Tailor-Made Programs for Preventive Falls that Match the Level of Physical Well-Being in Community-Dwelling Older Adults

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1. Introduction

Falls are relatively common in the elderly, with approximately 30% of individuals aged 65 and older falling at least once a year and approximately half of them experiencing repeated falls (Tinetti et al., 1988). Falls and fractures have a major impact on elderly individuals, their caregivers, health service providers, and the community. Sherrington et al. reported that up to 42% of falls can be prevented by well-designed exercise programs that target balance and involve a good amount of exercise (Sherrington et al., 2008).

In daily life, locomotion occurs under complicated circumstances, with cognitive attention focused on a particular task, such as watching the traffic or reading street signs, rather than on performing a simple motor task such as walking. A seminal study demonstrating that the characteristic "stops walking when talking" could serve as a predictor of falls introduced a novel method for predicting falls based on dual-task (DT) performance (Lundin-Olsson et al., 1997). Our recent study indicated that different factors may be related to fall incidents depending on the level of frailty of the community-dwelling elderly adults (Yamada et al., 2011a). These findings suggest that fall prevention programs should be tailored to the elderly adult's level of physical well-being. The purpose of this review is to review approaches to fall prevention tailored to an individual's level of physical well-being.

2. What is "Dual-task"?

Recently, several investigators have reported that DT gait is associated with fall incidents in elderly adults. A summary of these DT studies is shown in Table 1.

3. How can we use DT to assess fall risk in the elderly?

3.1 Game-based fall risk assessment

DT performance may be a reliable predictor of falls in elderly adults. The Nintendo Wii Fit program requires the distribution of attention to the motor task and the monitor (cognitive task). Thus, it is assumed that this program includes a constituent of DT. We examined whether the Wii Fit program's Basic Step can be used for fall risk assessment in healthy,

	Primary task	Secondary task	Fall related
Beauchet et al., 2008	Walk	Cognitive task	○
Beauchet et al., 2008	Walk	Cognitive task	○
Kressing RW et al, 2008	Walk	Cognitive task	○
Beauchet et al., 2007	Walk	Cognitive task	○
Faulkner KA et al, 2007	Walk	Cognitive task	○
Toulotte C et al, 2006	Walk	Manual task	○
Springer S et al, 2006	Walk	Cognitive task	×
Bootsma-vander Wiel A et al, 2003	Walk	Cognitive task	×
Verghese et al., 2002	Walk	Cognitive task	○
Stalenhoef PA et al, 2002	Walk	Cognitive task	×
Lundin-Olsson L et al, 1997	Walk	Cognitive task	○

○, related to falls; x, non-related to falls

Table 1. Effect of dual tasking on falls.

community-dwelling elderly adults (Yamada et al., 2011b). The results suggested that game-based fall risk assessment has a high generality and is very useful for assessing community-dwelling elderly adults (Fig. 1).

This study included a Wii Fit Balance Board, which was placed under the participants' feet. A score of 111 points on Basic Step was used to classify 88.6% of the cases correctly ($p < 0.001$). The horizontal demonstrates the cutoff point.

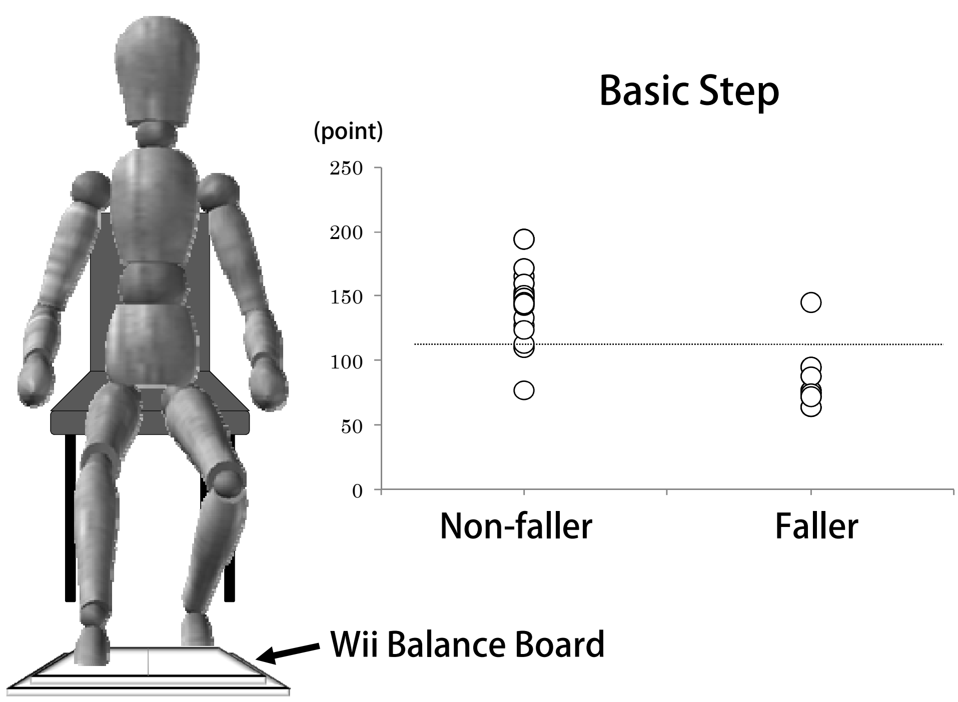

Fig. 1. Schematic diagram of Basic Step as played in a sitting position and scatter chart.

3.2 Smartphone-based fall risk assessment

The Android-based Smartphone can be used to develop applications freely. These applications can then be disseminated across the world via the internet. The use of Android-based applications is advantageous because they are free to develop, offer flexible design options, and can be easily and rapidly distributed over the internet. We developed an Android application (RollingBall) for the assessment of fall risk (available for download at http://www.kuhp.kyoto-u.ac.jp/~kazuya/RollingBall.apk) in which a small blue ball (1.5 cm in diameter) is moved on a large white circle (4 cm in diameter) by tilting the phone. The angle of the phone is determined by triaxial accelerometers (Fig. 2). The Android application also calculates a score on the basis of the coordinate data of the ball on the circle; higher scores indicate that the blue ball is closer to the center of the circle. The application was based on the "walking while carrying a ball on a tray" task. We previously examined whether the score determined by the Android application for DT-based fall risk assessment was related to falls in a population of community-dwelling elderly people (Yamada et al., 2011c). The results suggested that the Android application is very useful for fall risk assessment in elderly adults (Fig. 2).

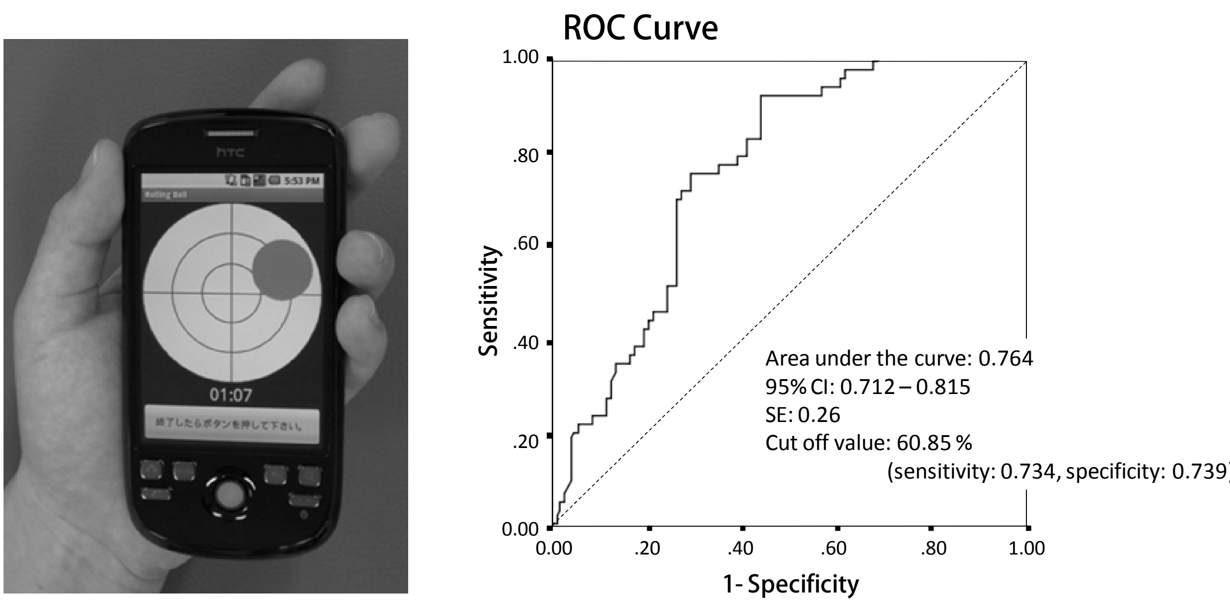

Fig. 2. An Android application allows users to control the position of a small blue circle (1.5 cm in diameter) on a large white circle (4 cm in diameter). Scores are automatically calculated on the basis of coordinate tracking data for the blue circle.

ROC (receiver operating characteristic) curve of the dual tasking (DT) total cost for the classification of fall risk. The area under the curve was 0.764. For the DT total cost, the cut-off value was 60.85% (sensitivity = 73.4%, specificity = 73.9%). CI, confidence interval

3.3 Multitarget Stepping Test (MTST)

We developed a walking test, the multitarget stepping test (MTST) (Yamada et al., 2011d). During the test, stepping and avoidance failures were measured while participants walked along a 10-m walkway and stepped on multiple targets. The MTST was performed on a black elastic mat (10 m long × 1 m wide). Forty-five 10 cm × 10 cm squares were on the mat (see Fig. 3). These squares were arranged into 3 rows (15 cm between each row) and 15 lines (61 cm between each line). Each square was marked with red, blue, or yellow tape. Each line had one of the 3 colored squares in a random order. One square (blue or yellow) was the footfall target, whereas the others were distracters. The color of the footfall target was counterbalanced among the participants and announced to each participant before he or she began walking.

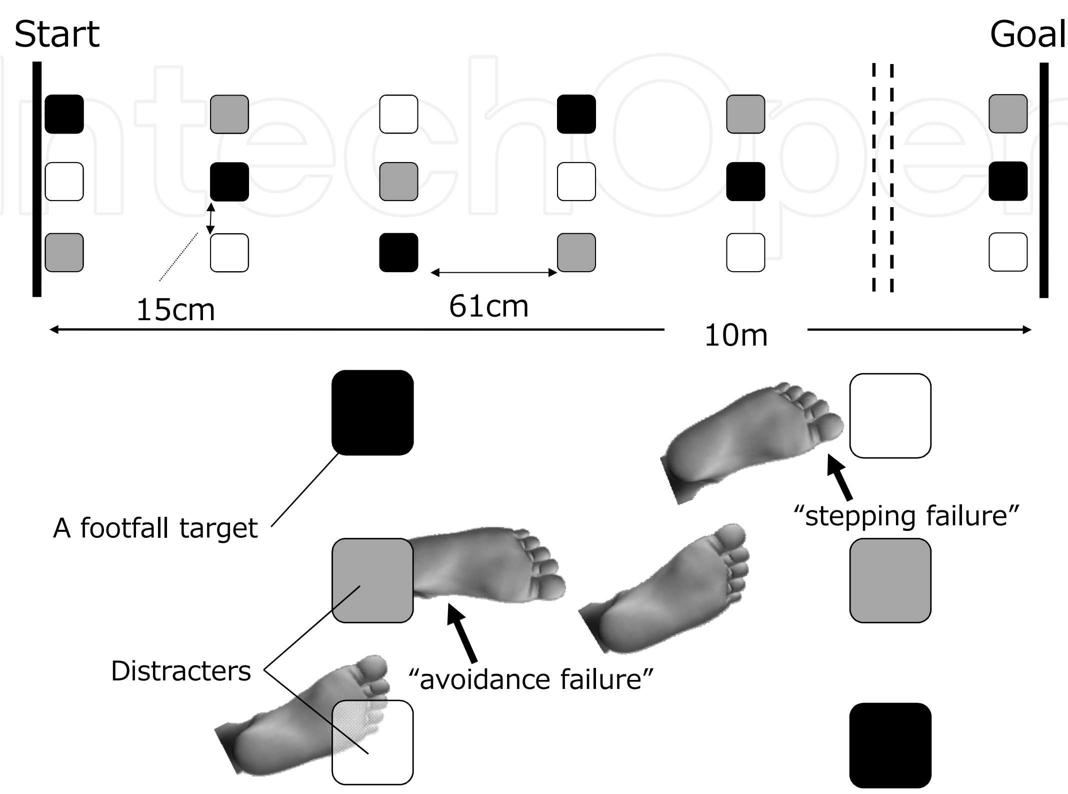

Fig. 3. The 10-m walkway used in the multitarget stepping test (MTST): Each square was made of red, blue, or yellow tape. The MTST measured 2 types of failure. A participant intended to step on footfall targets (displayed in white). Failure to step on the footfall target was regarded as a stepping error. Failure to avoid a distracter was regarded as an avoidance failure. As shown in this figure, avoidance failure was always the result of an accidental step as the participant walked from target to target; it did not occur because of selecting the wrong target out of the 3 squares on the line on which the participant intended to step.

The participants walked on the mat at a self-selected pace while stepping on the target square placed on each line. The participants were instructed (a) to step on a footfall target with either side of the foot and any part of the sole, (b) to take as many steps as necessary while walking between the lines to comfortably walk toward the next footfall target, and (c) to not step on the distracters. The main dependent measures were 2 types of failure indicating less accurate stepping performance: a stepping failure (i.e., failure to step on the footfall target) and an avoidance failure (i.e., failure to avoid distracters).

The results demonstrated that the stepping failure was independently associated with falling (odds ratio [OR] = 19.365, 95% confidence interval [CI] = 3.28–113.95; $p < 0.001$). Hence, measurements of stepping accuracy while performing the MTST, particularly precise stepping failure, could help identify elderly individuals at high risk for a fall.

3.4 Questionnaire-based fall risk assessment

As discussed, DT walking, game-based assessment, Smartphone assessment, and/or MTST can be used to identify elderly adults at high risk of falling. However, more simple and reliable assessment methods are necessary for community-dwelling elderly people. We previously examined whether a newly developed index we had designed to assess complex-task locomotion was related to falls in a robust elderly population (Yamada et al., in press a). The results suggested that a score of more than 1 point on the new index can predict falls in elderly adults (Table 2, Fig. 4).

	Item	0	1
1)	Can you stand up without a support?	Yes	No
2)	Can you turn in the opposite way, while holding an empty glass?	Yes	No
3)	Can you walk without dropping a glass of water?	Yes	No
4)	Have you ever tripped over an obstacle while going to the bathroom or picking up the telephone?	No	Yes

Table 2. Newly developed index

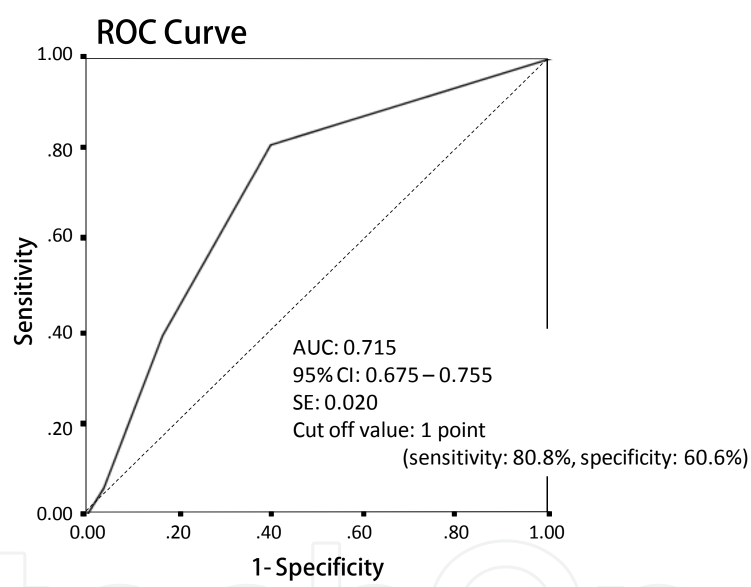

Fig. 4. The ROC (receiver operating characteristic) curve for the total points used for the classification of fall risk: The area under the curve (AUC) was 0.715. Concerning the total points, the cut-off value was determined at 1 point (sensitivity, 80.8%; specificity, 60.6%). CI, confidence interval

4. Different factors related to fall incidents

Our research has indicated that different factors may be related to fall incidents depending on the level of frailty in community-dwelling elderly adults.

One study population consisted of 1038 elderly Japanese subjects aged 65 years or older living in a community (401 men, 637 women; mean age, 77 ± 8 years). We assessed 6 items of physical functioning: timed up and go (TUG), functional reach, 5-chair stand, single-task (ST) 10-m walking time, and DT (CT [cognitive task], MT [manual task]) 10-m walking time.

In the TUG test, participants were asked to stand up from a standard chair with a seat height of 40 cm, walk a distance of 3 m at a maximum pace, turn, walk back to the chair, and sit down (Podsiadlo et al., 1991). Functional reach was measured using a simple clinical apparatus consisting of a yardstick secured to the wall at right acromion height as previously described (Duncan et al., 1990). In the 5-chair stand, participants were asked to stand up and sit down 5 times as quickly as possible and were timed from the initial sitting position to the final standing position at the end of the fifth stand (Guralnik et al., 1994). In ST walking, the participants were asked to walk as fast as possible along a 10-m straight line, with a 1-m approach at both ends, for a total length of 12 m. The time required was measured. In CT walking, participants walked 15 m at the most comfortable speed while counting numbers aloud in reverse order starting at 100. In MT walking, participants walked 15 m at the most comfortable speed while carrying a ball (7 cm in diameter, 150 g in weight) on a tray (17 cm in diameter, 50 g in weight). The DT cost (CT and MT) was then calculated as follows: DT cost [%] = 100 × (DT walking time – ST walking time)/([ST walking time + DT walking time]/2).

Information on fall incidents over the following year was collected from participants via a monthly telephone interview. A fall was defined as any event that led to unplanned, unexpected contact with a supporting surface during walking.

For analysis, we divided the TUG test results into quartiles (fastest, faster, slower, and slowest). A multivariate analysis by means of logistic regression using a stepwise-forward method was performed to investigate which of the 5 measures of physical functioning (i.e., ST walking time, CT cost, MT cost, functional reach, or 5-chair stand test) was independently associated with falls.

A total of 20% in the fastest group, 18.2% in the faster group, 34.1% in the slower group, and 44.1% in the slowest group experienced falls over the following year. In the fastest group (n = 230), the regression analysis indicated that the MT cost (OR = 1.068, 95% CI = 1.04–1.10; $p < 0.001$) was an independent variable that remained in the final step of the regression model. In the faster group (n = 258), the regression analysis indicated that the CT cost (OR = 1.03, 95% CI = 1.01–1.04; $p < 0.001$) was an independent variable. In the slower (n = 264) and slowest (n = 286) groups, the 5-chair stand test (slower group: OR = 1.11, 95% CI = 1.03–1.19; $p < 0.001$; slowest group: OR = 1.05, CI = 1.01–1.09; $p < 0.045$) was found to be a significant and independent variable of falls. A summary of these results is shown in Fig. 5.

5. Fall prevention programs tailored to levels of physical well-being

Fig. 5 shows that different factors may be related to fall incidents depending on one's level of physical well-being. DT walking is associated with falls in the robust elderly population, and thus this population should be given the rhythmic stepping exercise (Yamada et al., 2011e). DT walking and muscle strength are associated with falls in the intermediate elderly population, and thus this population should be given the seated stepping exercise (Yamada et al., 2010a). Muscle strength and DT walking are associated with falls in the pre-frail elderly population (Yamada et al., 2010b) and thus this population should be given the trail walking exercise. Finally, muscle strength is associated with falls in the frail elderly population, and thus this population should be given resistance exercise (Yamada et al., 2011f).

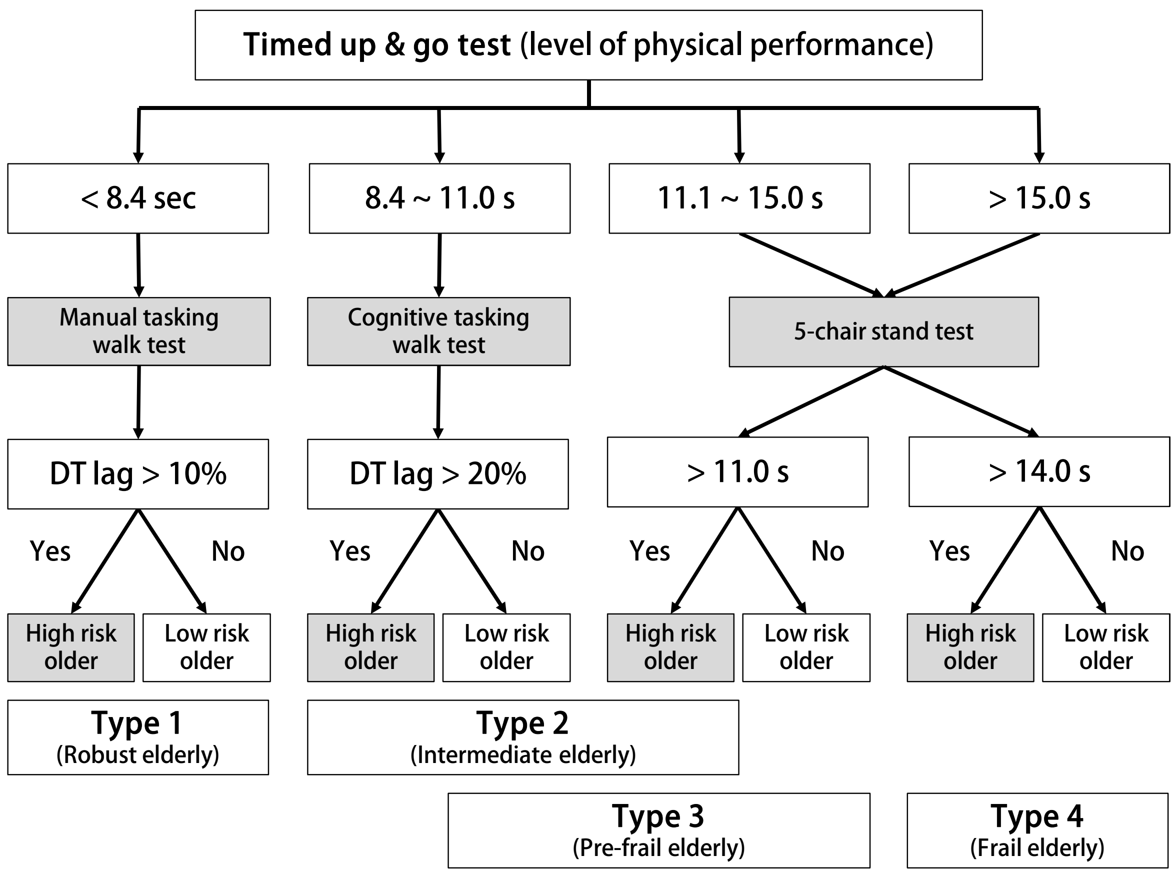

Fig. 5. Flow chart showing that the different factors may be related to fall incidents depending on an individual's level of physical well-being; DT, dual tasking

5.1 Rhythmic stepping exercise

Rhythmic stepping exercises were performed on a thin elastic mat (150 × 150 cm) that was partitioned into 5 squares (50 cm each) to form a cross (Fig. 6). The stepping exercises included forward, backward, and sideways step patterns. The participants were required to step at a tempo of 60–120 beats/min along with the accompanying rhythm sound and to step into the square indicated verbally by the supervisor (e.g., "right," "forward," "back"). Cognitive functioning (reaction, short-term memory, etc.) and motor functioning (stepping in multiple directions) were simultaneously required of the participants. In order to change the level of difficulty, the instruction method transposed not only direction but also color (e.g., "red," "blue") or number (e.g., "3," "7"). The participants completed 5 sets of 1 min per set of stepping exercises between weeks 1 and 8, which was then increased to 3 sets of 3 min per set between weeks 9 and 16 and 3 sets of 5 min per set between weeks 17 and 24. The instructions given at the beginning of each class were as follows: "Please step as correctly as possible, and avoid making mistakes as much as you can."

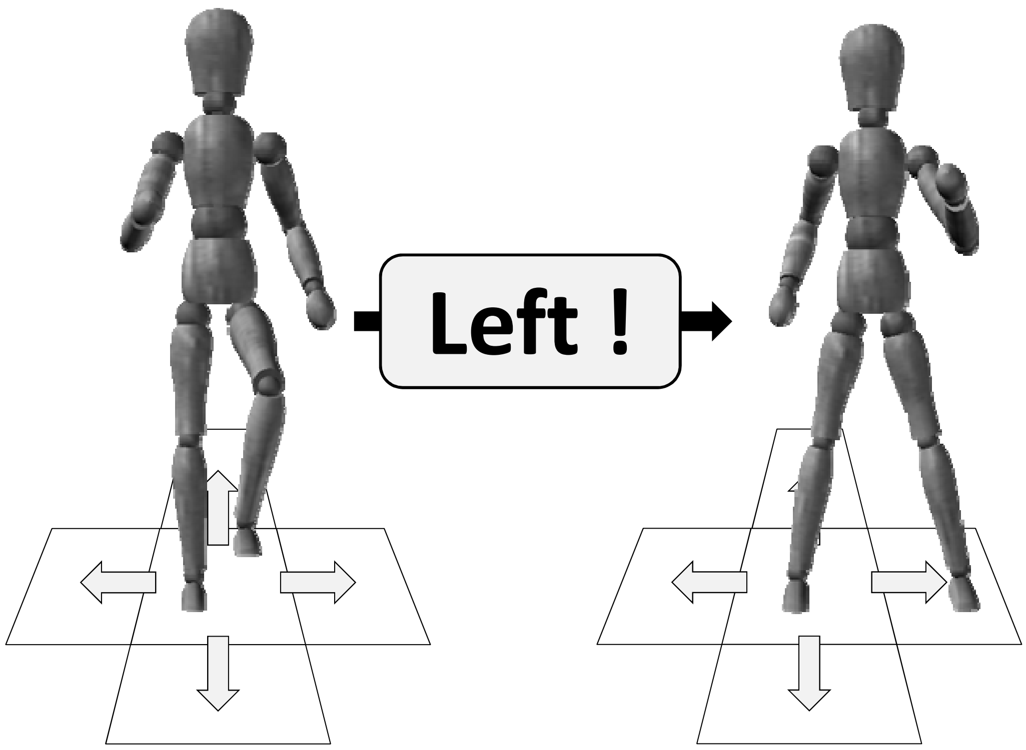

Fig. 6. Schematic representation of the stepping exercises.

The stepping exercises were performed on a thin elastic mat that was partitioned into 5 squares (50 cm each) to form a cross shape. The stepping exercises included forward, backward, and sideways step patterns.

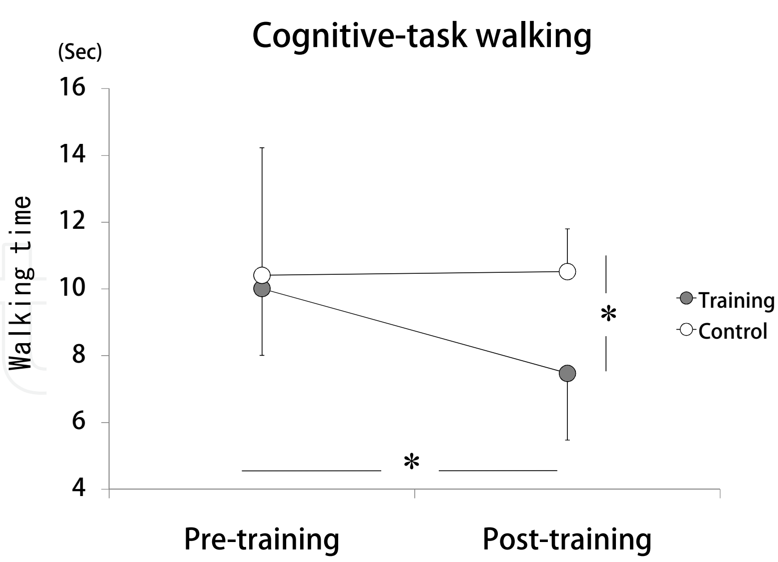

Fig. 7. Cognitive task walk time in training (rhythmic stepping exercise) and control groups during pre- and post-training. Significant differences were observed between the 2 groups ($p < 0.05$).

We evaluated whether a 24-week rhythmic stepping exercise program would effectively improve physical functioning and reduce fear of falling in community-dwelling elderly adults. The results of this study suggested that the rhythmic stepping exercise program was indeed effective at improving DT walking ability and fear of falling (Yamada et al., 2011e).

5.2 Seated stepping exercise

The participants were instructed on how to perform the seated stepping exercises by using a standard dining room chair (Fig. 8). The participants stepped up and down alternating between left and right legs as quickly as possible while returning the legs to the initial starting position. The minimum lifting height for stepping was the lifting of the plantar surface above the ground. The intensity of the exercise was increased over the 12-week period by increasing the total stepping time. The participants completed 10 sets of 5 s per set in weeks 1–12, increasing to 10 sets of 10 s per set in weeks 13–24. The participants were asked to perform a verbal fluency task during stepping (DT condition). This task consisted of listing words within a category (e.g., animals, vegetables, fruits, fish) or by letter (e.g., a word that begins with “A”) at a self-selected speed. This task was self-generated; the participants did not read from a list but had to conceptualize and vocalize each word. The verbal fluency task was changed for each exercise session. The participants were not specifically instructed to prioritize either task but were asked to combine both tasks as much as they could. The instructions were as follows: “Please step as quickly as possible, and avoid making mistakes as much as you can.”

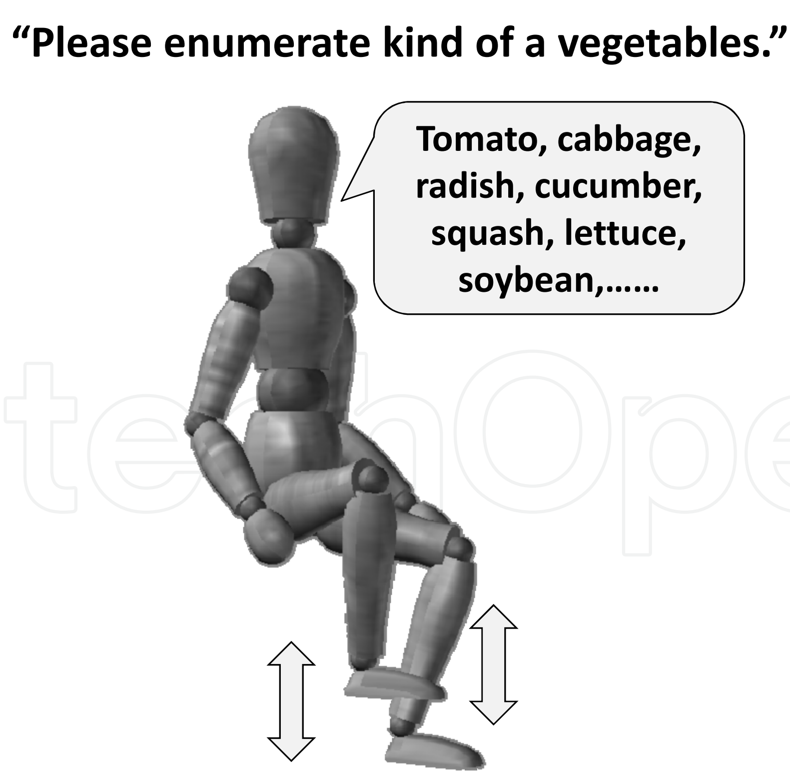

Fig. 8. Schematic representation of the seated stepping exercise

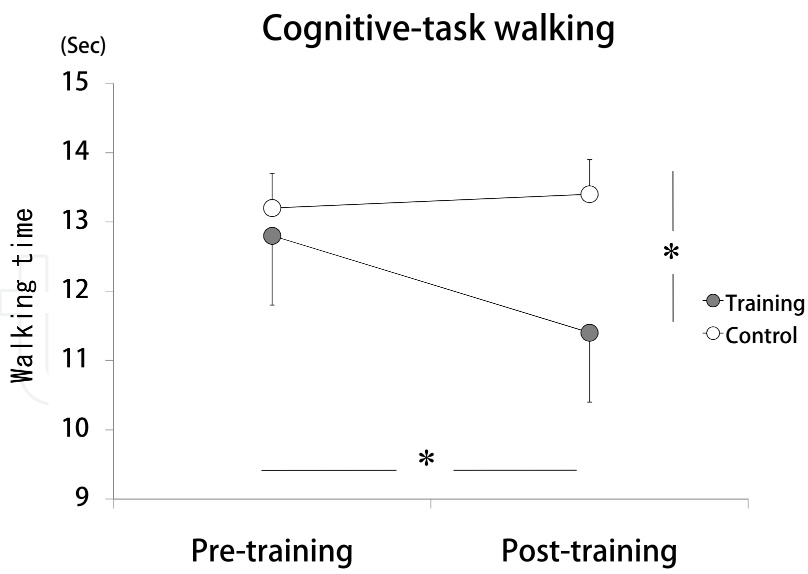

Fig. 9. Cognitive task walk time in training (seated stepping exercise) and control groups during pre- and post-training. Significant differences were observed between the 2 groups ($p < 0.05$).

We evaluated whether a 24-week seated stepping exercise program would effectively improve physical functioning in community-dwelling elderly adults. The results of this trial suggested that the seated stepping exercise program was indeed effective at improving DT walking ability (Yamada et al., 2010a).

However, unsupervised exercise is difficult to control and monitor in many elderly adults. In recent years, several studies have demonstrated the effectiveness of various video- or internet-based exercises in elderly adults or orthopedic patients.

We also investigated the feasibility and effectiveness of a DVD-based seated stepping exercise for the improvement of DT walking capability in community-dwelling elderly adults. The participants received 20 min of group training twice a week for 24 weeks (Fig. 10). The exercise class used an exercise DVD that included a 15-min basic exercise section and a 5-min seated DT stepping exercise section. An exercise DVD with 4 volumes was used. The basic training involved stretching, strength, and agility training while seated. An example from the exercise program is shown below: *http://www.youtube.com/watch?v=1391kzEYMJM* and *http://www.youtube.com/watch?v=mcaWhPLN7Es*. This study reports the feasibility and effectiveness of DVD-based exercise for the improvement of DT walking capability (Yamada et al., in press b).

5.3 Trail walking exercise

In the trail walking exercise, flags were set randomly at each of 15 positions in a 25-m² area (5 m × 5 m; Fig. 12). Participants were asked to pass sequentially from No. 1 to No. 15. A circle 30 cm in diameter was drawn on the ground around each flag, and participants were required to step in the circle to pass the flag. The height of the flag was 30 cm. The tester gave the following instructions to the participants: “Please move to No. 15 as quickly and correctly as possible.” The 24-week program included a progressive aspect in which the

Fig. 10. Schematic representation of the DVD-based seated stepping exercise.

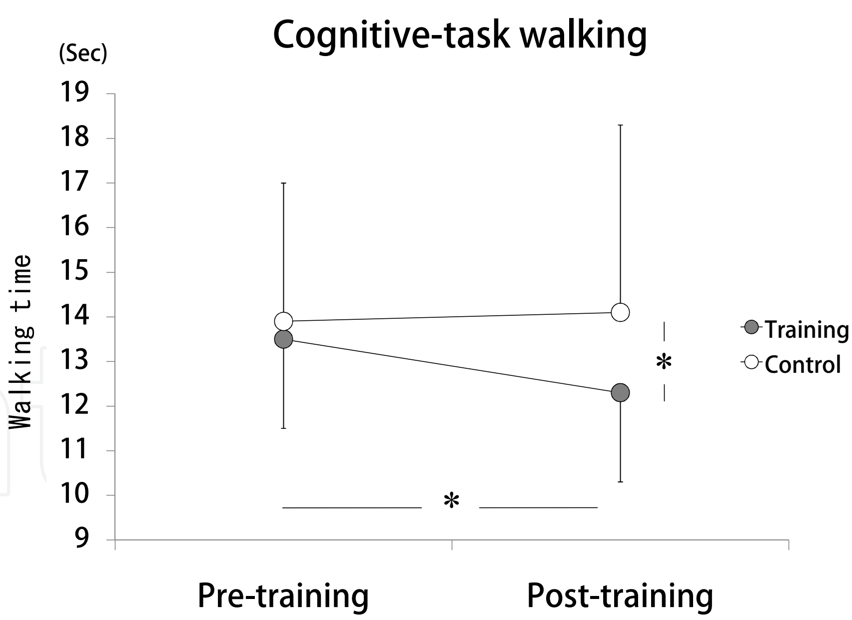

Fig. 11. Cognitive task walk time in training (DVD-based seated stepping exercise) and control groups during pre- and post-training. Significant differences were observed between the 2 groups ($p < 0.05$).

participants were asked to pass sequentially from No. 1 to No. 15 during weeks 1 to 12 but were asked to pass sequentially from No. 15 to No. 1 during weeks 13 to 24. The flag positions were changed for each day of training.

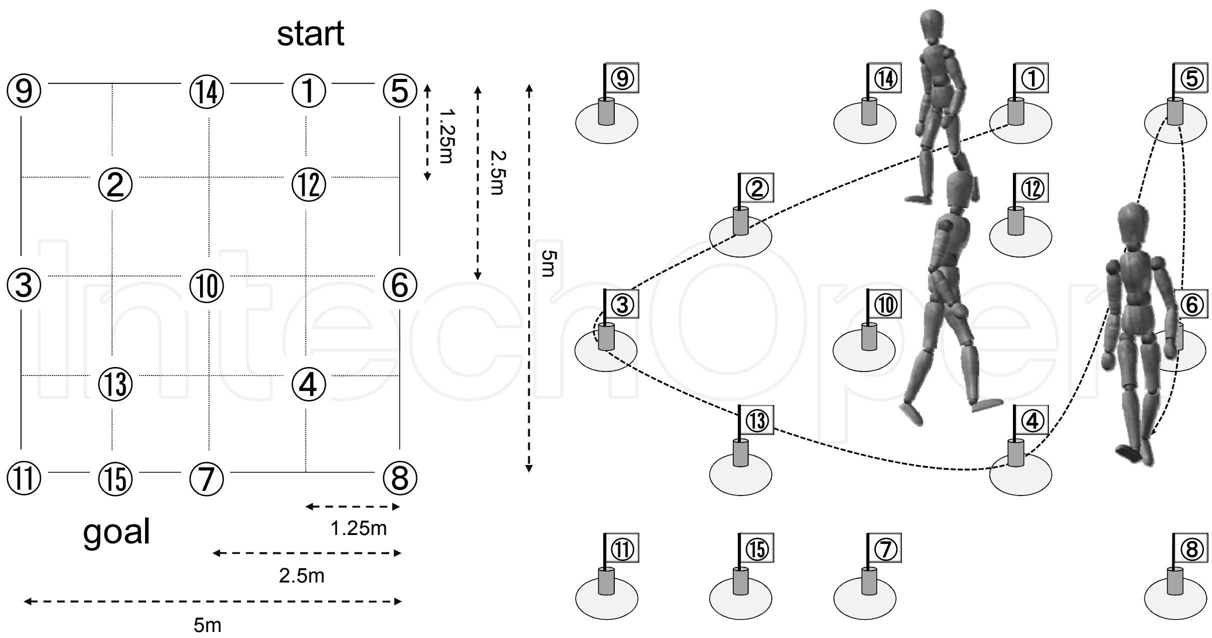

Fig. 12. Schematic representation of the trail walking exercise

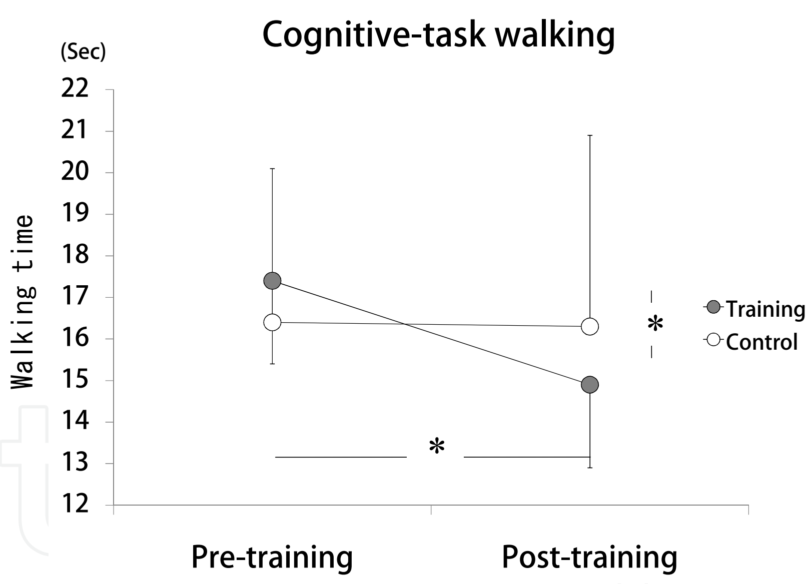

Fig. 13. Cognitive task walk time in training (trail-walking exercise) and control groups during pre- and post-training. Significant differences were observed between the 2 groups ($p < 0.05$).

We evaluated whether a 16-week trail walking exercise program would effectively improve physical functioning and reduce fall incidents in community-dwelling elderly adults. The results of this trial suggested that the trail walking exercise program was indeed effective at improving DT walking ability and decreasing the incident rate of falls 6 months after trial completion (Yamada et al., 2010b).

5.4 Resistance exercise for frail elderly adults

The participants underwent resistance training sessions twice a week for 24 weeks. All participants performed seated row, leg press, leg curl, and leg extension exercises on resistance training machines. Training loads were chosen using the 10-repetition maximum (10-RM; the maximum weight that can be lifted 10 times). The participants used the 10-RM for 3 sets of 10 repetitions for each machine exercise. The participants were required to adjust the training weight to ensure failure at the 10-RM. It took approximately 1 h to finish all sessions, with a 15-min warm-up at the beginning and a 10-min cool-down stretch at the end.

We compared the effects of resistance training on skeletal muscle mass, physical performance, and fear of falling in pre-frail and frail elderly adults. The results of this trial suggested that the skeletal muscle mass was increased by the resistance training program in both groups. However, improvements in the fear of falling and physical functioning were limited to the frail elderly adults (Yamada et al., 2011f).

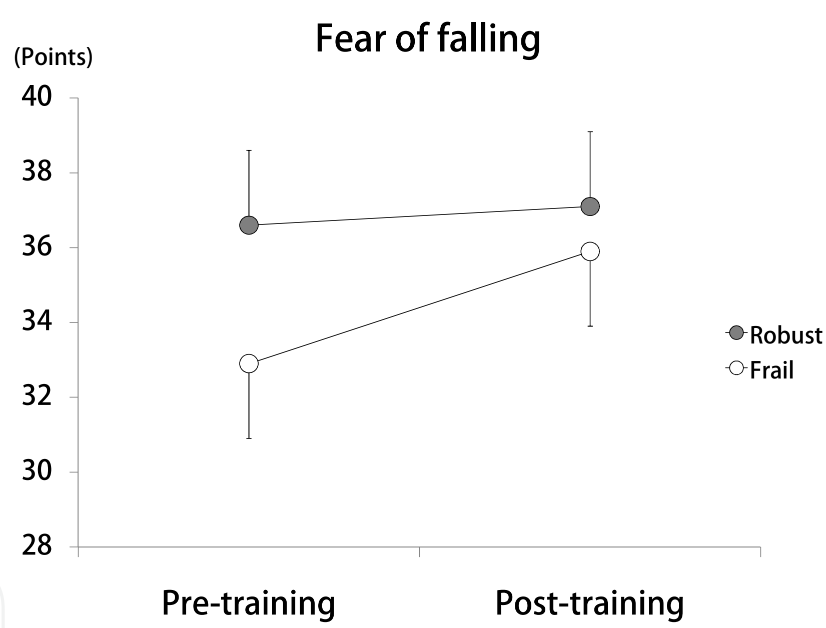

Fig. 14. Fear of falling in robust and frail groups during pre- and post-resistance training. Significant differences were observed between the 2 groups ($p < 0.05$).

6. Conclusions

The findings of this review suggest that fall prevention programs should be tailored to an individual's level of physical well-being; robust elderly adults should be given the rhythmic stepping exercise; intermediate elderly adults, the trail walking exercise; pre-frail elderly adults, the seated stepping exercise; and frail elderly adults, resistance exercises. A summary of interventions tailored to the individuals' levels of physical well-being is shown in Fig. 15.

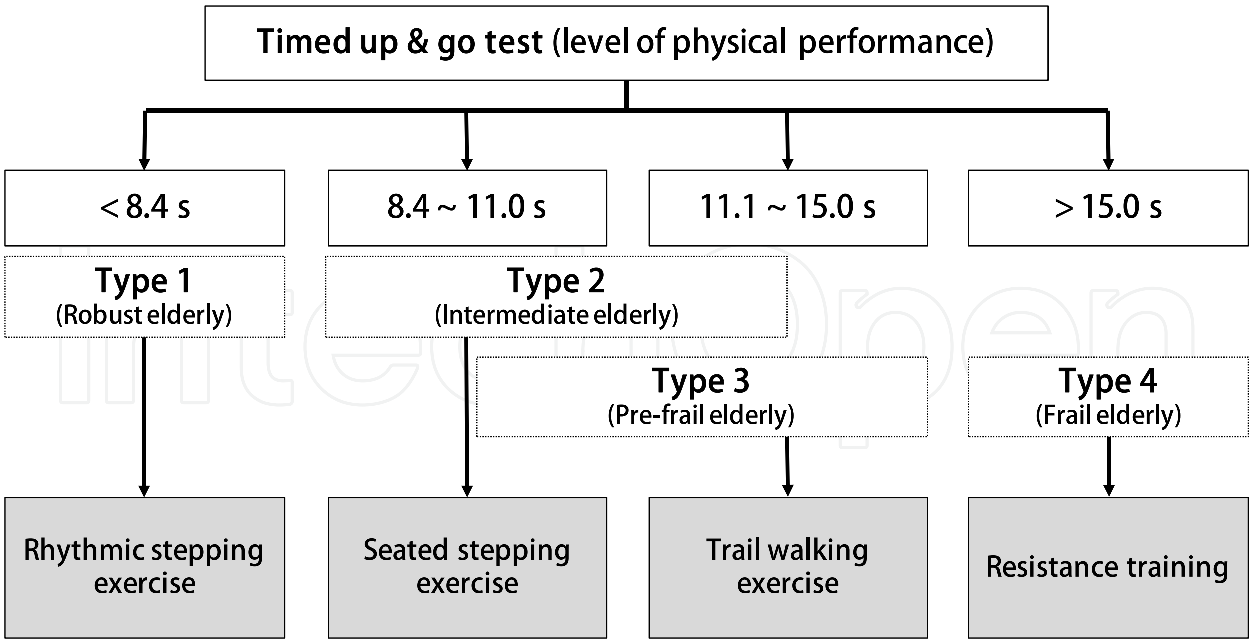

Fig. 15. Flow chart showing interventions tailored to levels of physical well-being.

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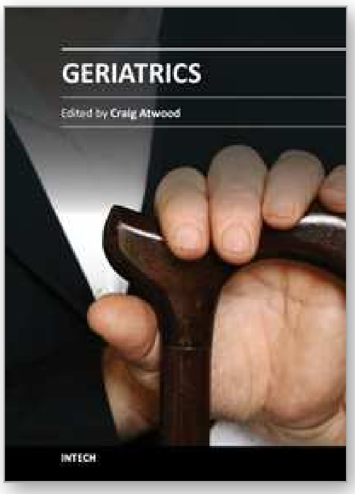

Geriatrics
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With the baby boomer generation reaching 65 years of age, attention in the medical field is turning to how best to meet the needs of this rapidly approaching, large population of geriatric individuals. Geriatric healthcare by nature is multi-dimensional, involving medical, educational, social, cultural, religious and economic factors. The chapters in this book illustrate the complex interplay of these factors in the development, management and treatment of geriatric patients, and begin by examining sarcopenia, cognitive decline and dysphagia as important factors involved in frailty syndrome. This is followed by strategies to increase healthspan and lifespan, such as exercise, nutrition and immunization, as well as how physical, psychological and socio-cultural changes impact learning in the elderly. The final chapters of the book examine end of life issues for geriatric patients, including effective advocacy by patients and families for responsive care, attitudes toward autonomy and legal instruments, and the cost effectiveness of new health care technologies and services.

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