J. Phys. Ther. Sci.
22: 323–329, 2010

Age-Related Changes in Attentional Capacity and the Ability to Multi-Task as a Predictor for Falls in Adults Aged 75 Years and Older

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Abstract. [Purpose] Examine the age-related deterioration of attentional capacity and predictive validity of multi-tasking performances for falls in adults aged 75 and older. [Methods] This study involved 45 elderly individuals and 15 healthy and young volunteers. Reaction times to a visual stimulus were measured under three different conditions: 1) stepping in place (dual-tasking condition with dynamic balance demands); 2) counting backwards during quiet standing (dual-tasking condition with cognitive demands); and 3) counting backwards while stepping in place (triple-tasking condition). The participating elderly individuals reported subsequent falls after a 5-month follow-up period. [Results] Elderly adults demonstrated significantly longer reaction time responses in all task conditions in comparison to young adults. There were statistically significant differences in reaction times between fallers and non-fallers during dual-tasking conditions, but not during triple-tasking conditions. The slower reaction times during dual-tasking conditions with dynamic balance demands were significantly related to the occurrence of subsequent falls, whereas there was only a weak association in model-adjusted physical performance tests. [Conclusions] Attentional capacity in multi-tasking conditions decreases with aging. Slow reaction time response during dual-tasking conditions with dynamic balance demands may be a predictor of falls in adults aged 75 and older.
Key words: Falling, Dual-task paradigm, Reaction time

(This article was submitted Mar. 2, 2010, and was accepted Apr. 9, 2010)

INTRODUCTION

Falls are a common and significant health problem among elderly people. The risk of falling increases with age, and approximately 30 to 40% of individuals aged 75 years and older sustain at least one fall over the course of a one-year period[1,2)]. One of the most important risk factors of falling among elderly people is poor multi-tasking performance[3)]. Changes in task performance (e.g., reaction time responses) while dual-tasking are interpreted as interference because of the competing demands for attentional resources needed for both tasks[4,5)]. Poor multi-tasking performance is presumed to be an indicator of aged-related changes in attentional capacity and may be sensitive in measures predicting the risk of falling[5]. For instance, Lundin-Olsson et al. demonstrated that “stops walking when talking” could be a predictor of falls and introduced a new approach to fall prediction based on dual-tasking performance[6]. Other researchers have reported clinical tests of dual-tasking performance with cognitive demands[7–12], and have used these methods as practical tools in the field of physical therapy[13].

Some retrospective studies have reported that impaired dual-tasking is not associated with falls[14], although some prospective studies have recognized a significant relationship between dual-tasking performance and predicting the likelihood of falling[14]; however, a prospective population-based study has reported that dual-tasking performance has no predictive value above that of single-task tests in the prediction of falling[15]. Most of these studies have assessed physical performance during cognitive tasks; however, it is not clear whether task combinations can be strong predictors of falls in elderly people.

The purpose of this study was to identify multi-tasking combinations that require cognitive and balance demands that are better predictors for the risk of falling in elderly adults aged 75 years and older. We believe that an increase in available prospective data will improve the predictive value of fall risk assessments based on multi-tasking performance in the area of geriatric physical therapy.

SUBJECTS AND METHODS

Subjects

This study involved 15 healthy and young volunteers aged 21 to 35 years and 45 elderly individuals living at home aged 75 to 86 years. Young volunteers were university students, postgraduate students, and employees who worked for the university. A sample of 45 elderly subjects who were living independently at home were recruited to participate in the “WHITE project” (Winter Time, Health Improvement Tactics for the Elderly), an interventional study on health promotion for elderly individuals in Hokkaido, Japan, using videos and texts developed by the International Life Sciences Institute, Japan. Data for this study originate from three communities (Hidaka town, Toyako town, and Makkari village), which agreed to join our project. Criteria for inclusion into this study required that the participant be 75 years or older, living independently in the community, and have no serious neurological or musculoskeletal diagnoses, such as Parkinson’s disease. In this study, all elderly participants showed a full score (=5) in the five-item Instrumental Self-Maintenance subscale of the Tokyo Metropolitan Institute of Gerontology-Index of Competence (TMIG-IC)[16]. The reliability and validity of the TMIG-IC were confirmed in a large sample[16]. Subjects were excluded if they reported serious visual or balance impairments that rendered them unable to step in place without support. The baseline survey was conducted in December of 2008, and our elderly participants responded to a follow-up survey conducted in May of 2009. The Sapporo Medical University ethics committee approved the project and this study. All participants provided written informed consent.

Methods

Information concerning the incidence of falls at the end of the five-month follow-up period was collected by a self-reported questionnaire from the elderly participants. If they failed to return the questionnaire, we asked about the incidence of falls via the in-person interview. Elderly participants were classified as having no falls or falls (one or more) based on subsequent falls during the five-month follow-up period.

Participants performed tests for knee-extension strength, one-legged standing, and 5-m walking. Knee-extension strength was assessed using a portable hand-held dynamometer (μTas F-1, ANIMA Corp). One-legged standing is a commonly used balance assessment of postural stability. The participants were asked to stand on their preferred leg as long as possible with their arms hanging down and with their eyes open. One-legged standing balance was measured as the time (0 to 60 seconds) participants could stand on one leg. Subjects’ maximum walking speed was measured during walking along an 11 m straight and level path. Time measured in seconds to pass the middle 5 m of the path, as indicated by two markers was used as the subject’s score. A 3-m approach was allowed before reaching the starting marker and an additional 3 m of space was provided after the end marker of the 5-m path to ensure a maximum walking pace throughout the task.

Participants were instructed to walk the 11-m path at a maximum walking pace.

Reaction time, measured by pushing a handheld button as quickly as possible in response to a visual stimulus (a bright red light), was measured under three different conditions: 1) counting backwards during quiet standing (dual-tasking condition with cognitive demands); 2) stepping in place (dual-tasking condition with dynamic balance demands); and 3) counting backwards while stepping in place (triple-task with cognitive and dynamic balance demands). First, the participants' reaction times were measured during quiet standing. Participants practiced at least twice before data collection. The reaction time was defined as the temporal interval between the presentation of a visual stimulus and the onset of a button-pushing response. The light stimulus was composed of seven small lights (each with a diameter of 5 mm). The experimenter confirmed that the participants stood safely and quietly, and he then issued the verbal command "ready" as a starting signal to the participants before the reaction time measurement. A starting signal and verbal warning preceded each trial. An assessor (a physical therapist) explained the detailed test protocols to each participant and conducted practice sessions of reaction time measurement to ensure participant understanding of the test protocols. Next, the reaction time was measured for each participant under each task condition for the speed of response to a visual stimulus given only once under each condition. A visual stimulus was provided after one of three randomly generated intervals following the starting signal: five, seven or nine seconds. Reaction time responses were measured by a time counter (PTS-010, DKH Inc.) and displayed in milliseconds (ms). After participants practiced reaction time responses without balance and/or cognitive demands, the other three tasks were randomly presented to participants in order to avoid any learning and task effects. In the cognitive dual-tasking and triple-tasking conditions, the participants were asked to count backwards to 1, starting from 100, 80, or 60 (selected randomly). The participants stepped in place at self-selected speeds and rhythms in the dual-tasking condition with balance demands and triple-tasking condition. The participants were asked to perform reaction time responses during each task in the dual-tasking conditions with cognitive or dynamic balance demands and in the triple-tasking condition with cognitive and dynamic balance demands. The reaction time of the first performance of each condition was used in the analyses. In a previous study, each task condition showed moderate or excellent test-retest reliability[17].

The 45 elderly participants were categorized into faller and non-faller groups based on fall incidences during the 5-month follow-up period. We compared differences in age, sex, knee-extension strength, one-legged standing time, and 5-m walking time between participant groups using the unpaired t-test and chi-square test. Group differences in reaction times under each task condition among the younger adults, non-faller, and faller groups were examined using one-way analysis of variance (ANOVA). Tukey's post hoc analysis was used to identify specific group differences. Receiver-operated characteristics (ROC) curves were used to determine cut-off points for reaction times under each multi-task condition that best discriminated between those who did and did not experience subsequent falls during the five-month follow-up period. ROC curve and area under the ROC curve (AUC) statistics were calculated, wherein if demonstrated statistical significance, then cut-off points for maximizing the sensitivity and specificity of the reaction times were determined using the Youden Index[18]. Finally, a multiple logistic regression analysis was performed to identify the relationship between subsequent falls and the cut-off points for reaction time responses. One logistic model was adjusted for age and sex, while another model was adjusted for age, sex, knee-extension strength, one-legged standing time, and 5-m walking time. All statistical analyses were performed using SPSS 17.0 version (SPSS Inc., Chicago, IL). In all statistical tests, $p<0.05$ was considered to be significant.

RESULTS

Out of the 45 elderly participants, 17.8% (n=8) experienced at least one fall during the 5-month follow-up period. Three elderly participants had fallen recurrently. Although fallers showed significantly shorter one-legged standing times than non-fallers, there were no significant differences in age, sex, knee-extension strength, and 5-m walking time between non-fallers and fallers (Table 1).

One-way ANOVA indicated significant effects of the group in all task conditions (dual-tasking

Table 1. Characteristics of participants

	Younger adults (n = 15)	Elderly adults (n=45)	
		Non-fallers (n=37)	Fallers (n=8)
Age (years)	25.0 ± 4.6	79.4 ± 3.4	80.8 ± 2.9
(range)	21 – 35	75 – 86	76 – 86
Female (%)	53.3	67.6	87.5
Number of falls (%)			
One	–	–	62.5
Recurrent	–	–	37.5
Knee-extensor strength (Nm/kg)[†]	–	1.6 ± 0.5	1.4 ± 0.5
One-legged standing test (sec)	–	32.6 ± 21.8	13.1 ± 19.5*
5-m walking time (sec)	–	2.8 ± 0.6	3.2 ± 0.6

Data are expressed as means ± SD, *p<0.05, [†]One missing datum in fallers (n=7)

Table 2. Comparison of reaction times (ms) in each task condition among the three groups

	Younger adults (n=15)	Non-fallers (n=37)	Fallers (n=8)	ANOVA	
Task conditions				*F*-value	Tukey's post-hoc comparisons
Dual-task conditions with dynamic balance demands	224.8 ± 27.7	305.7 ± 84.2	419.9 ± 201.2	10.43**	Fallers>Youngeradults**, Non-fallers* Non-fallers>Younger adults*
Dual-tasking conditions with cognitive demands	296.6 ± 49.8	566.6 ± 193.4	773.6 ± 329.2	17.86**	Fallers>Younger adults**, Non-fallers* Non-fallers>Younger adults**
Triple	329.2 ± 145.5	575.9 ± 237.3	668.4 ± 379.5	7.15**	Fallers>Younger adults** Non-fallers>Younger adults**

* p<0.05, ** p<0.01, Data are expressed as means ± SD, ANOVA: analysis of variance.

conditions with dynamic balance demands: F=10.43, p<0.01; dual-tasking conditions with cognitive demands: F=17.86, p<0.01; triple-tasking conditions: F=7.15, p<0.01). Fallers demonstrated significantly longer reaction time responses in all task conditions in comparison to younger adults (all task conditions: p<0.01). Non-fallers also demonstrated significantly slower reaction times than younger adults in the three task conditions (dual-tasking condition with balance demand: p<0.05, dual-tasking condition with cognitive demand, and triple-tasking condition: p<0.01). In addition, there were significant differences between fallers and non-fallers in reaction times during dual-tasking conditions with dynamic balance demands (p<0.05) and dual-tasking conditions with cognitive demands (p<0.05), but no significant differences during triple-tasking conditions (p=0.59) (Table 2).

The ROC curves for the reaction times under the three different task conditions against subsequent falls are depicted in Fig.1. The AUC of dual-tasking conditions with dynamic balance demands, dual-tasking conditions with cognitive demands, and triple-tasking conditions were 0.75 [95% confidence interval (CI) 0.57–0.94, p<0.05], 0.69 [95% CI 0.47–0.91, p=0.10], and 0.52 (p=0.85), respectively. The dual-tasking condition with dynamic balance demand showed the highest and most statistically significant AUC statistic, wherein the reaction time during the dual-tasking condition with dynamic balance demands cut-off point for subsequent falls was determined from the ROC curve to be 306 ms, with a sensitivity of 87.5% and a specificity of 59.5%. In Model 1, using multivariate logistic regression analysis and, adjusting for age and sex, the slower reaction time response during dual-tasking conditions with dynamic balance demands (slower than the cut-off point, 306 ms) related significantly to subsequent falls during the 5-month follow-up period [odds ratio (OR) 9.88, 95% CI 1.04–94.17, p<0.05]; however, in Model 2, with adjustment for Model 1 covariates plus knee-extension strength, one-legged standing time, and 5-m walking time, there was no evidence of an association between the slower reaction time response with balance dual-tasking and subsequent

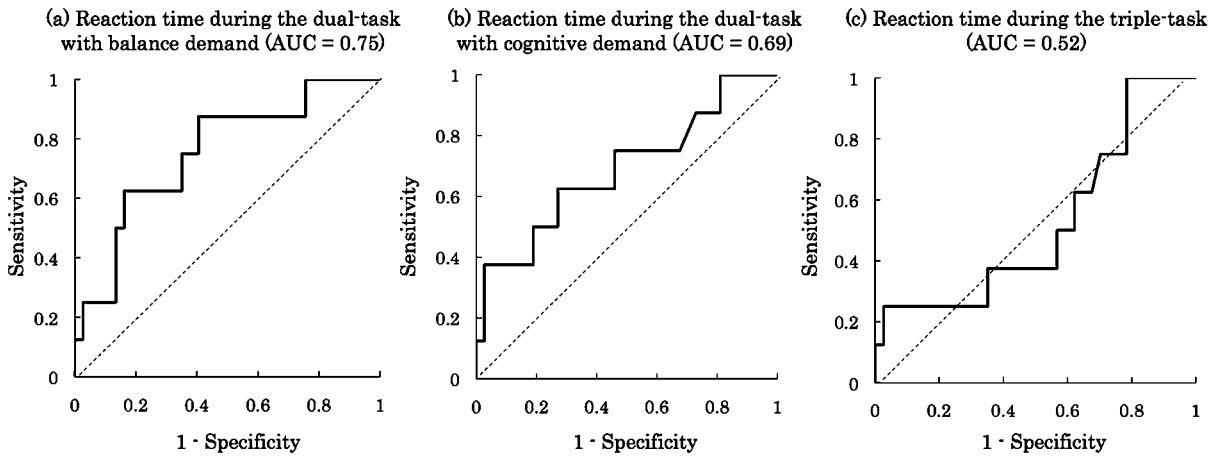

Fig.1. Receiver operating characteristic (ROC) curves of subsequent falls during the five-month follow-up period for reaction time responses under three different conditions. Each value of the area under the ROC curve (AUC) is shown. (a) Reaction time during the dual-task with balance demand (AUC=0.75), (b) Reaction time during the dual-task with cognitive demand (AUC=0.69), (c) Reaction time during the triple-task (AUC=0.52)

falls (OR 6.20, 95% CI 0.57–67.52, p=0.13).

DISCUSSION

In this study, the elderly participants exhibited poor reaction time responses during multi-tasking conditions that combined cognitive and/or balance demands as concurrent tasks when compared to young adults. Moreover, there were significant differences in reaction times between fallers and non-fallers during dual-tasking conditions with dynamic balance demands and dual-tasking conditions with cognitive demands, but no significant differences during triple-tasking conditions. In addition, this study demonstrated that the poor reaction time responses under dual-tasking conditions with dynamic balance demands might be a predictor of falls in adults aged 75 years and older. There was no strong association between slower reaction time responses with dual-tasking conditions with dynamic balance demands and subsequent falls with adjustments to knee-extension strength, one-legged standing time, and 5-m walking time. Falls in community-dwelling elderly people frequently occur during activities when they are carrying out simultaneous tasks that require the simultaneous allocation of attention[19]. The ability to perform multiple tasks concurrently declines with advancing age[20,21]. Assessment methods that apply dual-tasking paradigms appear to be helpful in revealing the effect of age on the allocation of attention to postural tasks, and may be sensitive in predicting fall risk and/or in evaluating outcomes of fall interventions in elderly people[5,14]. Our results indicate that there were significant differences in reaction time responses during multi-tasking conditions between younger and elderly adults. These findings are consistent with many previous studies[5,22] that observed age-related deterioration in multi-tasking performance. According to previous studies, increases in dual-tasking costs in association with aging relate to limitations of cognition[23], a reduced capacity of working memory, and perceptual-motor ability[24]. We observed age-related changes in reaction time responses in dual-tasking conditions, even when the concurrent secondary task was balance or cognition. Furthermore, in multi-tasking conditions that involved balance and cognitive demands, elderly adults also demonstrated significantly slower reaction times in comparison to younger adults. Our results suggest an attentional capacity decline in various complex situations as a function of advancing age.

Another goal of this study was to examine poor reaction times under multi-tasking conditions as a predictor for future falls in adults aged 75 years and older. Previous studies have demonstrated a relationship between the occurrences of falls and performing an attention-demanding task while dual-tasking among elderly adults[25]. For instance, Beauchet and colleagues performed experiments that demonstrated that poorer walking performance among elderly participants counting backwards aloud while walking related to the occurrence of falls in a 12-month follow-up period[26,27]. Lajoie and colleagues have reported that attentional demands increase when the balance requirements of the task increase[28]. We have observed that, in dual-tasking conditions with balance or cognitive demands, fallers demonstrated significantly slower reaction times than non-fallers. These results may suggest that even easy task conditions without walking increase attentional demands for a secondary task, and can be associated to an increased risk of falling; however, in multi-tasking conditions that require both balance and cognitive demands as concurrent secondary tasks, we did not find a significant difference in reaction time responses between non-fallers and fallers. If the attentional capacity required for the primary task is low, the capacity remaining for processing the secondary task will be relatively large[29]. In multi-tasking conditions that require balance and cognitive demands, the attentional capacities of non-fallers might decrease unexpectedly for the primary task similarly as would occur for fallers because of the large attention required for complex secondary tasks. Therefore, it might be impossible to identify a clear risk of falling by response to stimuli under multi-tasking conditions that consist of secondary tasks combined with balance and cognitive demands. Our additional interesting finding is that a poor reaction time response during dual-tasking conditions with dynamic balance demands may be a better predictor of falls than performance during dual-tasking conditions with cognitive demands. Although some studies with a prospective data collection of falls have indicated that poor dual-tasking performance is a good predictor of falls[14], no studies have indicated which concurrent tasks as dual-tasks were better predictors of falls. Our results indicate that poor response to stimuli with balance demands could be a better predictor of falls than performance with cognitive demands in independent elderly adults. The reaction time during dual-tasking conditions with dynamic balance demands (stepping in place) cut-off point for subsequent falls was determined from the ROC curve to be 306 ms, and a reaction time slower than this cut-off point significantly correlated to subsequent falls; however, reaction times slower than the cut-off point were not significantly associated with the occurrence of falling in the age-, sex-, and physical performance-adjusted model. These results suggest that poor multi-tasking performance with dynamic balance demands is not a strong and independent predictor of falls; however, dual-tasking performance with balance demands may provide more added values for fall prediction than performances in dual-tasking conditions with cognitive demands.

Some limitations to this study should be noted. First, our faller group is very small (n=8). Our elderly participant sample was not large, and our follow-up period of 5-months was short in comparison to previous prospective studies[14]. In a previous study, the 1-year incidence of falling within the general population of elderly was about 40% for any fall and 20% for recurrent falls[15]. A larger sample size and a longer follow-up period are required to resolve these limitations. Thus, our results cannot be generally applied to all community-dwelling elderly people. Second, the method for ascertaining falls in this study involved a 5-month follow-up survey by self-reported questionnaire despite the fact that this study was prospectively designed. This may have led to an underreporting of falls in our sample and may have led to misclassification of non-fallers. We should have also applied prospective assessments using reliable methods of fall monitoring (e.g., postcard, calendar, diary, or some combination of these) to cope with these limitations.

In conclusion, the authors found that community-dwelling independent elderly adults aged 75 years and above showed poor reaction time responses during any multi-tasking conditions that combined cognitive and/or balance demands as concurrent tasks in comparison to young adults. Furthermore, this study indicates that a poor reaction time response under dual-tasking conditions with dynamic balance demands may be a predictor of falls in adults aged 75 years and older. Physical therapists are in a strategic position with respect to the assessment of the risk of falling and, through risk factor modification, the prevention of falls. Therefore, well-designed intervention research is required to assess the impact of fall prevention and rehabilitation programs that include the training of combinations of primary tasks and concurrent tasks for elderly individuals. Furthermore, more prospective data are needed to improve the predictive value of multi-task-based fall risk assessments in the elderly.

ACKNOWLEDGEMENTS

We would like to thank the staff in Hidaka town, Makkari village, and Toyako town for help with participant recruitment and informed consent for this study. This study is a part of the WHITE project supported by the International Life Sciences Institute, Japan.

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