1)	3.4	(1)	0.682
Staggering	0	(0)	6.9	(2)	0.318
Suffered injuries					
Nothing	27.3	(6)	48.3	(14)	0.128
Abrasion	40.9	(9)	37.9	(11)	0.829
Hip fracture	0	(0)	0	(0)	-
Other fracture	0	(0)	6.9	(2)	0.318
Incised wound	27.3	(6)	6.9	(2)	0.056
Sprain	0	(0)	6.9	(2)	0.318
Other injuries	4.5	(1)	3.4	(1)	0.682

Percent (n).[1] Two falls in the walking group were missed

6.3.1. Main outcomes

The adjusted RRs (95% CIs) of falls per physically active person-day (0.38, 0.19-0.77) and falls per person-step (0.47, 0.26-0.85) among the walking group were significantly lower than those of the balance group (Figure 17, page 122). In contrast, the adjusted RRs (95% CIs) of trips per person-year (1.66, 1.34-2.05) and trips per physically active person-day (1.50, 1.12-2.00) of the walking group were significantly higher than those of the balance group. No other significant adjusted RRs were observed.

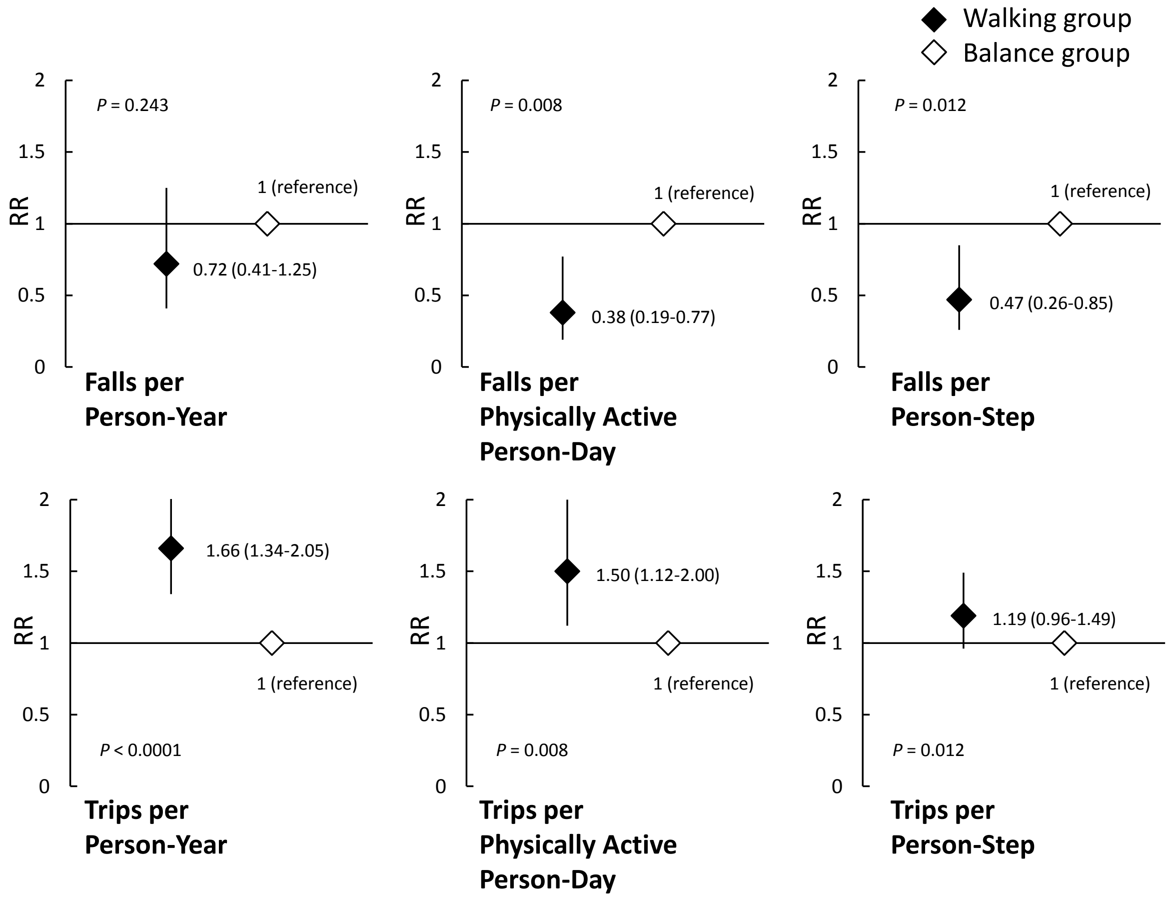

Figure 17. Rate ratios and 95% CIs for falls and trips by period or exposures among the walking (n = 50) and balance (n = 40) groups

RR and 95% CIs were adjusted for gender and baseline fall history.

6.3.2. Secondary outcomes

Post intervention, both groups demonstrated significant improvements in the obstacle avoidance walk and six-minute walk (Figure 18, page 124). At the follow-up, both groups maintained the improvements in the six-minute walk. However, significant between-group interactions in the six-minute walk test, fall efficacy, and daily step counts indicated that the walking group exhibited greater improvements than the balance group (P for interaction < 0.05). The obstacle-avoiding walk showed that the balance group improved more than the walking group, but this difference was not significant (P for interaction = 0.054). The one-leg stance with eyes closed significantly improved post intervention, only in the balance group, but significantly decreased at the follow-up. No significant between-group interaction was observed in the one-leg stance with eyes closed.

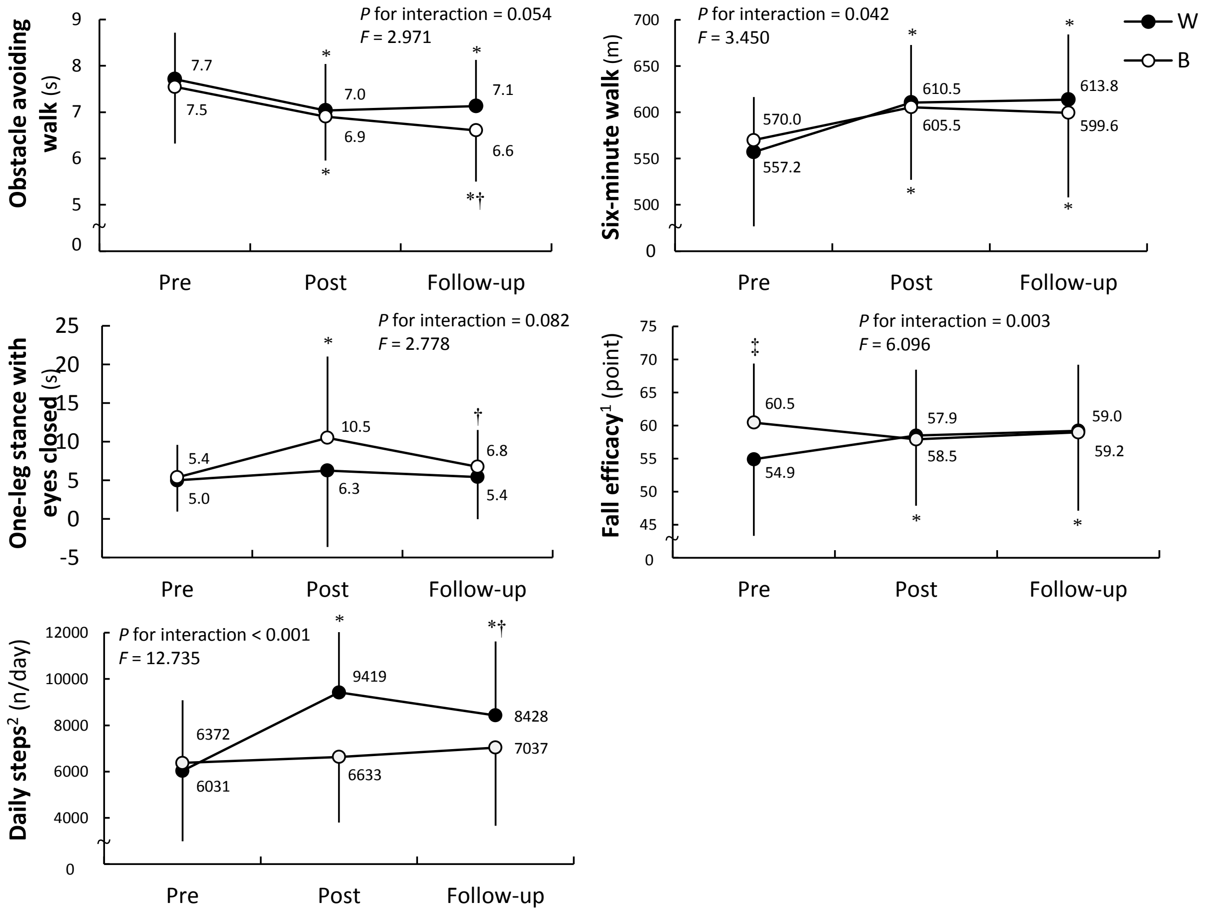

Figure 18. Changes of physical and psychological fall-related function and physical activity at pre- and post-intervention and follow-up among the walking (n = 42) and balance (n = 33) groups.

Circle: mean, error bar: standard deviation, * $P < 0.05$ vs pre, † $P < 0.05$ vs post, ‡ $P < 0.05$ vs the walking group at pre, [1] B (n = 36) and W (n = 45). [2] B (n = 35) and W (n = 47)

6.4. Discussion

To the best of our knowledge, this is the first study to demonstrate the beneficial effects of walking on fall prevention evaluated with exposure among community-dwelling, older adults. Despite the increase of trips with walking, the significant fall reduction effect of walking was observed when the fall risk was evaluated as falls per person-physically active day and falls per person-step.

6.4.1. Comparison with previous reports

The discrepancy between the positive finding of this study and the negative findings of the previous studies (Sherrington et al., 2008) could be partly explained by a couple of reasons. First, the systematic review with a meta-analysis indicated that walking had adverse effects on the number of falls (ratio of rate ratio: 1.32, 95% CI: 1.11-1.58) (Sherrington et al., 2008). However, the majority of the analyzed studies recruited high-risk participants such as frail nursing home residents (Mulrow et al., 1994), patients with Parkinson’s disease (Protas et al., 2005), osteoporosis (Madureira et al., 2007), stroke (Green et al., 2002), or those with a recent history of fractures (Ebrahim et al., 1997). In the Study 1, the harmful association between walking and fall history was observed only among high-risk participants (adjusted OR: 4.61, 95% CI: 1.32-16.09), and a beneficial relationship between walking and a lower fall history was observed among low-risk participants (adjusted OR: 0.44, 95% CI: 0.20-0.97). A similar modifying effect of frailty or having a high risk of falling on the association between walking and falls have been reported in longitudinal analysis of the Study 2 (Okubo et al., 2014b) and an intervention trial (Faber et al., 2006). Second, the 165 community-dwelling women aged 66.4 ± 7.8 years with recent histories of upper limb fractures included in the RCT by Ebrahim et al. (1997) were probably the closest to our study participants in terms of age and living conditions. Those participants were encouraged to gradually work up to walking for 40 minutes three times a week without supervision at a self-selected pace that was faster than their normal walking speed. In contrast, in our study, the walking exercise performed by the participants was supervised once a week for the first three months, and then the participants were encouraged to continue their walking for the 13-month follow-up. Moreover, the health lectures regarding fall-prone situations, walking patterns, and the importance of paying proper attention might also have played a role. We warned the participants that although a fast walking speed and wide stride were important in improving their physical function, those walking patterns made them vulnerable to falling after trips (Pavol et al., 2001) and to slipping (Espy et al., 2010), respectively.

The results of the current study were consistent with other studies conducted among relatively healthy community-dwelling older adults. Freiberger et al. (2007) conducted a valuable RCT which targeted preventing falls among physically active community-dwelling older people. An intervention group which received strength, balance, motor coordination, and endurance (normal walking and Nordic walking) exercises demonstrated significant 23% reduction of falls compared to a control group (RR: 0.77, 95% CI: 0.60-0.97). However, another intervention group which received strength, balance, and motor coordination exercises without endurance exercise showed no fall reduction compared to the control group (RR: 1.00, 95% CI: 0.75-1.34). Freiberger et al. (2007) left no clue for the mechanisms of the fall reduction effect because equal improvements in gait and lower-extremity strength were observed among the two intervention groups. Voukelatos et al. (2015) recently reported the results of an RCT of habitual walking (distribution of pedometers and pamphlets regarding habitual walking) among community-dwelling older adults. Comparing to the control group, the walking group demonstrated no significant reduction of multiple falls (RR: 1.01, 95% CI: 0.61-1.67). However, in the subgroup analyses among participants aged 65-74 years and 75+ years, non-significant 31% reduction of multiple falls (RR: 0.69, 95 CI: 0.36-1.34) and non-significant 82% increase of multiple falls (RR: 1.82, 95% CI:

0.79-4.23) were observed, respectively.

With regards to the balance group, the balance and strength program provided was similar to the programs reported to be effective in reducing falls among older adults who were frail and high risk of falling (Gardner et al., 2001). Despite of these previous reports and significant improvements in the lower-extremity performance (Study 3), no fall reduction was observed among the balance group. The muscle strengthening training using body weight (without using ankle weights or machines) may have been insufficient for the healthy, general community-dwelling older participants. Clemson et al. (2004), conducted a fall prevention RCT with balance and strength training, and reported that significant fall reduction effects were observed only among participants aged 75+ years (RR: 0.62, 95% CI: 0.43-0.89) but not among participants aged younger than 75 years (RR: 0.96, 95% CI: 0.50-1.85).

6.4.2. Evaluating falls with exposure

In the current study, the significant fall prevention effect of walking would not have been detected if the data had not been analyzed according to exposures. The significant reduction of fall risk by exposure indicates that the older adults were more physically active and walked more steps without falling. Wijlhuizen et al. (2007) reported that some older adults are afraid of falling and prevented falls by reducing their physical activity. However, a reduction in physical activity might lead to a faster functional decline and greater susceptibility to falling in the future. Additionally, Vetter et al. (1992) reported a non-significant increase in the number of falls by encouraging physical exercise and a positive outlook about their better mobility, quality of life, and even mortality. A fall prevention program should allow older populations to safely and freely walk to maintain a good quality of life.

6.4.3. Mechanisms of the fall prevention effect

Although the mechanisms by which walking led to the reduction of fall risk compared with the balance exercises are not fully understood, some possible explanations exist.

First, the six-minute walk, which tests gait or endurance, of the walking group significantly improved to a greater extent than the balance group. Mertz et al. (2010), studied 10,615 participants aged 20-87 years and reported that low endurance levels were associated with a history of walking-related falls after adjusting for age. The higher endurance capacity among the walking group may have contributed to preventing falls because fatigue is detrimental to postural control (Adlerton et al., 2003) and a fall may occur when an individual is fatigued.

Second, the walking group in our study experienced significantly more trips than the balance group did. Bhatt et al. (2012) reported an interesting laboratory experiment that showed an "inoculating effect" of a deliberate slipping experience against falling. Bhatt et al. (2012) showed that community-dwelling older adults who were exposed to frequent slipping trials (a three-month interval) were significantly better at controlling their stability in the slipping test than those who received less frequent exposures (a six-month interval). Pavol et al. (2001) reported that the quick initiation of a recovery step after a trip is important to avoid falling. Rogers et al. (2003) reported that training with "involuntary stepping" induced by pulling the waist was more effective in improving step initiation timing than voluntary step training. Grabiner et al. (2008) stressed the importance of task-specific training to avoid or to recover from tripping, and many studies have attempted to train older adults in situations similar to real-life tripping (Shigematsu and Okura, 2006; Shimada et al., 2004).

The increased trips experienced among the walking group may have served as the "involuntary" stepping and "real-life" recovery training to inoculate community-dwelling older adults against sudden and unpredictable chances of falling.

6.4.4. Strengths and Limitations

Strengths of the current study include prospective fall survey using monthly fall calendars, original evaluation of fall incidence accounting for the increased physical activity level, and adaption of Poisson regression analysis which could evaluate the number of falls in each participant (which could not be done by common methods such as logistic regression or Cox proportional hazard model). The simple walking program is also strength because it can be applied in wide range of health promotion programs.

However, the results of the current study need to be interpreted with caution because of the following limitations. First, no blinding was applied. Second, there was a risk of overestimation because an intention-to-treat analysis was not available. Third, we could not study a non-exercise group due to ethical reasons. Fourth, the reliability of the trip data was not high. Fifth, because the exposure variables (physically active days and steps) were measured post intervention, they did not reflect the change during the follow-up period. To be more precise, the exposure variables should be continuously measured throughout the follow-up period. A larger, high-quality randomized controlled trial is warranted to re-examine the results of this study and explore the mechanisms.

6.4.5. Conclusion of the Study 4

In conclusion, the results of the current study suggest that walking among community-dwelling older adults can be more effective for fall prevention than balance training. However, because walking did induce greater trips, walking may not be conducted with such safety and effectiveness among older adults who are susceptible to falling or frailty.

CHAPTER 7

COMPREHENSIVE DISCUSSION

7.1. Major findings

The major findings obtained in this doctoral thesis are as follows:

1) Habitual walking may increase the incidence of falling. However, this adverse effect of habitual walking on falls may be true only among older adults who are very frail or susceptible to falling.

2) Habitual walking is effective in maintaining the physical and psychological factors known to be associated with falling, such as dynamic balance, lower-extremity strength, gait, endurance, and fall self-efficacy, among general community-dwelling older adults without particular risk of falling. However, the greater effects on lower-extremity strength and balance can be obtained by traditional strength and balance training with greater safety.

3) Habitual walking can be more effective than traditional strength and balance training on fall prevention among general community-dwelling older adults without particular risk of falling.

7.2. Significance of the findings

There has been inconsistency regarding the association between walking and falls among the previous studies (Gregg et al., 2000; Sherrington et al., 2008). The results of the doctoral thesis explain that the reason for the inconsistency was mainly due to the different levels of risk of falling among the study participants. Beneficial effects or association of habitual waking (including physical activity) on falls were obtained among the lower-risk, general older population (Heesch et al., 2008; Mertz et al., 2010). In contrast, harmful effects or association were obtained among the higher-risk, frail older population (Sherrington et al., 2008).

In the previous cohort studies which examined the habitual walking as a potential fall risk factor (Ribom et al., 2009; Sorock and Labiner, 1992; Tromp et al., 2001), no statistically significant association was observed. Figure 8 (page 55) in the Study 1 partially explains the reason for the ambiguous results by the previous studies, namely a contamination of beneficial and harmful associations among the lower- and higher-risk participants, may be the cause of the non-significant association.

Otaka et al. (2003), in their review of fall prevention interventions, reported that the characteristics of the participants and fall prevention programs had to be well matched, for an effective fall prevention. This doctoral thesis shows that walking is an effective fall prevention exercise among general community-dwelling older adults, which is the main target population of community-wide fall prevention program. Although the importance of selecting the proper population for a certain type of fall prevention program has been described by several researchers (Rose and Hernandez, 2010), to the best of my knowledge, this doctoral thesis was the first to challenge the selection of proper participants in a systematic manner.

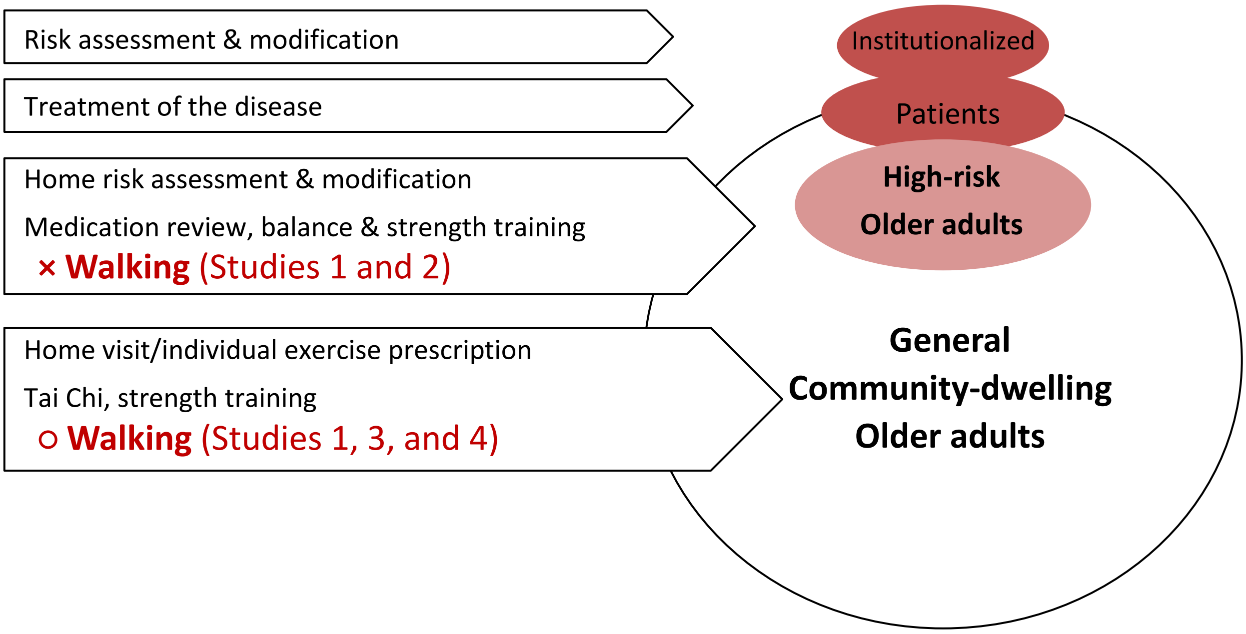

Figure 19. Characteristics of participants and corresponding intervention programs shown to be effective in fall prevention

Otaka et al., 2003. The Effectiveness of Fall Prevention Programs: A Review: 2. Fall-related Issues and Future Perspectives of Fall Related Research (article in Japanese). The Japanese Journal of Rehabilitation Medicine 40: 389-97. Figure was modified.

7.3. An important question to be answered: Contribution of muscle strength in fall prevention by habitual walking

Muscle strength, the ability of muscle to generate adequate force is a fundamental component of maintaining balance (Wolfson et al., 1995). Although, a significant improvement in muscle strength was observed in the Study 3, the magnitude may be smaller than that obtained by the strength and balance program. The small improvement in muscle strength among the walking group was not adequate to explain the mechanism of the beneficial fall prevention effects of walking which was observed in the Study 4. Therefore, previous literatures which examined the contribution of muscle strength/weakness on fall prevention/occurrence were briefly reviewed below.

7.3.1. Muscle weakness and falls

Rubenstein et al. (1994), summarized results of four case-control studies, and reported that muscle weakness was related to fall history (mean RR/OR: 6.2, range: 4.9-8.4). Rubenstein and Josephson (2002), reviewed results of 16 prospective cohort and case-control studies, and reported that muscle weakness (detected by either functional performance tests or manual muscle examination) was the strongest risk factor (mean RR/OR: 4.4, range: 1.5-10.3) for falls among community-dwelling and institutionalized older adults. More specifically, Moreland et al. (2004) conducted a systematic review and meta-analysis of 13 prospective studies to examine the association between muscle weakness and falls among community-dwelling and institutionalized older adults, and reported that upper- and lower-extremity muscle weakness was significantly associated with future falls. It was highly likely that the upper-extremity muscle weakness was simply a marker for other fall risk factors including lower-extremity muscle weakness. Moreland et al. (2004) also discussed that lower-extremity muscle weakness may also be the marker of other risk factors because most studies included in the meta-analysis only reported results of univariate analysis (Luukinen et al., 1995a, b; Northridge et al., 1996; Thapa et al., 1995; Tinetti et al., 1986) or simple multivariable analysis without previous fall history as a covariate (Davis et al., 1999; Nevitt et al., 1989).

Although, it is common to use some combination of resistance, balance, endurance, and flexibility exercises, three RCTs, in the Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) studies (Province et al., 1995), examined the effects of isolated resistance strength training on prevention of falls. In Boston FICSIT trial (Fiatarone et al., 1993), providing nursing home residents aged 70+ years, high resistance training using resistance of 80% 1RM (repetition maximum), 3 days for 10 weeks, reported no effects on fall incidence (adjusted incidence ratio (IR): 0.95: 95% CI: 0.64-1.41). In Farmington FICSIT trial (Wolfson et al., 1993), providing community-dwelling older adults strength training using ankle weights, 3 days for 13 weeks, reported non-significant reduction of fall incidence (adjusted IR: 0.64, 95% CI:

0.34-1.09). In Seattle FICSIT trial (Buchner et al., 1993), providing community-dwelling older adults resistance training using increasing resistance of 50% to 80% 1RM, reported no effects on fall incidence (adjusted IR: 0.91, 95% CI: 0.48-1.74). Moreover, the systematic review and meta-analysis by Sherrington et al. (2008) which explored effective components of fall prevention programs, reported that strength training (moderate- or high-intensity) was not effective in reducing falls (RR: 1.19, 95% CI: 0.96-1.46).

7.3.2. Ceiling effect of muscle strength on gait

There are reports suggesting the contribution of muscle strength on walking ability or avoid falling has a “ceiling effect”. Buchner et al. (Buchner et al., 1996), studied among 409 older adults aged 60-96 years, and reported that the association between muscle strength and gait speed was non-linear (Figure 20). Although significant linear relationship between walking speed and leg strength was observed among participants with leg strength score of < 275 Nm, among those with leg strength score of ≥ 275 Nm, significant linear regression was no longer observed (the slop of the regression is almost zero). The non-linear relationship represents a mechanism by which small changes in physiological capacity may produce relatively large effects on performance in frail older adults, while large changes in capacity have little or no effect on daily function in healthy older adults (Buchner et al., 1996). It was also reported that improvement in muscle strength by resistance training was accompanied by increased walking speed among frail older adults (Fiatarone et al., 1994) but not accompanied by increased walking speed among healthier older adults (Buchner et al., 1997b).

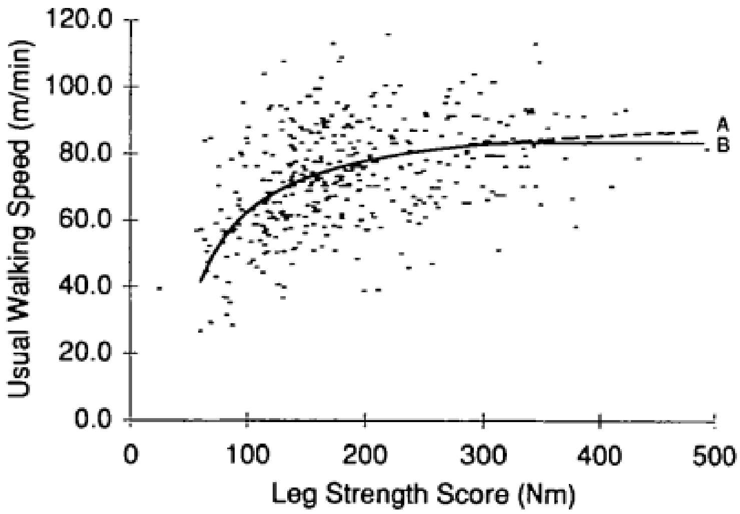

Figure 20. Non-linear regression curve with leg strength score and usual gait speed (n = 409)

Buchner DM, Larson EB, Wagner EH, Koepsell TD, de Lateur BJ. Evidence for a non-linear relationship between leg strength and gait speed. Age Ageing 25 (5): 386-391, 1996.

7.3.3. Different contribution of intrinsic and extrinsic risk factors

Muscle weakness, as well as balance deficit, visual deficit, and dizziness, are classified as intrinsic risk factors for falls. The contribution of intrinsic risk factors becomes greater among frail institutionalized older adults than among healthier community-dwelling older adults (Nickens, 1985). The contribution of the intrinsic risk factors was 80% among the institutionalized and 39-53% among community-dwelling older adults (Lach et al., 1991; Rubenstein et al., 1994). In 2013, Rovinobitch et al. (2013) used innovative approach to uncover real life falls using more than 200 digital video cameras to record fall incidence in long-term care institutions. A major finding was that most falls occurred with no extrinsic cause (e.g., trips or slips), but simply by incorrect weight shifting. These falls were considered to be attributable to extreme loss of muscle function. Yamada et al. (2011), examining the fall risk factors among older adults stratified by physical functional levels, and reported that among those with poor physical function, lower-extremity muscle weakness (five-chair stand) was strongly related to falls. In contrast, among those with good physical function, dual-task ability was strongly related to falls. The dual-task ability is considered to be important in dividing attention to multiple tasks in complicated environment and recognize sudden extrinsic risk factors. In the Study 4, the majority (69%) of falls were caused by extrinsic risk factors (trips and slips) (Lach et al., 1991), and proper attention and avoidance of the extrinsic risk factors were more important over intrinsic factors than muscle strength among the heathier older population.

In summary, the contribution of muscle strength on fall incidence among the study participants of the Studies 3 and 4 was limited because (1) muscle weakness may not be an independent risk factor for falls (though it affects falls in multifactorial manner with balance and gait), (2) the general (lower-risk or healthier) community-dwelling older adults may already have sufficient muscle strength to maintain balance, (3) most of the falls were caused by extrinsic factors (trips and slips in accidental situation). In contrast, plausible hypothetical mechanisms of the fall prevention effects of walking were that the 56% increased daily steps and frequent experience of trips (mostly successful avoiding falls) served as involuntary stepping training to avoid accidental falls, and reduction of fatigue during continuous walking (see 6.4.3 for more detail, in page 129).

7.4. Clinical implications

7.4.1. Community-based fall prevention programs including habitual walking

Based on the findings of the doctoral thesis, a health promotion and fall prevention program for community-dwelling older people can include recommendation of habitual walking. However, simple risk management strategy with screening check-list for risk of falling should also be included. Among the general community-dwelling older adults without particular risk of falling (risk factors < 2), which is the majority of older population in communities, habitual walking can be widely recommended.

On the other hand, an extra caution is warranted if walking is to be recommended for older adults with high risk of falling. For these high risk or very frail older population, the traditional balance and strength trainings can be safely recommended (Sherrington et al., 2011). These trainings can be included as part of the secondary prevention policy for frail older adults screened by the Kihon Checklist (Fukasaku et al., 2011; Tomata et al., 2011). The Study 3 showed that the strength and balance training improved physical fall-related factors including balance and muscle strength. Tinetti et al. (1994) provided fall risk assessments and multifactorial interventions (e.g., strength and balance training, medication review, treatment of postural hypertension) to community-dwelling older adults with at least one fall risk factor (mean 3.9 ± 1.7), and reported a significant reduction in the number of fall risk factors (mean -1.1 ± 1.6). If clinically significant improvements in balance and lower-extremity strength and other fall risk factors were confirmed, then the older adults can be guided to gradually and safely initiate habitual walking. It is important to guide older adults until the level which they can habitually walk, because the ultimate purpose of fall prevention is not merely to avoid falling (occasionally done by suppressing physical activity or physical restraint in the worst case (Shimanuki, 2014; Wijlhuizen et al., 2007)) but rather to help older adults to freely walk, be physically active, confident in mobility, and maintain a good quality of life.

7.4.2. How to minimize the side-effects of habitual walking for fall prevention

The problematic nature of a walking intervention aiming at fall prevention is that along with the improvements in physical and psychological functions, it is also accompanied by an increased exposure to environmental hazards and trips. These hazards and trips can be called as “side-effects” of habitual walking (Otaka et al., 2003). Throughout the studies in this doctoral thesis, it was confirmed that among the general (or lower-risk) community-dwelling older adults, the beneficial effects of habitual walking outweighs the side-effects. However, it is important to find a route to minimize the side-effects while maintaining the beneficial effects of habitual walking, for a better outcome in the fall prevention efforts.

Based on findings from previous reports, several of suggestions could be made. First, the walking pattern during exercise and activity of daily living should be clearly distinguished. A fast walking pace with large stride length is commonly instructed to older adults to obtain improvements in physical function. However, it was reported that a fast walking speed and wide stride rendered participants vulnerable to falling after trips (Pavol et al., 2001) and to slipping (Espy et al., 2010), respectively. Berg et al. (1997) reported that "hurrying too much" was the most common cause of falls among community-dwelling older adults. Therefore, it is important to instruct older adults to slow down their walking pace and shorten their stride to a normal extent in activities of daily living (especially when encountering a fall-prone situation). Second, recognition of fall-prone situations and paying proper attention should be educated. The fall-prone situations include wet places (e.g., kitchen, bathroom, rainy roads), difference in level (e.g., stairs, ramp, block, doorsill), and untidy rooms (e.g., clothes, bags, boxes, cords, on the floor). Even when walking for exercise, participants should slow down their pace when they recognize the fall-prove situations as difference in level. Third, other fall risk factors including drugs (e.g., sedatives and psychotropic), vision problems (e.g., multifocal glasses and cataract), foot wears (e.g., sandals and slippers), activities (e.g., standing on chair and riding a bicycle), and characteristics/behavior (e.g., risk taking) (Butler et al., 2014) should also be addressed. Forth, it may be important to directly inform older adults that engaging in habitual waking may increase the "number" of falls while decreasing the "rate" of falls accounting for exposures.

If the attempts to minimize the side-effects of habitual walking (e.g., injurious falls) were proven to be effective, application of a walking program to the higher-risk community-dwelling older adults will be enabled.

7.4.3. Habitual walking and the traditional strength and balance exercises: suitability to different populations

Although, habitual walking was suggested to be effective in maintaining the physical and psychological fall-related functions such as dynamic balance, lower-extremity strength, gait, endurance, and fall self-efficacy, among the general community-dwelling older adults, the magnitude of the effects on lower-extremity strength and balance tended to be greater in the traditional strength and balance training (Study 3). Enormous amount of evidence suggests the effectiveness of the traditional strength and balance exercises (Gillespie et al., 2012; Province et al., 1995; Sherrington et al., 2011; Sherrington et al., 2008; Suzuki et al., 2004), especially among older adults with muscle weakness and balance deficit (Tinetti et al., 1994). Habitual walking cannot be replaced with the traditional strength and balance exercises in fall prevention programs (Sherrington et al., 2011). However, the structured strength and balance exercise programs supervised by instructors can only reach to limited number of older people. Moreover, among healthy community-dwelling older adults with sufficient muscle strength at baseline, the effects on physical function may be small (Buchner et al., 1996). These supervised exercises were appropriate for the high-risk approach.

On the other hand, habitual walking can be can be implemented regardless of time, place, or previous sports experience, is suitable for the population-wide approach. Significant fall prevention effects were also obtained when accounting for the exposure variables among the general community-dwelling older adults who need to deal with frequent environmental hazards (Study 4). Although, the improvements obtained by habitual walking among the participants were relatively small (Study 3), they may be sufficient to prevent future progression of risk of falling. It was also reported that habitual exercises conducted among community-dwelling older adults including walking, when continued for four years or longer was significantly associated with fewer history of falls (Okubo et al., 2014c).

Therefore, a combination of population-based approach for the general community-dwelling older people using habitual walking, and high-risk approach using strength and balance exercises may be effective, or a hybrid-type fall prevention program may be effective.

7.4.4. Should walking not be recommended for higher-risk older adults?

Although the harmful effect of habitual walking among the higher-risk older adults was observed in the Studies 1 and 2, restriction of walking may be an imprudent idea. It is true that recurrent falls and injurious falls were serious health issue for older adults, and should warn for the potential risk. It should also be noted that habitual walking among older population has enormous beneficial effects on non-communicable diseases including type 2 diabetes, cardiovascular diseases (e.g., heart disease, stroke, hypertension, hyperlipidemia), muscle skeletal diseases (e.g., arthritis and lower-back pain), and mental health (e.g., dementia and depression) (American College of Sports et al., 2009; Lee and Buchner, 2008). Although, Vetter et al. (1992) reported a non-significant increase in the number of falls and fractures by encouraging physical exercise, they wrote a positive outlook about their better mobility, quality of life, and even mortality. Ebrahim et al. (1997) reported that a brisk walking group showed a significant increase of fall rates over one year but a decrease in bone mineral density at the femoral neck was smaller than that in the placebo group (mean net difference between the brisk walking and placebo groups 0.019 g/cm^2, 95% CI: -0.0026 to +0.041 g/cm^2, P = 0.056). Gill et al. (2002) and von Koch et al. (2000), providing early hospital discharge and home rehabilitation to frail community-dwelling older adults or stroke survivors, reported slight increase of falls but confirmed significant benefits in functional disability, independent in ADL, and mortality.

It is important to realize that fall prevention may not be a final goal but only a method which allows older population to safely and freely walk, and maintain a good quality of life. It is up to the older individual to make their decision on their health promotion; weighing various health benefits and side-effects of each method including habitual walking. Health care professionals should provide reliable information based on scientific evidence, supplemented by experience, to help older individuals to choose their methods which are suitable in their lifestyle.

7.4.5. Cut point to screen community-dwelling older adults with risk of increasing falls with habitual walking

The Studies 1 and 2 have shown that the association between habitual walking and falls is modified by the presence of risk of falling. If we are to adapt this finding to clinical or community settings, it is important to determine the optimal level of risk of falling in which community-dwelling older adults can safely and effectively walk for their health and prevention of falls. Figure 8 (page 55) in the Study 1 suggests that when community-dwelling older adults have *three* or more risk factors for falling, the adverse effects of habitual walking outweigh the beneficial effects of habitual walking. On the other hand, Figure 10 (page 78) in the Study 2 suggests that when community-dwelling older adults have *two* or more risk factors for falls, the adverse effects of habitual walking outweigh the beneficial effects of habitual walking. To be conservative and superior the longitudinal, Study 2 to the cross-sectional, Study 1, the cut point of *two* or more risk factors for falling was used to exclude participants with potential risk of increasing fall incidence by walking intervention in the Studies 3 and 4. It should be noted that telephone screening in the Studies 3 and 4 were limited to convenient items (without assessments of poor balance and depressive symptoms), and older adults with more risk factors for falling may potentially be included. It was considered that this had little impact on the results because the walkers with two risk factors for falling demonstrated significantly fewer prevalence of fall history than the non-walkers did in the Study 1. No clear cut point, as to the number of risk factors for falling to screen high risk older adults when engaged in habitual walking, could be made from this doctoral thesis. However, when older adults have three or more risk factors for falling, habitual walking should not be the first choice of recommendation. For those with two risk factors for falling, habitual walking may be beneficial in fall prevention but caution is needed regarding the potential risk of increasing falls by engaging in habitual walking.

7.5. Future directions

7.5.1. Methodological consolidation

In order to overcome the methodological limitations which have been stated in each study, following consolidation should be adopted in the future research or re-examination.

In observational studies, (1) random sampling and recruitment with sufficient statistical power, (2) home visit assessments to include frail and inactive older adults, (3) prospective collection of fall data using monthly fall calendars, (4) assessment of all potential confounding factors including physical activity, cognitive function, dual-task performance, and risk-taking behavior, (5) a study design and effort to maintain high follow-up rate (≥ 90%) should be adopted. Re-examination in different countries with different lifestyle, environments, ethnics and race should also be considered.

In intervention studies, (1) random sampling from whole target population, (2) sufficient sample size for all main and secondary outcome measurements (approximately 500 participants), (3) arrangement of a non-exercise control group (e.g., cross-over design, waiting list, or hobby classes without exercise), (4) strict blinding of assessors, exercise instructors, statistical analysts (randomization and data analyses), and possibly participants, (5) intention-to-treat analysis, (6) minimizing and management of missing data with multiple imputation, (7) prospective assessment of exposure variables such as daily step counts and physically active days, as well as fall status, (8) a follow-up period of two years or longer (because the effects of walking is relatively small), should be adopted. The latest study design of RCTs such as SMART design (sequential multiple assignment randomized trial) which systematically allows and assesses adoption of intervention approach to individual variation, and MOST design (multiphase optimization strategy) which examine effects of several components (e.g., frequency, duration, and intensity of walking, difference shoes, education on proper attention) in one trial should be considered (Collins et al., 2007; Collins et al., 2014).

Even within the lower- and higher-risk categories, there is large variability among older individuals (e.g., chronic disease, disability, personality, and lifestyle). A limitation of common epidemiological studies, which use mean values, is that they do not account for the individual variability. Additional examination with case-study and qualitative research which focuses on the different individual responses may also be beneficial.

7.5.2. Research questions

The mechanism of how habitual walking among community-dwelling older adults affects walking pattern (e.g., stride length, width, gait variability, trunk acceleration, harmonic ratio), pattern of attention during walking for exercise and in activities of daily living, volitional and reactive responses to environmental hazards which may cause accidental falls should be examined in epidemiological studies and laboratory experiments. An effective strategy to reduce the risk of falling among the high-risk older population and safe walking program should be developed and examined in the future studies.

Promising fall prevention exercises should not be limited to a few types of exercise which have been identified in previous research (e.g., strength and balance exercise). Although the high-risk older adults may benefit more from engaging in structured exercise programs that systematically target the fall risk factors, for healthy and lower-risk community-dwelling older adults, engaging in a broad range of physical activities designed to improve aerobic endurance, strength, and balance on a regular basis is likely to be sufficient to substantially reduce the risk of falling (Rose and Hernandez, 2010). Various types of habitual exercise among community-dwelling older adults have movement patterns such as stepping in multiple directions and load to lower-extremity muscle which may be effective in fall prevention when continued for a sufficient length of period and with sufficient dose (Okubo et al., 2014c). In the future research, wide variety of exercise modality should also be examined for their effects on fall prevention.

7.6. Conclusion

The findings from this doctoral thesis can be summarized as follows: 1) habitual walking significantly increases the risk of falling only among higher-risk older adults, 2) walking can be as effective as traditional strength and balance training in reducing the incidence of falls among general community-dwelling older adults without particular risk of falling. However, the strength and balance training is probably more effective than habitual walking in reducing the physical risk factors among the higher-risk older adults. 3) A hybrid-type fall prevention program, with population-based approach for the general community-dwelling older people using habitual walking, and high-risk approach using strength and balance exercises may be effective.

It should be noted that these statements only apply to prevention of falls (mainly caused by extrinsic or accidental factors) among general community-dwelling older adults. Since the effects of habitual walking alone on maintaining muscle strength and balance is limited, it is desirable to include muscle strengthening and balance training in prevention of sarcopenia, frailty, mobility limitation, or even falls in longer terms.

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REFERENCES

Adlerton, A.K., Moritz, U., Moe-Nilssen, R., 2003. Forceplate and accelerometer measures for evaluating the effect of muscle fatigue on postural control during one-legged stance. Physiother Res Int 8, 187-199.

Aharonoff, G.B., Koval, K.J., Skovron, M.L., Zuckerman, J.D., 1997. Hip fractures in the elderly: predictors of one year mortality. J Orthop Trauma 11, 162-165.

American College of Sports, M., Chodzko-Zajko, W.J., Proctor, D.N., Fiatarone Singh, M.A., Minson, C.T., Nigg, C.R., Salem, G.J., Skinner, J.S., 2009. American College of Sports Medicine position stand. Exercise and physical activity for older adults. Med Sci Sports Exerc 41, 1510-1530.

American Geriatrics Society, British Geriatrics Society, American Academy of Orthopaedic Surgeons Panel on Falls Prevention., 2001. Guideline for the prevention of falls in older persons. J Am Geriatr Soc 49, 664-672.

Avers, D., Brown, M., Chui, K.K., Wong, R.A., Lusardi, M., 2011. Use of the Term “Elderly”. J Geriatr Phys Ther 34, 153-154.

Berg, W.P., Alessio, H.M., Mills, E.M., Tong, C., 1997. Circumstances and consequences of falls in independent community-dwelling older adults. Age Ageing 26, 261-268.

Bhatt, T., Yang, F., Pai, Y.C., 2012. Learning to resist gait-slip falls: long-term retention in community-dwelling older adults. Arch Phys Med Rehabil 93, 557-564.

Borg, G.A., 1982. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14, 377-381.

Brown, M., Holloszy, J.O., 1993. Effects of walking, jogging and cycling on strength, flexibility, speed and balance in 60- to 72-year olds. Aging (Milano) 5, 427-434.

Buchner, D.M., Cress, M.E., de Lateur, B.J., Esselman, P.C., Margherita, A.J., Price, R., Wagner, E.H., 1997a. A comparison of the effects of three types of endurance training on balance and other fall risk factors in older adults. Aging Clin Exp Res 9, 112-119.

Buchner, D.M., Cress, M.E., de Lateur, B.J., Esselman, P.C., Margherita, A.J., Price, R., Wagner, E.H., 1997b. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. J Gerontol A Biol Sci Med Sci 52, M218-224.

Buchner, D.M., Cress, M.E., Wagner, E.H., de Lateur, B.J., Price, R., Abrass, I.B., 1993. The Seattle FICSIT/MoveIt study: the effect of exercise on gait and balance in older adults. J Am Geriatr Soc 41, 321-325.

Buchner, D.M., Larson, E.B., Wagner, E.H., Koepsell, T.D., de Lateur, B.J., 1996. Evidence for a non-linear relationship between leg strength and gait speed. Age Ageing 25, 386-391.

Butler, A.A., Lord, S.R., Taylor, J.L., Fitzpatrick, R.C., 2014. Ability Versus Hazard: Risk-Taking and Falls in Older People. J Gerontol A Biol Sci Med Sci.

Cameron, I.D., Gillespie, L.D., Robertson, M.C., Murray, G.R., Hill, K.D., Cumming, R.G., Kerse, N., 2012. Interventions for preventing falls in older people in care facilities and hospitals. Cochrane Database Syst Rev 12, CD005465.

Campbell, A.J., Borrie, M.J., Spears, G.F., 1989. Risk factors for falls in a community-based prospective study of people 70 years and older. J Gerontol 44, M112-117.

Campbell, A.J., Robertson, M.C., 2010. Comprehensive approach to fall prevention on a national level: New Zealand. Clin Geriatr Med 26, 719-731.

Chu, L.W., Chiu, A.Y., Chi, I., 2006. Impact of falls on the balance, gait, and activities of daily living functioning in community-dwelling Chinese older adults. J Gerontol A Biol Sci Med Sci 61, 399-404.

Collins, L.M., Murphy, S.A., Strecher, V., 2007. The multiphase optimization strategy (MOST) and the sequential multiple assignment randomized trial (SMART): new methods for more potent eHealth interventions. Am J Prev Med 32, S112-118.

Collins, L.M., Nahum-Shani, I., Almirall, D., 2014. Optimization of behavioral dynamic treatment regimens based on the sequential, multiple assignment, randomized trial (SMART). Clin Trials 11, 426-434.

Clemson L., Cumming R.G., Kendig H., Swann M., Heard R., Taylor K., 2004. The effectiveness of a community-based program for reducing the incidence of falls in the elderly: a randomized trial. J Am Geriatr Soc 52(9), 1487-94.

Davis, J.W., Ross, P.D., Nevitt, M.C., Wasnich, R.D., 1999. Risk factors for falls and for serious injuries on falling among older Japanese women in Hawaii. J Am Geriatr Soc 47, 792-798.

Delbaere, K., Close, J.C., Brodaty, H., Sachdev, P., Lord, S.R., 2010a. Determinants of disparities between perceived and physiological risk of falling among elderly people: cohort study. BMJ 341, c4165.

Delbaere, K., Close, J.C., Heim, J., Sachdev, P.S., Brodaty, H., Slavin, M.J., Kochan, N.A., Lord, S.R., 2010b. A multifactorial approach to understanding fall risk in older people. J Am Geriatr Soc 58, 1679-1685.

Deshpande, N., Metter, E.J., Lauretani, F., Bandinelli, S., Guralnik, J., Ferrucci, L., 2008. Activity restriction induced by fear of falling and objective and subjective measures of physical function: a prospective cohort study. J Am Geriatr Soc 56, 615-620.

Ebrahim, S., Thompson, P.W., Baskaran, V., Evans, K., 1997. Randomized placebo-controlled trial of brisk walking in the prevention of postmenopausal osteoporosis. Age Ageing 26, 253-260.

Espy, D.D., Yang, F., Bhatt, T., Pai, Y.C., 2010. Independent influence of gait speed and step length on stability and fall risk. Gait Posture 32, 378-382.

Etman, A., Wijlhuizen, G.J., van Heuvelen, M.J., Chorus, A., Hopman-Rock, M., 2012. Falls incidence underestimates the risk of fall-related injuries in older age groups: a comparison with the FARE (Falls risk by Exposure). Age Ageing 41, 190-195.

Faber, M.J., Bosscher, R.J., Chin, A.P.M.J., van Wieringen, P.C., 2006. Effects of exercise programs on falls and mobility in frail and pre-frail older adults: A multicenter randomized controlled trial. Arch Phys Med Rehabil 87, 885-896.

Faulkner, K.A., Cauley, J.A., Studenski, S.A., Landsittel, D.P., Cummings, S.R., Ensrud, K.E., Donaldson, M.G., Nevitt, M.C., Study of Osteoporotic Fractures

Research, G., 2009. Lifestyle predicts falls independent of physical risk factors. Osteoporos Int 20, 2025-2034.

Fiatarone, M.A., O'Neill, E.F., Doyle, N., Clements, K.M., Roberts, S.B., Kehayias, J.J., Lipsitz, L.A., Evans, W.J., 1993. The Boston FICSIT study: the effects of resistance training and nutritional supplementation on physical frailty in the oldest old. J Am Geriatr Soc 41, 333-337.

Fiatarone, M.A., O'Neill, E.F., Ryan, N.D., Clements, K.M., Solares, G.R., Nelson, M.E., Roberts, S.B., Kehayias, J.J., Lipsitz, L.A., Evans, W.J., 1994. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 330, 1769-1775.

Freiberger E., Menz H.B., Abu-Omar K., Rutten A., 2007. Preventing falls in physically active community-dwelling older people: a comparison of two intervention techniques. Gerontology 53(5), 298-305.

Fried, L.P., Tangen, C.M., Walston, J., Newman, A.B., Hirsch, C., Gottdiener, J., Seeman, T., Tracy, R., Kop, W.J., Burke, G., McBurnie, M.A., Cardiovascular Health Study Collaborative Research, G., 2001. Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci 56, M146-156.

Fukasaku, T., Okuno, J., Tomura, S., Seino, S., Kim, M.J., Yabushita, N., Okura, T., Tanaka, K., Yanagi, H., 2011. Intervention effects of inclusive support in an "exercise and a nutritional community-based prevention program" for pre-frail elderly individuals (article in Japanese). Nihon Koshu Eisei Zasshi 58, 420-432.

Fukuhara, S., Bito, S., Green, J., Hsiao, A., Kurokawa, K., 1998. Translation, adaptation, and validation of the SF-36 Health Survey for use in Japan. J Clin Epidemiol 51, 1037-1044.

Gardner, M.M., Buchner, D.M., Robertson, M.C., Campbell, A.J., 2001. Practical implementation of an exercise-based falls prevention programme. Age Ageing 30, 77-83.

Gibson, M.J., 1990. Falls in later life, in: Kane, R., Evans, J.G., Macfadyen, D. (Eds.), Improving the health of older people: A World View. Oxford Univ. Press, New York, pp. 296-315.

Gill, T.M., Baker, D.I., Gottschalk, M., Peduzzi, P.N., Allore, H., Byers, A., 2002. A program to prevent functional decline in physically frail, elderly persons who live at home. N Engl J Med 347, 1068-1074.

Gillespie, L.D., Robertson, M.C., Gillespie, W.J., Sherrington, C., Gates, S., Clemson, L.M., Lamb, S.E., 2012. Interventions for preventing falls in older people living in the community. Cochrane Database Syst Rev 9, CD007146.

Graafmans, W.C., Ooms, M.E., Hofstee, H.M., Bezemer, P.D., Bouter, L.M., Lips, P., 1996. Falls in the elderly: a prospective study of risk factors and risk profiles. Am J Epidemiol 143, 1129-1136.

Grabiner, M.D., Donovan, S., Bareither, M.L., Marone, J.R., Hamstra-Wright, K., Gatts, S., Troy, K.L., 2008. Trunk kinematics and fall risk of older adults: translating biomechanical results to the clinic. J Electromyogr Kinesiol 18, 197-204.

Green, J., Forster, A., Bogle, S., Young, J., 2002. Physiotherapy for patients with mobility problems more than 1 year after stroke: a randomised controlled trial. Lancet 359, 199-203.

Gregg, E.W., Pereira, M.A., Caspersen, C.J., 2000. Physical activity, falls, and fractures among older adults: a review of the epidemiologic evidence. J Am Geriatr Soc 48, 883-893.

Guralnik, J.M., LaCroix, A.Z., Abbott, R.D., Berkman, L.F., Satterfield, S., Evans, D.A., Wallace, R.B., 1993. Maintaining mobility in late life. I. Demographic characteristics and chronic conditions. Am J Epidemiol 137, 845-857.

Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G., Scherr, P.A., Wallace, R.B., 1994. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol 49, M85-94.

Hanlon, J.T., Landerman, L.R., Fillenbaum, G.G., Studenski, S., 2002. Falls in African American and white community-dwelling elderly residents. J Gerontol A Biol Sci Med Sci 57, M473-478.

Hayashi, T., Kondo, K., 2011. Why building community for preventing nursing care:

The limitations of a high risk strategy and the problems of a population strategy (article in Japanese). Hokenfu Zasshi 67, 670-675.

Heesch, K.C., Byles, J.E., Brown, W.J., 2008. Prospective association between physical activity and falls in community-dwelling older women. J Epidemiol Community Health 62, 421-426.

Hesseberg, K., Bentzen, H., Bergland, A., 2014. Reliability of the Senior Fitness Test in Community-dwelling Older People with Cognitive Impairment. Physiother Res Int.

Japanese Cabinet Office, 2006. Public opinion poll on physical fitness and sports (article in Japanese).

Japanese Ministry of Education, Culture, Sports Science and Technology, 2013. National Survey on Physical Fitness and Sports.

Japanese Ministry of Health, Labour and Welfare, 2000. Healthy Japan 21 (The National Health Promotion Movement in the 21st century）.

Japanese Ministry of Health, Labour and Welfare, 2010. Comprehensive Survey of Living Conditions.

Japanese Ministry of Health, Labour and Welfare, 2013. White Paper on Aging Society.

Japanese Ministry of Health, Labour and Welfare, 2012. National Health and Nutrition Survey (article in Japanese)

Jones, C.J., Rikli, R.E., Beam, W.C., 1999. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. Res Q Exerc Sport 70, 113-119.

Judge, J.O., Ounpuu, S., Davis, R.B., 3rd, 1996. Effects of age on the biomechanics and physiology of gait. Clin Geriatr Med 12, 659-678.

Kamioka, H., Okada, S., 2008. Exercise programs for falls prevention: exercise playing (article in Japanese), in: Muto, Y. (Ed.), Encyclopaedia of falls prevention medicine. Japan Medical Journal, Tokyo, pp. 257-263.

Kaneko, 1990. Biomechanical analysis of walking and fitness testing in elderly women, in: M, K. (Ed.), Fitness for the Aged, Disabled and Industrial Worker Ⅲ Human Kinetics Publishers, pp. 84-89.

Kaneko, M., Morimoto, Y., Kimura, M., Fuchimoto, K., Fuchimoto, T., 1991. A kinematic analysis of walking and physical fitness testing in elderly women. Can J Sport Sci 16, 223-228.

Karinkanta, S., Piirtola, M., Sievanen, H., Uusi-Rasi, K., Kannus, P., 2010. Physical therapy approaches to reduce fall and fracture risk among older adults. Nat Rev Endocrinol 6, 396-407.

Kervio, G., Ville, N.S., Leclercq, C., Daubert, J.C., Carre, F., 2004. Intensity and daily reliability of the six-minute walk test in moderate chronic heart failure patients. Arch Phys Med Rehabil 85, 1513-1518.

Kikuchi, T., 1992. The walking ability after femoral neck fractures (article in Japanese). Surgical Technique 43, 1879-1883.

Kloseck, M., Crilly, R.G., Gibson, M., 2008. Can personality theory help us understand risk of falls? J Rehabil Res Dev 45, 1125-1134.

Koyano, W., Shibata, H., Nakazato, K., Haga, H., Suyama, Y., 1991. Measurement of competence: reliability and validity of the TMIG Index of Competence. Arch Gerontol Geriatr 13, 103-116.

Kubo, K., Ishida, Y., Suzuki, S., Komuro, T., Shirasawa, H., Ishiguro, N., Shukutani, Y., Tsunoda, N., Kanehisa, H., Fukunaga, T., 2008. Effects of 6 months of walking training on lower limb muscle and tendon in elderly. Scand J Med Sci Sports 18, 31-39.

Lach, H.W., Reed, A.T., Arfken, C.L., Miller, J.P., Paige, G.D., Birge, S.J., Peck, W.A., 1991. Falls in the elderly: reliability of a classification system. J Am Geriatr Soc 39, 197-202.

Lamb S. E., Jørstad-Stein E.C., Hauer K., Becker C., Prevention of Falls Network Europe and Outcomes Consensus Group, 2005. Development of a common outcome data set for fall injury prevention trials: the Prevention of Falls Network Europe consensus. J Am Geriatr Soc 53(9), 1618-1622.Lee, I.M., Buchner, D.M., 2008. The importance of walking to public health. Med Sci

Sports Exerc 40, S512-518.

Luukinen, H., Koski, K., Laippala, P., Kivela, S.L., 1995a. Predictors for recurrent falls among the home-dwelling elderly. Scand J Prim Health Care 13, 294-299.

Luukinen, H., Koski, K., Laippala, P., Kivela, S.L., 1995b. Risk factors for recurrent falls in the elderly in long-term institutional care. Public Health 109, 57-65.

Madureira, M.M., Takayama, L., Gallinaro, A.L., Caparbo, V.F., Costa, R.A., Pereira, R.M., 2007. Balance training program is highly effective in improving functional status and reducing the risk of falls in elderly women with osteoporosis: a randomized controlled trial. Osteoporos Int 18, 419-425.

Maurer, M.S., Burcham, J., Cheng, H., 2005. Diabetes mellitus is associated with an increased risk of falls in elderly residents of a long-term care facility. J Gerontol A Biol Sci Med Sci 60, 1157-1162.

McClure, R., Turner, C., Peel, N., Spinks, A., Eakin, E., Hughes, K., 2005. Population-based interventions for the prevention of fall-related injuries in older people. Cochrane Database Syst Rev, CD004441.

Menz, H.B., Lord, S.R., 2001. The contribution of foot problems to mobility impairment and falls in community-dwelling older people. J Am Geriatr Soc 49, 1651-1656.

Mertz, K.J., Lee, D.C., Sui, X., Powell, K.E., Blair, S.N., 2010. Falls among adults: the association of cardiorespiratory fitness and physical activity with walking-related falls. Am J Prev Med 39, 15-24.

Moreland, J.D., Richardson, J.A., Goldsmith, C.H., Clase, C.M., 2004. Muscle weakness and falls in older adults: a systematic review and meta-analysis. J Am Geriatr Soc 52, 1121-1129.

Morris, J.N., Hardman, A.E., 1997. Walking to health. Sports Med 23, 306-332.

Mulrow, C.D., Gerety, M.B., Kanten, D., Cornell, J.E., DeNino, L.A., Chiodo, L., Aguilar, C., O'Neil, M.B., Rosenberg, J., Solis, R.M., 1994. A randomized trial of physical rehabilitation for very frail nursing home residents. JAMA 271, 519-524.

Murphy, J., Isaacs, B., 1982. The post-fall syndrome. A study of 36 elderly patients. Gerontology 28, 265-270.

Murray, M.P., Kory, R.C., Clarkson, B.H., 1969. Walking patterns in healthy old men. J Gerontol 24, 169-178.

Nachreiner, N.M., Findorff, M.J., Wyman, J.F., McCarthy, T.C., 2007. Circumstances and consequences of falls in community-dwelling older women. J Womens Health (Larchmt) 16, 1437-1446.

Nemoto, K., Gen-no, H., Masuki, S., Okazaki, K., Nose, H., 2007. Effects of high-intensity interval walking training on physical fitness and blood pressure in middle-aged and older people. Mayo Clin Proc 82, 803-811.

Nevitt, M.C., Cummings, S.R., Kidd, S., Black, D., 1989. Risk factors for recurrent nonsyncopal falls. A prospective study. JAMA 261, 2663-2668.

Nickens, H., 1985. Intrinsic factors in falling among the elderly. Arch Intern Med 145, 1089-1093.

Niino, N., Kozakai, R., Eto, M., 2003. Epidemiology of falls among community-dwelling elderly people. Nippon Ronen Igakkai Zasshi 40, 484-486.

Niino, N., Tsuzuku, S., Ando, F., Shimokata, H., 2000. Frequencies and circumstances of falls in the National Institute for Longevity Sciences, Longitudinal Study of Aging (NILS-LSA). J Epidemiol 10, S90-94.

Northridge, M.E., Nevitt, M.C., Kelsey, J.L., 1996. Non-syncopal falls in the elderly in relation to home environments. Osteoporos Int 6, 249-255.

O'Loughlin, J.L., Robitaille, Y., Boivin, J.F., Suissa, S., 1993. Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. Am J Epidemiol 137, 342-354.

Okubo, Y., Osuka, Y., Jung, S., Figueroa, R., Tsujimoto, T., Aiba, T., Teaho, K., Tanaka , K., 2014a. The effects of walking on physical and psychological fall-related factors in community-dwelling older adults: A walking versus balance program. J Phys Fitness Sports Med (In press).

Okubo, Y., Seino, S., Yabushita, N., Matsuo, T., Osuka, Y., Kim, M., Jung, S., Nemoto, M., Otsuki, N., Tanaka, K., 2011. Association between habitual walking and multiple or injurious falls among community-dwelling older adults: Difference by risk of falling (article in Japanese). Jpn J Phys Fitness Sports Med 60, 239-248.

Okubo, Y., Seino, S., Yabushita, N., Osuka, Y., Jung, S., Nemoto, M., Figueroa, R., Tanaka, K., 2014b. Longitudinal association between habitual walking and fall occurrences among community-dwelling older adults: analyzing the different risks of falling. Arch Gerontol Geriatr (in press).

Okubo, Y., Seino, S., Yabushita, N., Osuka, Y., Jung, S., Nemoto, M., Figueroa, R., Tanaka, K., 2015. Longitudinal association between habitual walking and fall occurrences among community-dwelling older adults: Analyzing the different risks of falling. Arch Gerontol Geriatr 60, 45-51.

Okubo, Y., Seino, S., Yabushita, N., Osuka, Y., Jung, S., Nemoto, M., Kim, M., Figueroa, R., Tanaka, K., 2014c. Habitual exercise and falls among community-dwelling older Japanese adults (article in Japanese). Jpn J Phys Fitness Sports Med 63, 391-400.

Orishige, H., Kiyomi, S., 2004. The results of the fourth national survey of hip fractures: the estimate of new incidence patients in 2002 and change in 15 years (article in Japanese). Japan Medical Journal 4180, 25-30.

Otaka, Y., Liu, M., Uzawa, M., Chino, N., 2003. The Effectiveness of Fall Prevention Programs: A Review: 2. Fall-related Issues and Future Perspectives of Fall Related Research (article in Japanese). Jpn J Rehabil Med 40, 389-397.

Paillard, T., Lafont, C., Costes-Salon, M.C., Riviere, D., Dupui, P., 2004. Effects of brisk walking on static and dynamic balance, locomotion, body composition, and aerobic capacity in ageing healthy active men. Int J Sports Med 25, 539-546.

Pavol, M.J., Owings, T.M., Foley, K.T., Grabiner, M.D., 2001. Mechanisms leading to a fall from an induced trip in healthy older adults. J Gerontol A Biol Sci Med Sci 56, M428-437.

Podsiadlo, D., Richardson, S., 1991. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 39, 142-148.

Protas, E.J., Mitchell, K., Williams, A., Qureshy, H., Caroline, K., Lai, E.C., 2005. Gait and step training to reduce falls in Parkinson's disease. NeuroRehabilitation 20, 183-190.

Province, M.A., Hadley, E.C., Hornbrook, M.C., Lipsitz, L.A., Miller, J.P., Mulrow, C.D., Ory, M.G., Sattin, R.W., Tinetti, M.E., Wolf, S.L., 1995. The effects of exercise on falls in elderly patients. A preplanned meta-analysis of the FICSIT Trials. Frailty and Injuries: Cooperative Studies of Intervention Techniques. JAMA 273, 1341-1347.

Radloff, L., 1977. The CES-D scale: A self-report depression scale for research in the general population. Applied Psychological Measurement 1, 385-401.

Rapp, K., Becker, C., Lamb, S.E., Icks, A., Klenk, J., 2008. Hip fractures in institutionalized elderly people: incidence rates and excess mortality. J Bone Miner Res 23, 1825-1831.

Ribom, E.L., Grundberg, E., Mallmin, H., Ohlsson, C., Lorenzon, M., Orwoll, E., Holmberg, A.H., Mellstrom, D., Ljunggren, O., Karlsson, M.K., 2009. Estimation of physical performance and measurements of habitual physical activity may capture men with high risk to fall--data from the Mr Os Sweden cohort. Arch Gerontol Geriatr 49, e72-76.

Robbins, A.S., Rubenstein, L.Z., Josephson, K.R., Schulman, B.L., Osterweil, D., Fine, G., 1989. Predictors of falls among elderly people. Results of two population-based studies. Arch Intern Med 149, 1628-1633.

Robinovitch, S.N., Feldman, F., Yang, Y., Schonnop, R., Leung, P.M., Sarraf, T., Sims-Gould, J., Loughin, M., 2013. Video capture of the circumstances of falls in elderly people residing in long-term care: an observational study. Lancet 381, 47-54.

Rogers, M.W., Johnson, M.E., Martinez, K.M., Mille, M.L., Hedman, L.D., 2003. Step training improves the speed of voluntary step initiation in aging. J Gerontol A Biol Sci Med Sci 58, 46-51.

Rooks, D.S., Kiel, D.P., Parsons, C., Hayes, W.C., 1997. Self-paced resistance training and walking exercise in community-dwelling older adults: effects on neuromotor performance. J Gerontol A Biol Sci Med Sci 52, M161-168.

Rose, D.J., Hernandez, D., 2010. The role of exercise in fall prevention for older adults. Clin Geriatr Med 26, 607-631.

Rossiter-Fornoff, J.E., Wolf, S.L., Wolfson, L.I., Buchner, D.M., 1995. A cross-sectional validation study of the FICSIT common data base static balance measures. Frailty and Injuries: Cooperative Studies of Intervention Techniques. J Gerontol A Biol Sci Med Sci 50, M291-297.

Rubenstein, L.Z., Josephson, K.R., 2002. The epidemiology of falls and syncope. Clin Geriatr Med 18, 141-158.

Rubenstein, L.Z., Josephson, K.R., Robbins, A.S., 1994. Falls in the nursing home. Ann Intern Med 121, 442-451.

Schnell, S., Friedman, S.M., Mendelson, D.A., Bingham, K.W., Kates, S.L., 2010. The 1-year mortality of patients treated in a hip fracture program for elders. Geriatr Orthop Surg Rehabil 1, 6-14.

Schwartz, A.V., Nevitt, M.C., Brown, B.W., Jr., Kelsey, J.L., 2005. Increased falling as a risk factor for fracture among older women: the study of osteoporotic fractures. Am J Epidemiol 161, 180-185.

Seino, S., Ysbushita, N., Kim, M., Matsuo, T., Jung, S., Fukasaku, T., Okuno, J., Okura, T., Tanaka, K., 2010. Fall-related factors to target in community-based interventions for prevention of falls (article in Japanese). Jpn J Phys Fitness Sports Med 59, 415-426.

Sherrington, C., Tiedemann, A., Fairhall, N., Close, J.C., Lord, S.R., 2011. Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations. N S W Public Health Bull 22, 78-83.

Sherrington, C., Whitney, J.C., Lord, S.R., Herbert, R.D., Cumming, R.G., Close, J.C., 2008. Effective exercise for the prevention of falls: a systematic review and meta-analysis. J Am Geriatr Soc 56, 2234-2243.

Shigematsu, R., Okura, T., 2006. A novel exercise for improving lower-extremity functional fitness in the elderly. Aging Clin Exp Res 18, 242-248.

Shigematsu, R., Okura, T., Nakagaichi, M., Tanaka, K., Sakai, T., Kitazumi, S., Rantanen, T., 2008. Square-stepping exercise and fall risk factors in older adults: a single-blind, randomized controlled trial. J Gerontol A Biol Sci Med Sci 63, 76-82.

Shimada, H., Obuchi, S., Furuna, T., Suzuki, T., 2004. New intervention program for preventing falls among frail elderly people: the effects of perturbed walking exercise using a bilateral separated treadmill. Am J Phys Med Rehabil 83, 493-499.

Shimanuki, M., 2014. The Physical Restraint of Users and Patients in Welfare Facilities and Hospitals, and the Related Legal Problems. Japanese Journal of Social Welfare 55, 1-12.

Shinkai, S., Watanabe, S., Kumagai, S., Fujiwara, Y., Amano, H., Yoshida, H., Ishizaki, T., Yukawa, H., Suzuki, T., Shibata, H., 2000. Walking speed as a good predictor for the onset of functional dependence in a Japanese rural community population. Age Ageing 29, 441-446.

Siris, E.S., Chen, Y.T., Abbott, T.A., Barrett-Connor, E., Miller, P.D., Wehren, L.E., Berger, M.L., 2004. Bone mineral density thresholds for pharmacological intervention to prevent fractures. Arch Intern Med 164, 1108-1112.

Sorock, G.S., Labiner, D.M., 1992. Peripheral neuromuscular dysfunction and falls in an elderly cohort. Am J Epidemiol 136, 584-591.

Soyano, A., Kamioka, H., 2001. How to care the fear of falling? (article in Japanese). Expert Nurse 17, 41-43.

Stevens, J.A., Powell, K.E., Smith, S.M., Wingo, P.A., Sattin, R.W., 1997. Physical activity, functional limitations, and the risk of fall-related fractures in community-dwelling elderly. Ann Epidemiol 7, 54-61.

Strycker, L.A., Duncan, S.C., Chaumeton, N.R., Duncan, T.E., Toobert, D.J., 2007. Reliability of pedometer data in samples of youth and older women. Int J Behav Nutr Phys Act 4, 4.

Suzuki, T., 2003. Epidemiology and implications of falling among the elderly (article in Japanese). Nippon Ronen Igakkai Zasshi 40, 85-94.

Suzuki, T., Kim, H., Yoshida, H., Ishizaki, T., 2004. Randomized controlled trial of exercise intervention for the prevention of falls in community-dwelling elderly Japanese women. J Bone Miner Metab 22, 602-611.

Suzuki, T., Sugiura, M., Furuna, T., Nishizawa, S., Yoshida, H., Ishizaki, T., Kim, H., yukawa, H., Shibata, H., 1999. Association of Physical Performance and Falls Among the Community Elderly in Japan in a Five Year Follow-up Study (article in Japanese). Nippon Ronen Igakkai Zasshi 36, 472-478.

Takenaka, K., Chikagawa, M., Honda, G., Matsuzaki, C., 2002. Development of falling self-efficacy scale for elderly people : the reliability and validity (article in Japanese). Japan J Phys Educ Hlth Sport Sci 47, 1-13.

Tanaka, K., Shigematsu, R., 2010. A Paradigm Shift for Designing Health-related Intervention Studies in Exercise Science and Physical Education (article in Japanese). Jpn J Phys Fitness Sports Med 59, 457-464.

Thapa, P.B., Gideon, P., Fought, R.L., Ray, W.A., 1995. Psychotropic drugs and risk of recurrent falls in ambulatory nursing home residents. Am J Epidemiol 142, 202-211.

Tinetti, M.E., Baker, D.I., King, M., Gottschalk, M., Murphy, T.E., Acampora, D., Carlin, B.P., Leo-Summers, L., Allore, H.G., 2008. Effect of dissemination of evidence in reducing injuries from falls. N Engl J Med 359, 252-261.

Tinetti, M.E., Baker, D.I., McAvay, G., Claus, E.B., Garrett, P., Gottschalk, M., Koch, M.L., Trainor, K., Horwitz, R.I., 1994. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. N Engl J Med 331, 821-827.

Tinetti, M.E., Doucette, J., Claus, E., Marottoli, R., 1995. Risk factors for serious injury during falls by older persons in the community. J Am Geriatr Soc 43, 1214-1221.

Tinetti, M.E., Richman, D., Powell, L., 1990. Falls efficacy as a measure of fear of falling. J Gerontol 45, P239-243.

Tinetti, M.E., Speechley, M., Ginter, S.F., 1988. Risk factors for falls among elderly persons living in the community. N Engl J Med 319, 1701-1707.

Tinetti, M.E., Williams, T.F., Mayewski, R., 1986. Fall risk index for elderly patients based on number of chronic disabilities. Am J Med 80, 429-434.

Tomata, Y., Hozawa, A., Ohmori-Matsuda, K., Nagai, M., Sugawara, Y., Nitta, A., Kuriyama, S., Tsuji, I., 2011. [Validation of the Kihon Checklist for predicting the risk of 1-year incident long-term care insurance certification: the Ohsaki Cohort 2006 Study]. Nihon Koshu Eisei Zasshi 58, 3-13.

Tromp, A.M., Pluijm, S.M., Smit, J.H., Deeg, D.J., Bouter, L.M., Lips, P., 2001. Fall-risk screening test: a prospective study on predictors for falls in community-dwelling elderly. J Clin Epidemiol 54, 837-844.

Uemura, K., Shimada, H., Makizako, H., Doi, T., Yoshida, D., Tsutsumimoto, K., Anan, Y., Suzuki, T., 2013. Cognitive function affects trainability for physical performance in exercise intervention among older adults with mild cognitive impairment. Clin Interv Aging 8, 97-102.

Vellas, B.J., Wayne, S.J., Romero, L., Baumgartner, R.N., Rubenstein, L.Z., Garry, P.J., 1997. One-leg balance is an important predictor of injurious falls in older persons. J Am Geriatr Soc 45, 735-738.

Vetter, N.J., Lewis, P.A., Ford, D., 1992. Can health visitors prevent fractures in elderly people? BMJ 304, 888-890.

von Koch, L., Widen Holmqvist, L., Kostulas, V., Almazan, J., de Pedro-Cuesta, J., 2000. A randomized controlled trial of rehabilitation at home after stroke in Southwest Stockholm: outcome at six months. Scand J Rehabil Med 32, 80-86.

Voukelatos, A., Merom, D., Rissel, C., Sherrington, C., Watson, W., Waller, K., 2011. The effect of walking on falls in older people: the 'Easy Steps to Health' randomized controlled trial study protocol. BMC Public Health 11, 888.

Voukelatos A., Merom D., Sherrington C., Rissel C., Cumming R.G., Lord S.R., 2015. The impact of a home-based walking programme on falls in older people: the Easy Steps randomised controlled trial. Age Ageing (in press)

Wijlhuizen, G.J., Chorus, A.M., Hopman-Rock, M., 2010. The FARE: a new way to express FAlls Risk among older persons including physical activity as a measure of exposure. Prev Med 50, 143-147.

Wijlhuizen, G.J., de Jong, R., Hopman-Rock, M., 2007. Older persons afraid of falling reduce physical activity to prevent outdoor falls. Prev Med 44, 260-264.

Wolfson, L., Judge, J., Whipple, R., King, M., 1995. Strength is a major factor in balance, gait, and the occurrence of falls. J Gerontol A Biol Sci Med Sci 50 Spec No, 64-67.

Wolfson, L., Whipple, R., Judge, J., Amerman, P., Derby, C., King, M., 1993. Training balance and strength in the elderly to improve function. J Am Geriatr Soc 41, 341-343.

World Health Organization, 1984. The uses of epidemiology in the study of the elderly. Report of a WHO Scientific Group on the Epidemiology of Aging. World Health Organ Tech Rep Ser 706, 1-84.

World Health Organization, 2008. WHO Global Report on Falls Prevention in Older Age.

World Health Organization, 2014. Definition of an older or elderly person.

Yamada, M., Aoyama, T., Arai, H., Nagai, K., Tanaka, B., Uemura, K., Mori, S., Ichihashi, N., 2011. Dual-task walk is a reliable predictor of falls in robust elderly adults. J Am Geriatr Soc 59, 163-164.

Yoo, E.J., Jun, T.W., Hawkins, S.A., 2010. The effects of a walking exercise program on fall-related fitness, bone metabolism, and fall-related psychological factors in elderly women. Res Sports Med 18, 236-250.

Zisser, H., Gong, P., Kelley, C.M., Seidman, J.S., Riddell, M.C., 2011. Exercise and diabetes. Int J Clin Pract Suppl, 71-75.

APPENDIXES

Related Articles Published in Refereed Journals

1) Okubo Y, Seino S, Yabushita N, Matsuo T, Osuka Y, Kim M, Jung S, Nemoto M, Otsuki N, Tanaka K: Association between habitual walking and multiple or injurious falls among community-dwelling older adults: Difference by risk of falling (article in Japanese). Jpn J Phys Fitness Sports Med 60(2):239-248, 2011.

2) Okubo Y, Seino S, Yabushita N, Osuka Y, Jung S, Nemoto M, Figueroa R, Tanaka K. Longitudinal association between habitual walking and fall occurrences among community-dwelling older adults: analyzing the different risks of falling. Arch Gerontol Geriatr 60(1):45-51, 2015. (in press)

3) Okubo Y, Osuka Y, Jung S, Figueroa R, Tsujimoto T, Aiba T, Kim T, Tanaka K. The effects of walking on physical and psychological fall-related factors in community-dwelling older adults: A walking versus balance program. J Phys Fitness Sports Med 3(5): 515-524, 2014.

4) Okubo Y, Osuka Y, Jung S, Figueroa R, Tsujimoto T, Aiba T, Kim T, Tanaka K. Walking can be more effective than balance training in fall prevention among community-dwelling, older adults. Geriatr Gerontol Int. (in press)