International Journal of Gerontology 17 (2023) 99–104
https://doi.org/10.6890/IJGE.202304_17(2).0004

International Journal of Gerontology

journal homepage: http://www.sgecm.org.tw/ijge/

Original Article

Falling Mechanism during a Dual Task Based on Eye Movement and Frontal Blood Flow in the Elderly

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ARTICLE INFO

Accepted 22 June 2022

Keywords:
accidental falls,
aging,
eye movements,
frontal cerebral blood flow,
walking

SUMMARY

Background: As the human population ages, there is an urgent need to find new fall prevention strategies that differ from the conventional strategy of improving physical motor functions. Therefore, this study aimed to investigate the mechanism of falling during a dual task based on eye movements and frontal blood flow in the elderly.
Methods: Thirteen healthy elderly women participants performed the following tasks while walking on the spot: stepping at a normal walking speed (single task), stepping at a normal walking speed while solving mathematical problems (dual task), and stepping at a normal walking speed while looking carefully at an image in front of them (control task). Eye movements, stepping state (number of steps and toe height), and frontal blood flow of the participants were measured.
Results: The participants' eye movements were significantly greater during the dual task than during the single and control tasks. However, the number of steps was not significantly different while performing the dual and single tasks. Toe height was significantly lower during the dual task than during the single task. Finally, frontal blood flow increased while performing the dual task compared with while the single task.
Conclusion: This study clarified the mechanism by which fall occurs in elderly participants. Eye movements increased during dual task walking; however, the additional task involving "thinking" required focus, the visual search became sparse, and the toe height was reduced. These factors increased the risk of "stumbling," which is considered the primary mechanism of falls.

1. Introduction

According to the Japanese Cabinet Office, falls and fractures have increased by 3.2% between 2009 and 2019.[1] In Japan, the revised Long-Term Care Insurance Law (2006) prevents long-term care; therefore, measures to prevent falls in the elderly have been developed for more than 10 years. In the United States, the 1995 Frailty and Injuries: Cooperative Studies of Intervention Techniques[2] were effective in improving complex exercises and balance, including strength training for fall prevention. In Japan, efforts have been made to improve physical function in the elderly. These efforts have achieved some success in reducing fall rates. However, the number of fatalities (mortality rate per 100,000 population) among the elderly due to falls (slip, stumbling, or staggering), examined every 5 years, has exhibited an increasing trend: 3,879 in 2005 (3.1%), 4,843 in 2010 (3.8%), and 5,636 in 2015 (4.5%). Although the elderly population has increased since 2005, these results show an increase in the number of deaths and mortality rate from falls.[3] With the inclusion of cases wherein a fall did not lead to death, the results show that a large number of fall accidents have occurred. As the aged human population grows, there is an urgent need to develop new fall prevention strategies that differ from the conventional strategy that focuses only on improving physical motor functions.

Humans obtain approximately 80% of the necessary information from vision.[4] Generally, poor eyesight impairs balance and increases the risk of falls and fall-associated fractures. Visual information is important in fall prevention, and we believe that not only visual acuity, but also eye movements are necessary in moving the eyeballs to search the visual field. Therefore, the development of fall prevention measures that focus on visual function is logical and practical. Previous studies on vision and falls have reported that visual training is an important consideration for fall prevention programs in the elderly living in communities[5] and that eyeball exercises are useful for improving balance and fall prevention efficacy in elderly individuals who have experienced a fall.[6] However, only a few studies on eye movements and falls have focused on the impact of the uptake of environmental information on falls. Therefore, we focused on dual task walking, namely, "walking while performing a task" (which is considered to have a high fall incidence), analyzed gaze movement, and clarified the relationship between visual factors different from physical and cognitive factors and falls.[7] In an earlier study, eye movements during simulated walking (walking on the spot), with and without computational tasks, were measured in young people without a risk of falling. Additionally, the line-of-sight movement when consciously looking ahead was confirmed. The results showed

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that the eyeball moved faster and to a greater extent during pseudo-walking while performing a dual task compared with during pseudo-walking while performing a single task. This was different from gaze movement. When walking while thinking, it was speculated that although the eyes were moving around, they did not always search visually, and their perception of the forward environment was reduced. However, there was no difference in the number of steps taken during pseudo-walking, with or without the calculation task, and the gait was not affected by the load of the calculation task. This may be because young people have sufficient lower limb muscle strength, good physical balance, and firm cognitive function.

In daily life, we typically perform two activities (dual task activities) simultaneously: walking while thinking, climbing stairs while talking, and changing clothes while maintaining a standing balance. During this time, the attention distribution function of the frontal association area is necessary,[8–10] and the amount of attention resources used to perform a task, which is constant for each person, is divided when performing multiple tasks. However, the amount of attention resources available decreases with age, and it becomes difficult to allocate attention resources effectively.[11,12] For this reason, elderly and dementia patients have more difficulties in performing two tasks simultaneously (under dual task conditions) compared with performing one task intensively. Other studies have reported that walking while solving problems, such as calculations and false retrieval in the elderly, delays walking speed[13] and increases trunk sway during walking.[14] These studies state that imposing a dual task affects gait and increases the risk of falls.

The purpose of our study was to examine the falling mechanism for the elderly under dual task conditions based on the results obtained for young people. We investigated the frontal lobe (attention) function, which decreases as an individual ages. We also monitored eye movements and stepping state during dual tasks.

2. Patients and methods

We analyzed 13 healthy elderly women (mean age: 80.7 ± 5.4 years) who volunteered for the study. The participants were community residents recruited based on their sex (women) since sexis considered a risk factor for falls,[15,16] and a higher incidence of falls was reported in women than in men.[17,18] The participants' comprehensive condition was that they had no problem with their visual acuity and visual field in their daily life, and their binocular vision required to renew their driver's license was 0.7 or more using the naked eye, glasses, or contact lenses.

All participants were informed of the purpose of this study, both in writing and verbally, and written consent was obtained from each participant. This study was approved by the Seijoh University Research Ethics Committee (2016 C0024).

In this study, "walking on the spot" was selected instead of actual walking, owing to the characteristics of the measuring equipment used. Participants stood 2 m away from a screen situated in front of them. The screen displayed a video captured with a video camera at the eye level (157 cm from the floor) of one of the examiners while walking in a straight path indoors at 1.4 m/s (average walking speed of an adult). Each participant was instructed to walk by stepping on the spot while watching the screen and imagining that they were actually walking. Participants were instructed to perform the following three tasks while watching the screen without moving their heads: 1) stepping at a normal walking speed (single task); 2) stepping at a normal walking speed while solving mathematical problems (dual task); and 3) stepping at a normal walking speed while carefully looking at an image in front of them (control task). The aim of the control task was to confirm the gaze movement when the participant consciously watched the screen.

In the dual task, the calculation task was to multiply a two-digit number by a single-digit number, which was regarded as the working memory task in a previous study.[19] When the participant started walking on the spot, the examiner verbally asked the mathematical task for calculation. Participants were required to answer the calculation task and repeat the calculation until they reached the correct answer. If the answer was correct, a new calculation task was provided. In addition, the examiner was positioned behind the participant, avoiding the participant's field of view. Participants' eye movements, stepping state (number of steps and toe height), and frontal blood flow were measured. Eye movements and stepping states were simultaneously measured.

The eye movement was measured at a sampling rate of 30 Hz using an eye movement tracking device (TalkEye Lite, Takei Scientific Instruments Co., Ltd, Niigata, Japan) for all tasks. TalkEye Lite is a goggle-type eye movement measurement system that processes pupillary images with the following settings: a detection light wavelength of 870 nm; a detection range of 50° to the left and right and 20° upward and downward; a detection resolution of 0.1° (≤ ±20°) and 0.5° for the entire area; and a detection error of ≤ 1° (≤ ±20°), ≤ 2° (≤ ±40°), and ≤ 3° for the entire area. The synthetic motion angles of both eyeballs for each measurement task were divided into vertical and horizontal components. The total vertical eye movement angle (sum of the angle at which the eyeball moved upward and downward during a measurement lasting 30 s) and the total horizontal eye movement angle (sum of the angle at which the eyeball moved left and right during a measurement lasting 30 s) were calculated. The measurement protocol comprised one cycle of 10 s of practice, 50 s of rest, and 30 s of performing the task (Figure 1). The measurement tasks were performed in the order of a single task, dual task, and control task to ensure that the participants were not conscious of "seeing."

An accelerometer (DSP wireless 9-axis motion sensor, Sports Sensing Inc., Fukuoka, Japan) was used for all the tasks. The device was secured with a belt just above the lateral malleolus of the fibula on the right lower extremity. The number of times the right lower limb was raised and the corresponding height to which it was raised were measured while walking on the spot.

Frontal blood flow was measured using optical encephalography (OEG-16; Spectratech Inc., Tokyo, Japan). This device is widely used to measure cerebral blood flow in desktop tasks. Although this study required measurements during motion, the participants were walking on the spot; thus, there were no problems regarding the use of this apparatus. Light was emitted via six two-wavelength em-

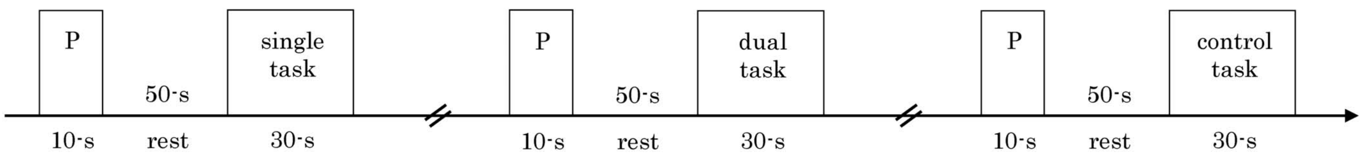

Figure 1. Measurement protocol for eye movements and stepping state (number of steps, toe height). Note: single task, dual task, and control task were performed in this order. There was ample rest time between tasks. Abbreviation: P, practice.

bedded light-emitting diodes (wavelength 1: 840 nm, wavelength 2: 770 nm). Light was received through six Si PIN photodiodes, which featured 16 simultaneous measurement channels, and the distance between the light-emitting and receiving components was 3 cm, obtained from the OEG-16 specifications. The dorsolateral prefrontal cortex (DLPFC) is involved in attentional function,[20] and attention control (attention persistence, attention selection, and attention distribution) becomes impossible if this part of the frontal lobe is damaged. Thus, we measured the level of oxyhemoglobin (Oxy-Hb) in the prefrontal area, including the DLPFC, through channels 1–16 in both single and dual tasks. To confirm the attention function during the dual task, the experimental protocol comprised a block design consisting of three cycles of 20 s of rest (single task) and 20 s of task-performing (dual task) (Figure 2). The difference in Oxy-Hb level detected during the task and at rest was calculated and averaged.

All results are presented as mean ± standard deviation. Before analyzing the data, a Q-Q plot was created to confirm that the data followed a normal distribution. For the data analysis, the total vertical eye movement angle, total lateral eye movement angle, number of steps, and height of toes were subjected to one-way repeated measures analysis of variance, Bonferroni's multiple comparison test, and Tukey's test for comparison between groups. The change in Oxy-Hb level was converted to Z-scores for comparison. Data were analyzed using SPSS (version 24.0; IBM Corporation, Chicago, IL, USA). The significance level (p) was set at < 0.05.

3. Results

The total vertical eye movement angle was significantly larger during the dual task (1008.1° ± 455.7°) than during the single task (756.8° ± 259.4°, $p = 0.027$) and control task (688.7° ± 185.4°, $p = 0.031$) (Figure 3). The total lateral eye movement angle was also significantly larger during the dual task (1043.0° ± 629.1°) than during the single task (809.0° ± 446.0°, $p = 0.017$) and control task (765.3° ± 374.1°, $p = 0.056$) (Figure 3). In the pupillary images obtained by TalkEye Lite, the eye movements showed that in the single task, the gaze remained within a certain range, whereas in the dual task, the eye movements were observed to move rapidly and irregularly in the vertical and horizontal directions, to stay there for a while, and to change gaze rapidly again.

The number of steps was not significantly different during the dual task (28.0 ± 1.6 steps), single task (27.8 ± 1.5 steps), and control task (27.8 ± 1.8 steps) (Figure 4). Toe height was significantly lower during the dual task (22.9 ± 14.0 cm) than during the single task (26.5 ± 13.7 cm, $p = 0.018$) and control task (27.1 ± 14.2 cm, $p = 0.024$) (Figure 4).

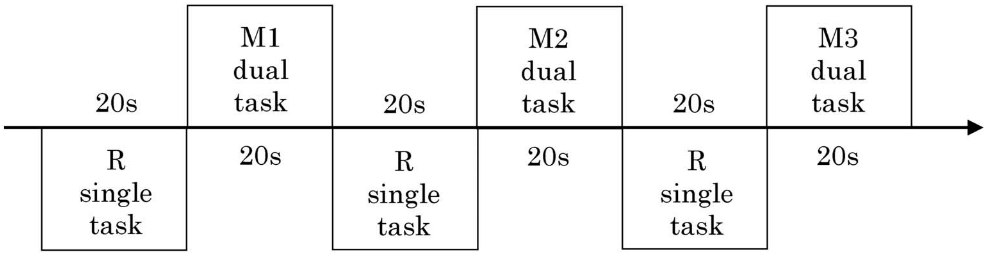

Figure 2. Measurement protocol for frontal blood flow. Note: A block design consisting of 3 cycles of a 20 s of rest (single task) and 20 s of task (dual task). The difference in Oxy-Hb level detected during the task and at rest was calculated and averaged. Abbreviation: R, rest. M1, 1st measurement. M2, 2nd measurement. M3, 3rd measurement.

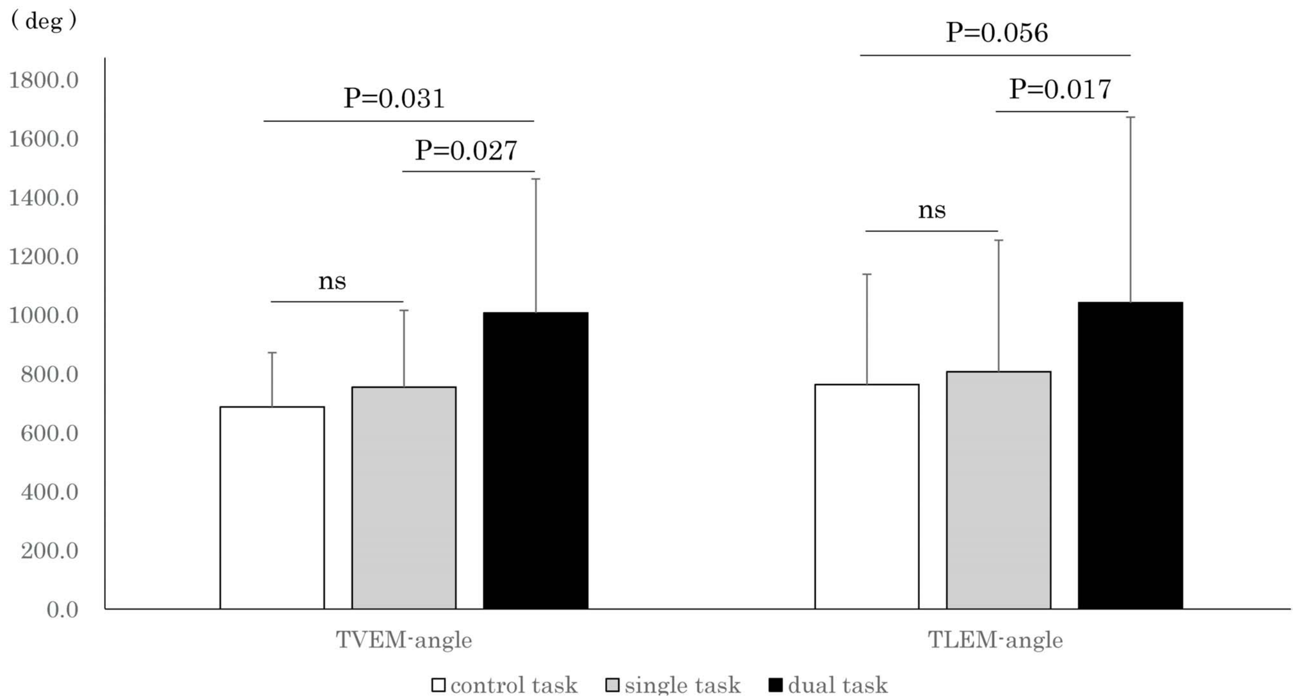

Figure 3. Comparison of the total vertical or lateral eye movement angles among the single, dual and control tasks. Note: One-way repeated measures analysis of variance and Bonferroni's multiple comparison test. Error bars show the standard deviation from the mean values. Abbreviation: TVEM-angle, total vertical eye movement angle. TLEM-angle, total lateral eye movement angle. ns, no significant.

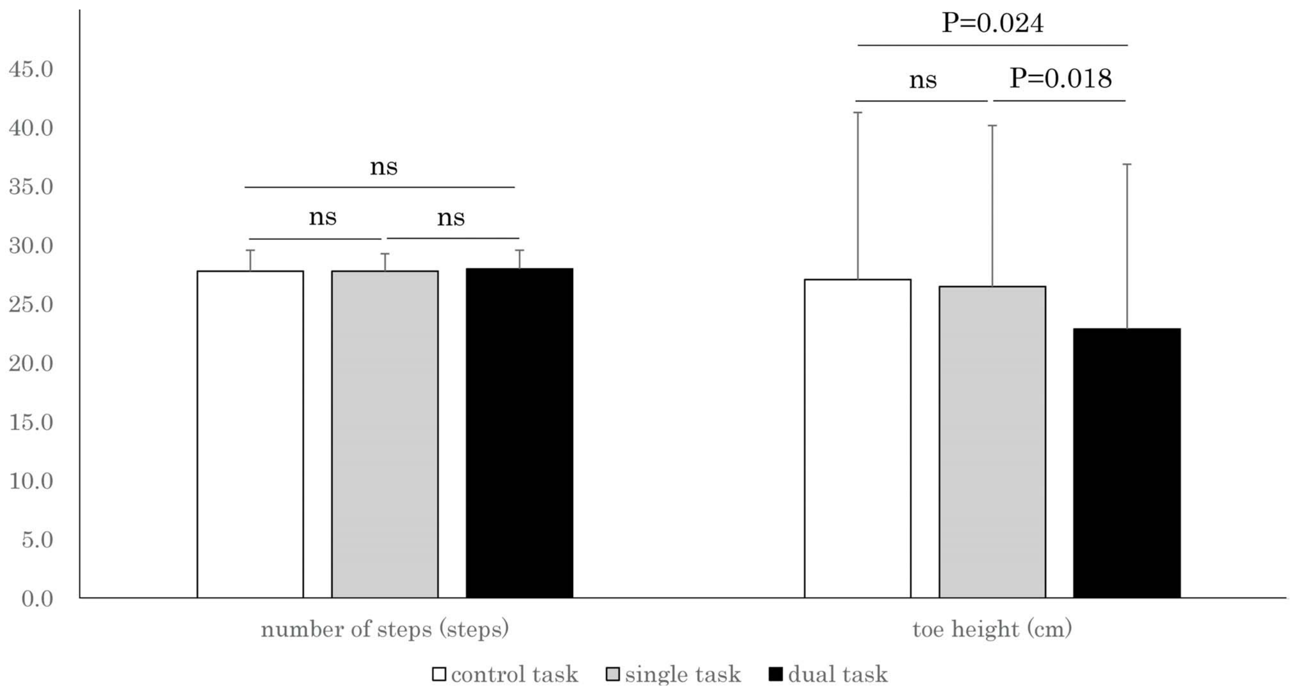

Figure 4. Comparison of the number of steps and the toe height among the single, dual and control tasks. Note: One-way repeated measures analysis of variance and Bonferroni's multiple comparison test. Error bars show the standard deviation from the mean values. Abbreviation: ns, no significant.

Changes in Oxy-Hb level were positive for the DLPFC, both on the right (0.513 ± 7.218) and left (0.584 ± 7.635) sides, and its level increased during the dual task compared with during the single task.

4. Discussion

The vestibular oculomotor reflex affects eye movements by moving the head.[21,22] However, in this study, the participants' head movements were minimized by instructing them to stepping at walk while watching the screen in front of them without moving their heads. Therefore, eye movements due to the vestibular oculomotor reflex were not considered.

In this study, it was found that oxy-Hb level in the frontal lobes were higher during the dual task with the calculation task than during the single task. The calculation task used in this study was the multiplication of two- and one-digit numbers. Therefore, working memory was needed to temporarily store the numbers, attention was paid in performing the multiplication task, and attentional distribution was increased for the multiplication task. The frontal lobe is responsible for attentional functions, and it was inferred that the high oxy-Hb level supported the activation of the DLPFC, which is involved in the distribution of attention. However, the amount of attentional resources decreases with age, making it difficult for the elderly to allocate attentional resources appropriately. Therefore, the possibility that attention was allocated and used to perform the calculation task cannot be ruled out. Eye movements were greater during the dual task than during the single task, although the visual environment was the same. Therefore, the reason for greater eye movements during the dual task could be attributed to the execution of the calculation task. If the attention described earlier was allocated to the execution of the multiplication task, it could be interpreted that attention was not directed to the search for the visual field and, as will be discussed later, eye movements were greater; however, visual information was not captured. Regarding walking, toe height was lower during the dual task than that during the single task. This may be because attention was not allocated to the execution of stepping or eye movements. Previous studies on dual-task walking with tasks such as calculation and false search in elderly subjects also reported a delay in walking speed[13] and trunk swaying during walking.[14] Therefore, it can be speculated that the elderly pay more attention to thinking and less attention to lifting their feet during the dual task, and under these conditions, falls due to stumbling may occur (Figure 5).

In this study, eye movements during the dual task were greater than during the single task. Compared with the single task, eye movements during the dual task were more rapid and irregular, such as moving the gaze up and down, left and right, staying there for a while, and then changing the gaze again rapidly. Eye movements can be classified into saccadic and smooth pursuit eye movements. The eye movements observed in this study were similar to saccadic eye movements, rather than slow movements following the movement of an object with the eyes as in glide-following eye movements. Saccades are fast and intermittent movements in which the eye seems to stop for a while in the direction of a particular point, and then stop in the opposite direction.[21] This saccade state may have increased the horizontal and vertical eye movements. Furthermore, it is important to note that saccades are not eye movements during thoughts. The eyeballs move but do not capture visual information. In addition, when thinking about something, we tend to unconsciously move our eyes upward. This may be related to the influx of information received from the eyes.[23,24] During deep thinking, information from eye distortions interferes with the thought process. Therefore, one may try to block information from the eyes by turning the gaze upward and looking at an empty landscape (a landscape with little or no information). This movement is seen as a vertical eye movement during the dual task and accounts for the greater movement. It can be said that in this condition, too, the eyes are moving but not capturing visual information.

Since eye movements during the dual task were different from those during the single task, it is presumed that participants did not maintain forward vision. Ebisawa et al.[25] noted that the more closely participants looked at an object, the more their gaze remained constant and the impulsive movement component decreased. During saccades, images are blocked by saccade suppression.[26] Thus, an in-

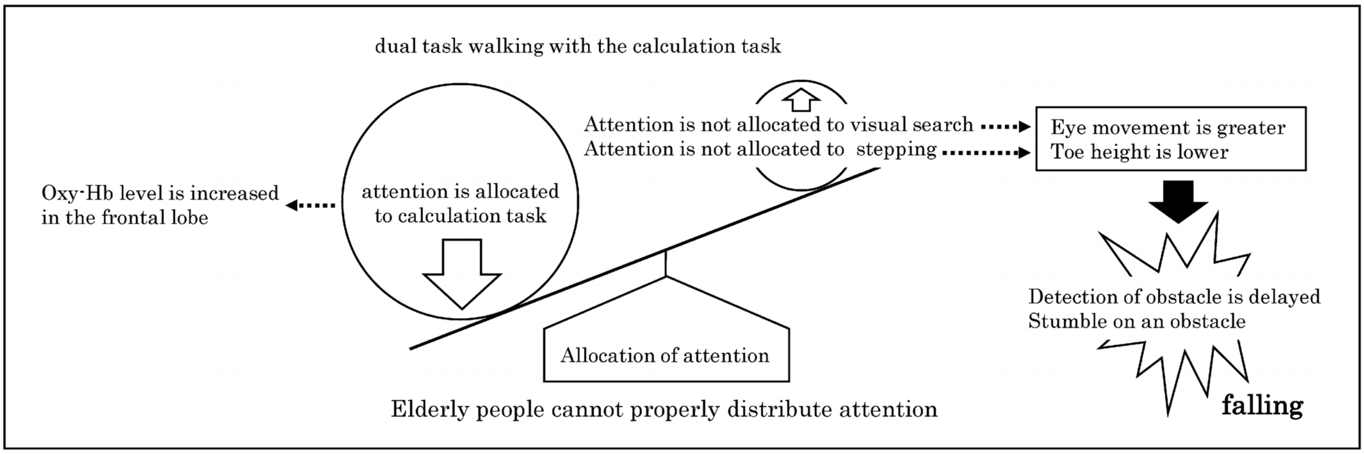

Figure 5. Relationship between eye movements, walking, and executive function (frontal blood flow) during the dual task.

crease in saccades during the dual-task indicates that visual information is not available. This also indicates that although the eyes are moving, they do not capture visual information. These facts indicate that when the elderly walk while engaged in other activities, they are unable to visually explore the environment ahead, although their eyes are moving widely, and their perception of the environment ahead is reduced. Under these circumstances, the risk of falling is undetectable and the risk of falling increases.

Poor eyesight is well-known as one of the risk factors for falls. The strength of this study is that we focused on eye movements of visual functions other than visual acuity, and clarified the mechanism by which eye movements cause falls. Based on this result, we would like to focus on vision training aimed at improving eye movements and examine whether improving visual function (eye movements) can be a fall prevention measure as the third function following motor and cognitive function.

However, the present study has several limitations and issues. The number of participants in this study was small; thus, our results cannot be generalized for the general community-dwelling population. Therefore, it is necessary to further increase the number of subjects including men as well as women. In addition, in this study, "walking on the spot" was used instead of actual walking. Therefore, we did not collect information on height, leg length, BMI, or other factors that are considered to influence walking ability. These factors should also be considered when conducting future walking studies. Moreover, the device used of this study did not have the ability to discriminate between saccadic eye movements and smooth pursuit eye movements, making it difficult to determine whether the observed eye movements were saccades. Therefore, it is necessary not only to compare the magnitude of single- and dual-task eye movements, but also to analyze the characteristics of each eye movement in more detail. And, although eye movement was measured using the same method as in the previous study, it is not ideal to simply compare the data of young people and the elderly. This is because the data were not collected at the same time.

This study investigated the falling mechanism experienced by the elderly during dual task walking. It is clarified that during dual task walking, the eye movement increased, visual search became sparse, and toe height was reduced. These factors increased the risk of "stumbling," which is considered the main falling mechanism. Based on the results of this study, we investigated the relationship between visual function and stepping motion, which is one of the responses for recovering the balance lost due to stumbling, and consideration of fall prevention strategies from the perspective of visual information should be investigated in future studies.

Acknowledgements

We would like to thank the community residents who volunteered to participate in this study.

Funding

This study was supported by JSPS KAKENHI (Grant No. JP16 K01481).

Conflicts of interest/Competing interests

The authors declare no conflict of interest.

References

1. Cabinet Office, Government of Japan. Annual Report on the Ageing Society [Summary] FY 2019. Accessed January 20, 2019. https://www8.cao.go.jp/kourei/english/annualreport/2019/pdf/2019.pdf
2. Province MA, Hadley EC, Hornbrook MC, et al. 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*. 1995;273:1341–1347.
3. e-Stat. Vital Statistics / Vital statistics of Japan Final data General mortality. Accessed January 20, 2019. https://www.e-stat.go.jp/en/stat-search/files?stat_infid=000031982769
4. Grüsser OJ, Grüsser-Cornehls U. Physiology of vision. In: Schmidt RF, ed. *Fundamentals of Sensory Physiology*. Springer-Verlag; 1978:144–198.
5. Reed-Jones RJ, Dorgo S, Hitchings MK, Bader JO. Vision and agility training in community dwelling older adults: Incorporating visual training into programs for fall prevention. *Gait Posture*. 2012;35:585–589.
6. Park JH. The effects of eyeball exercise on balance ability and falls efficacy of the elderly who have experienced a fall: A single-blind, randomized controlled trial. *Arch Gerontol Geriatr*. 2017;68:181–185.
7. Yamada K, Chihara M, Kimura D, Furukawa K, Watanabe K. Comparison of eye movements during single- and dual task walking. *Rigakuryoho Kagaku*. 2018;33:141–144.
8. Koechlin E, Basso G, Pietrini P, Panzer S, Grafman J. The role of the anterior prefrontal cortex in human cognition. *Nature*. 1999;399:148–151.
9. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cogn Psychol*. 2000;41:49–100.
10. Iidaka T, Anderson ND, Kapur S, Cabeza R, Craik FI. The effect of divided attention on encoding and retrieval in episodic memory revealed by positron emission tomography. *J Cogn Neurosci*. 2000;12:267–280.
11. Greene NR, Naveh-Benjamin M, Cowan N. Adult age differences in working memory capacity: Spared central storage but deficits in ability to maximize peripheral storage. *Psychol Aging*. 2020;35(6):866–880.
12. Baddeley A. The episodic buffer: a new component of working memory?.

Trends Cogn Sci. 2000;4(11):417–423.
13. Hollman JH, Salamon KB, Priest AW. Age-related differences in stride-to-stride variability during dual task walking: A pilot study. *J Geriatr Phys Ther*. 2004;27:83–87.
14. Hollman JH, Kovash FM, Kubik JJ, Linbo RA. Age-related differences in spatiotemporal markers of gait stability during dual task walking. *Gait Posture*. 2007;26:113–119.
15. Tinetti ME, Kumar C. The patient who falls: “It’s always a trade-off”. *JAMA*. 2010;303:258–266.
16. Miki T, Shimada H. Fall and fracture of the elderly people. *Nihon Ronen Igakkai Zasshi*. 2011;48:655–658.
17. Niino N, Kozakai R, Eto M. Epidemiology of falls among community-dwelling elderly people. *Nihon Ronen Igakkai Zasshi*. 2003;40:484–486.
18. Yasumura S, Haga H, Nagai H, Suzuki T, Amano H, Shibata H. Rate of falls and the correlates among elderly people living in an urban community in Japan. *Age Ageing*. 1994;23:323–327.
19. Tsuchida Y. What is working memory capacity?: Individual difference and influence on cognitive performance. *Bulletin of Faculty of Education, Hokkaido University.* 2009;109:81–92.
20. Kuwabara H, Kasai K, Takizawa R, et al. Decreased prefrontal activation during letter fluency task in adults with pervasive developmental disorders: A near-infrared spectroscopy study. *Behav Brain Res*. 2006;172:272–277.
21. Ukai K. Eye Movement: Characteristics and Method of Measurement. *Jpn J Opt*. 1994;23(1):2–8. [In Japanese]
22. Hirasaki E. Eye-head-trunk coordination strategies for gaze stabilization during locomotion. *Osaka University Knowledge Archive*. 2000;26:177–193.
23. Doherty-Sneddon G, Phelps FG. Gaze aversion: A response to cognitive or social difficulty? *Mem Cognit*. 2005;33:727–733.
24. Takehuta H, Hirayama T, Shoji H. Eye gaze patterns during conversation in social anxiety. *Bulletin of the Faculty of Education, Ibaraki University*. 2015;64:163–174. Accessed January 20, 2019. http://hdl.handle.net/10109/12605 [In Japanese]
25. Ebisawa Y, Minamitani H, Yamamoto M, Takase M. Relation between attention and characteristics of saccade during tracking eye movement. *Syst Comp Jpn*. 1988;19:70–79.
26. Richards W. Saccadic suppression. *J Opt Soc Am*. 1969;59:617–623.