Relationship Between Balance, Gait, and Activities of Daily Living in Older Adults With Dementia

Nam Gi Lee, PT, PhD¹, Tae Woo Kang, PT, PhD²*, and Hyun Ju Park, PT, PhD³

Abstract

Introduction: Gait characteristics are closely associated with executive functions including basic and high-level cognitive processes such as attention, working memory, decision-making, and problem-solving. Impaired cognitive function resulting from dementia is associated with loss of balance and poor activities of daily living (ADLs). If associations between gait parameters, balance, and ADLs are observed, then quantitative gait analysis may be optimal for reinforcing balance and ADL assessments in people with dementia. This study aimed to determine the association between balance, gait, and ADLs in older adults with dementia. Materials and Methods: A cross-sectional study was conducted in 46 older adults who have been diagnosed with dementia. Measurements including the Mini-Mental Statement Examination-Korean version (MMSE-K), Berg Balance Scale (BBS), 10-meter walk test (10MWT), Modified Barthel index (MBI), and GAITRite were used to assess cognitive function, balance, walking speed, ADLs, and gait parameters, respectively. The Pearson product correlation coefficient ($r$) was used for correlation analysis. Results and Discussion: Among the gait parameters, velocity was positively associated with the BBS, 10MWT, and MBI ($r = 0.341-0.516, P > .05$). Step length ($r = 0.301-0.586, P > .05$), stride length ($r = 0.329-0.580, P > .05$), and walk ratio ($r = 0.324-0.556, P > .05$) were positively associated with the MMSE-K, BBS, 10MWT, and MBI. A moderate positive association between single support time and MBI was observed ($r = 0.308, P = .039$). Additionally, a moderate negative association between double support time and the MBI was observed ($r = -0.349, P = .019$). This study presents the first empirical evidence on the association between balance, gait, and ADLs in older adults with dementia. Conclusions: This study identified important associations between balance, gait, and ADL assessments in people with dementia. Further studies involving targeted interventions addressing gait parameters and improving balance and functional performance in people with dementia are required in the future.

Keywords
activities of daily living, balance, dementia, gait parameters, older adults

Introduction

Dementia is a neurological syndrome characterized by progressive deterioration in global cognitive function, self-care function, and social behavior.¹ Approximately 60% and 20% of people with dementia have Alzheimer disease (a neurodegenerative process) and vascular dementia (repeated infarcts in the brain tissue), respectively,² while mixed types such as Alzheimer/vascular dementia and dementia with Lewy bodies are the other common presentations. Dementia is significantly more common in older people compared to younger people.³ The worldwide prevalence of people with dementia is expected to increase almost twice every 20 years, reaching 40.8 million in 2020 and 90.3 million in 2040.⁴ Therefore, dementia is recognized as a global public health problem worldwide.⁵ Dementia affects balance, gait performance, and activities of daily living (ADLs).⁶,⁷ Cognitive impairment is associated with a lack of balance due to a reduction in a person’s ability to problem-solve, make decisions, and perform tasks

¹ Rehabilitation Center, Chungnam National University Hospital, Daejeon, Republic of Korea
² Department of Physical Therapy, Woosuk University, Jeonbuk, Republic of Korea
³ Department of Physical Therapy, Good Daycare Center, Daejeon, Republic of Korea

Corresponding Author:
Tae Woo Kang, PT, PhD, Department of Physical Therapy, Woosuk University, 443, Samnye-ro, Samye-eup, Wanjungun, Jeonbuk 55338, Republic of Korea.
Email: ktwkd@hanmail.net

Creative Commons Non Commercial CC BY-NC. This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).
concurrently. Bruce-Keller et al revealed that a loss of balance is significantly more common in people with early-stage dementia compared to healthy adults. Moreover, several studies demonstrated that deficits in motor ability, specifically gait disturbance, may be present in early-stage dementia. Gait performance is a complex process that requires the integration of both sensorimotor and cognitive systems. However, delayed cognitive processing may be affected to compensate for the impairments of sensorimotor systems and negotiation of motor planning and reactions required for maintaining balance in unstable environments. Several investigators have reported a clear association between cognitive impairments and gait disturbance in older adults. Additionally, dementia is accompanied by increased functional disability over time, associated with loss of independence, ultimately leading to decline in ADLs, including basic ADLs (B-ADLs) and instrumental ADLs (I-ADLs). The deterioration in B-ADLs impacts the quality of life of caregivers and is a significant burden on health care systems.

Recently, several studies reported that impairments of balance and gait have consistently been associated with cognitive impairment and are also known risk factors for falls. Taylor et al found that 138 cognitively impaired older adults showed worse balance performance (sway on floor, sway on foam, controlled leaning balance, and near tandem standing ability) than 276 age- and sex-matched cognitively intact community-dwelling older adults. Savica et al showed that spatiotemporal parameters of gait were associated with a significant decline in global cognition and in specific domains including memory, executive function, visuospatial, and language in 3426 cognitively normal subjects. A study related with ADLs showed a linear association between I-ADLs and Mini-Mental Statement Examination (MMSE-K) in 107 people with Alzheimer disease at a 6- and 12-month follow-up. Several researchers have studied the association between cognitive function, balance, and gait. However, to the best of our knowledge, a previous study investigating the association between balance, ADLs, and gait in older adults with dementia has not been conducted yet. Furthermore, if associations between gait parameters, balance, and ADLs exist, then quantitative gait analysis may be optimal for reinforcing balance and ADL assessments in people with dementia. Therefore, this study aimed to determine the association between balance, gait, and ADLs in older adults with dementia. Based on the background information on balance, gait, and ADLs in people with dementia, it was hypothesized that cognition, balance, and ADLs are associated with gait parameters that could predict balance and ADLs in people with dementia.

### Methods

#### Patients

Forty-six patients diagnosed with dementia (of various etiologies) in their records were recruited from an elderly daycare center. A sample size of 46 was derived using \( n = \frac{Z^2 \times \sigma^2}{\delta^2} \) (2-tailed; 0.05), power (0.95), or \( \beta \) (0.05) and expected correlation coefficient (0.50) values according to the study by Hulley et al. The inclusion criteria were as follows: patients aged greater than 55 years, patients diagnosed with dementia according to the Clinical Dementia Rating Scale and International Classification of Diseases-Tenth Edition, patients with MMSE-Korean version (MMSE-K) score of less than 23, and patients who were able to walk 10 m with or without a walking aid. The exclusion criteria were as follows: patients who were medically unstable, patients with neuropsychiatric condition or other neurological diagnoses associated with cognitive impairment, and patients with severe communication problems and cardiopulmonary diseases. Details about the patients’ characteristics are presented in Table 1. All patients and their families were informed about the detailed purpose and procedures of the study prior to participation, and all patients subsequently provided informed consent for inclusion in the study. Experimental procedures used in this study were approved and monitored by the Institutional Review Board of Woosuk University (WS-2019-13).

#### Experimental Procedures

All patients who met the inclusion criteria were allocated in this study. All measurements were conducted in a measuring room to exclude environment impacts. Demographic data including age, height, and weight were measured by health care professionals in the facility (elderly daycare center). Measurement tools for examining the cognition, balance, walking speed, ADLs, and gait included MMSE-K, Berg Balance Scale (BBS), 10-meter walk test (10MWT), Modified Barthel index (MBI), and GAITRite, respectively. The sequence of the examination occasions was randomized by drawing lots of 5 pencils with the tests written to prevent bias and minimize learning effect. Measurement data were obtained by a well-trained physical therapist (working for more than 10 years) in the

### Table 1. Demographic and Clinical Characteristics of Patients.

| Characteristics | Data (N = 46) |
|-----------------|---------------|
| Age (years)     | 81.8 ± 7.6\(^a\) |
| Height (cm)     | 158.4 ± 9.9   |
| Weight (kg)     | 55.6 ± 9.9    |
| Female/male     | 26 (56.5)/20 (43.5)\(^b\) |
| MMSE-K          | 15.4 ± 5.1 (4-23)\(^c\) |
| Mild cognitive impairment | 7 (15.2%)\(^b\) |
| Moderate cognitive impairment | 32 (69.6%) |
| Severe cognitive impairment | 7 (15.2%) |
| BBS             | 33.7 ± 10.9 (9-53)\(^c\) |
| 10MWT (m/sec)   | 0.76 ± 0.30 (0.24-1.41) |
| MBI             | 64.3 ± 21.4 (8-93) |

Abbreviations: BBS, Berg Balance Scale; MBI, Modified Barthel Index; MMSE-K, Mini-Mental State Examination (Korean version); 10MWT, 10-Meter Walk Test.

\(^a\)Data are mean ± SD.
\(^b\)n (%).
\(^c\)Mean ± SD (range).
facility, and the results were not described until the examinations were completed. During the tests, all measurements were performed twice and with a resting time of 3 to 5 minutes on a chair between examinations to prevent fatigue; the average measurement was used for the data analysis.

**Measurements**

**Mini-mental state examination.** The MMSE-K was developed to evaluate cognitive function. This assessment tool comprises 30 subtitles on cognitive fields including orientation (time and place), memory (registration and recall), attention and calculation, language function, and understanding and judgment. Scores were adjusted according to the patient’s educational level and ranged from 0 to 30. A higher score indicates better cognitive function, and a lower score indicates poor function. In a previous study, a total of 19 to 24 points were required to establish the diagnosis of an impairment of cognitive function. The MMSE-K is advantageous because it has strong or excellent test–retest reliability ($r = 0.76-0.90$), inter-rater reliability (intraclass correlation coefficient [ICC] = 0.94-0.99), and concurrent validity ($r = 0.83-0.92$) for the evaluation of cognitive function in mild cognitive impairment, Alzheimer disease, and healthy adults.17

**Berg balance scale.** The BBS evaluates the balance ability of older adults based on the performance of various functional tasks. The BBS comprises 14 functional items such as sitting to standing, standing unsupported, chair transfers, standing with eye closed, tandem standing, and single leg standing; 0 to 4 points are given for each item, and the total score is 56. A score of 0 indicates a lack of ability to execute the task, while a score of 4 shows the achievement of the task successfully according to the programmed criterion. A higher score indicates better balance ability. Good to excellent test–retest and inter-rater reliability (ICC = 0.72-0.99) was reported among people with dementia.18,19

**10-meter walk test.** The 10MWT is usually used for the assessment of walking speed. It requires a 16-m walking path including 3 m for acceleration and deceleration at either side. Tape marks 3 meters before and after the 10-m path. The researcher instructed the patients to not stop before achieving the end line. This assessment tool requires significantly little equipment and is easily performed. Patients were instructed to walk at their self-selected speed. The researcher started the stopwatch as the patient passed a small, discrete, 3-m mark on the floor and stopped at a similar 10-m mark, so that only the mid 10-m walking was timed, thus excluding the acceleration and deceleration phases. The time of completion at the 10-m mark was measured by the researcher. Walking speed (meters/second) was calculated by dividing 10 m by the time measured. The 10MWT is a valid and reliable measurement because it has strong concurrent validity ($r = 0.74$) and excellent test–retest reliability (ICC = 0.90) in older adults.20

**Modified Barthel index.** The MBI is a measurement tool used to evaluate the level of functional independence in ADLs. This measurement tool comprises 10 subitems including feeding, transfer, personal hygiene, getting on/off toilet, bathing, walking on leveled ground, climbing stairs, dressing, and bowel and bladder control. Measurements were taken by family members or caregivers of those who joined the daycare center and by the personal care workers, nurses, therapists, and staff of those living in the residential care facility. Moreover, direct observations were conducted by the researcher as needed. Each item was given a score between 0 and 10, with a total score of 100. A higher score indicates higher levels of functional independence. The test–retest reliability has been shown to be moderate to strong (κ coefficients = 0.63-1.00) among local older adults.21

**Gait measurement.** GAITRite (AP1105, GAITRite EWPV CIR) instrumentation is used to evaluate gait parameters. We collected the gait parameters from GAITRite. The GAITRite comprises an electronic walkway of 4.88 m in length, 0.061 m in width, and 0.0064 m in height, and the GAITRite software (version 4.0) was used to analyze all the temporal and spatial parameters of gait to quantify the gait parameters. Data were sampled at 120 Hz and stored for subsequent analysis in a well-matched computer connected to a pressure-sensitive walkway. Each patient was instructed to walk at a comfortable pace without gait aids on the walkway, initiating and terminating their walk 1.5 m before and after the walkway, respectively. In this study, gait measurement focused on variable parameters of gait including individual spatial (step length and stride length), temporal (cadence, step time, swing time, stance time, single support time, and double support time), temporophasic (swing % of phase and stance % of phase), and spatiotemporal (velocity and walk ratio [WR]) parameters. Specific parameters of WR among the gait parameters should be provided. Walk ratio is calculated by dividing the step length with cadence.22 Sekiya et al suggested that the WR can be an index for describing gait pattern or temporal and spatial coordination at a variety of speed. In other words, WR assesses the quality of gait, while gait speed measures performance. A low ratio suggests that an individual takes small steps and has a high step frequency. A higher ratio indicates that the individual takes longer steps, holds a lower frequency, or both. The GAITRite is a valid and reliable tool that has excellent validity (ICC > 0.93) and reliability (ICC > 0.94) related to walking speed, cadence, and step time.23

**Data analyses.** Descriptive statistics include means and standard deviations. Pearson product correlation coefficient was used to investigate the associations between cognition, balance, gait, and ADLs measured by MMSE-K, BBS, 10MWT, MBI, and GAITRite. The Pearson product correlation coefficient, $r$, can take a range of values from 1 to $-1$, where 1 is total positive association, 0 is no linear association, and $-1$ is total negative association. An $r$ value between 1 and 0.7 is defined as strong association, a value in the range of 0.7-0.3 indicates
of gait parameters was significantly associated with BBS \( (r = 0.341, P = 0.025) \), 10MWT \( (r = 0.448, P = 0.001) \), and MBI \( (r = 0.516, P = 0.000) \), indicating moderate positive associations. Step length and stride length in gait parameters were significantly associated (moderate association) with all of the other outcome measures. Step length was positively associated with MMSE-K \( (r = 0.301, P = 0.045) \), BBS \( (r = 0.400, P = 0.008) \), 10MWT \( (r = 0.475, P = 0.001) \), and MBI \( (r = 0.586, P = 0.000) \). A moderate positive association between single support time and MBI was observed \( (r = 0.308, P = 0.039) \). Additionally, a moderate negative association between double support time and MBI was observed \( (r = -0.349, P = 0.019) \). Walk ratio was positively associated with MMSE-K \( (r = 0.324, P = 0.030) \), BBS \( (r = 0.383, P = 0.011) \), 10MWT \( (r = 0.362, P = 0.015) \), and MBI \( (r = 0.556, P = 0.000) \), indicating moderate associations. However, other gait parameters including cadence, step time, swing and stance time, and swing and stance phase duration were not associated with MMSE-K, BBS, MBI, and 10MWT (Table 3).

### Discussion

To the best of our knowledge, this study is the first empirical evidence investigating the association between balance, gait, and ADLs in older adults with dementia. As expected, significant associations were observed between cognition (MMSE-K) and ADLs (MBI) and between balance (BBS) and walking speed (10MWT) in people with dementia. In quantitative gait analysis, important associations were observed between gait parameters (eg, step length, stride length, and the quality of gait) and all clinical variables (e.g., cognition, balance, walking speed, and ADLs). Additionally, velocity was associated with other clinical measures, except for cognition, and single and
double support time parameters were associated with ADLs. Therefore, our findings clearly indicate that alterations in gait parameters such as step length, stride length, and the quality of gait (WR) are closely associated with balance and ADLs in people with dementia.

Regarding the associations between cognition and ADLs and between balance and walking speed, the results of this study were consistent with the results of the previous studies. A significant decline of cognition function was shown together with ADLs in this study. We suggest that cognition impairment is closely associated with the inability to perform ADLs in people with dementia. Cognitive impairment has severe implications on patients’ independence. Moreover, Chan and Pin found moderate positive associations between walking speed (10MWTs) and balance (BBS) in 39 older adults with dementia or Alzheimer disease. They reported findings of \( r = 0.49 \) (10MWT measured in 2-min walk test) and \( r = 0.35 \) (10MWT measured in 6-min walk test) between walking speed and balance. This result demonstrated that strong association between balance and walking speed suggests that older adults with dementia walk shorter distances over a longer period of time when a loss of balance performance occurs.

Regarding the association between quantitative gait analysis and clinical tests, specific gait parameters including velocity, step length, stride length, and the quality of gait (WR) were associated with cognition, balance, and ADLs in older adults with dementia. Additionally, the functional inabilities to perform ADLs were associated with shorter single support time and longer double support time in this study. Bruce-Keller et al examined the association between decline in cognition and gait disturbance in 50 individuals with early-stage dementia and showed significant associations (\( r = 0.31-0.50 \)) between cognition (MMSE) and gait parameters including velocity, cadence, and stride length (GAITRite). Jayakody et al found that higher double support time variability and slower gait speed were associated with decline in memory in 410 older adults. According to a meta-analysis study, previous studies have focused on gait parameters, such as velocity, stride length, stride time, and stride time variation. Single task gait velocity and stride length significantly decreased in people with mild cognition impairment, while stride time and stride time variation significantly increased. Thus, several authors suggested that a variability in gait parameter is closely associated with cognitive decline. These results are supported by neurobiological evidence through brain imaging assessing the association between pathological gait and decline in cognition. Normally, complex sequential behavior, in particular gait, is generated by a “central pattern generator” at the spinal level. In higher brain function, the motor cortex of the frontal lobe and basal ganglia would be involved in the regulation of fine motor programs for controlling limb trajectory and foot placement. In dementia-induced pathological gait, Nakamura et al reported that reduced mean values of regional cerebral blood flow in the basal ganglia and frontal region was shown to be associated with increased double support time and decreased walking speed and stride length. Dementia with cognitive impairment is also associated with the lesions of the hippocampus (memory) and prefrontal cortex (problem-solving, selective attention, and personality).

The associations between quality of gait (WR) and balance ability may be affected by a decline in cognition. Changes in the quality of gait are associated with slower sustained gait speed, which disturbs gait and balance performance in mild to severe cognitive impairment. Alterations in gait including slower gait speed, shortened steps, and increased stride variability are associated with risk of falls or loss of balance and aggravated under loading condition requiring high level of cognition function such as dual-task condition during dementia progression. Several studies have suggested that gait is closely associated with executive functions including basic and high-level cognitive processes such as attention, working memory, decision-making, and problem-solving. Additionally, the impaired executive function results in higher risk of falls and lower level of complex motor tasks, which leads to poor ADLs. Gait analysis associated with dementia may be important for classifying those at the highest risk of falls during dementia progression; thus, fall prevention programs could be implemented. Therefore, previous studies support our finding that quantitative gait analysis, specifically step length, stride length, and the quality of gait, is closely associated with balance and ADLs in people with dementia.

Although our study has revealed significant findings, this study has a few limitations. First, measured gait parameter types were different between studies, and the results varied between this study and those of the previous studies. Further studies should identify the most important gait parameters associated with dementia to assess the degree of dementia progression and exercise programs in a large-scale clinical trial. Second, all measurement data of this study were collected by one examiner; hence, further studies with measurement data investigated by several examiners are required. Third, the stride time, stride variation, and double support time variability in gait parameters associated with dementia revealed more significant differences compared with healthy adults in previous studies. However, this study showed stride time was not associated with cognition. Mini-Mental Statement Examination is commonly used as a cognitive screening test to evaluate the general cognition function. Finally, in this study, only B-ADLs were measured using MBI. Some studies have reported that IADLs should be assessed for people with dementia. Hence, if a more sensitive assessment tool such as Montreal Cognitive Assessment and IADL tool are used, persuasive results may be involved in further studies.

Conclusions

This study identified important associations between balance, gait, and ADL assessments in people with dementia. In particular, step length, stride length, and the quality of gait are...
closely associated with balance and ADLs in people with dementia. Further studies involving targeted interventions addressing gait parameters and improving balance and functional performance in people with dementia are required in the future.

Declaration of Conflicting Interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding
The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD
Tae Woo Kang, PT, PhD https://orcid.org/0000-0002-0083-2726

References
1. Knopman DS, DeKosky ST, Cummings JL, et al. Practice parameter: diagnosis of dementia (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology. Neurology. 2001;56(9):1143-1153.
2. Rizzi L, Rosset I, Koriz-Cruz M. Global epidemiology of dementia: Alzheimer’s and vascular types. Biomed Res Int. 2014;2014:1-8.
3. Rocca WA, Hofman A, Brayne C, et al. Frequency and distribution of Alzheimer’s disease in Europe: a collaborative study of 1980–1990 prevalence findings. The EURODEM-Prevalence Research Group. Ann Neurol. 1991;30(3):381-390.
4. Prince M, Bryce R, Albanese E, Wimo A, Ribeiro W, Ferri CP. The global prevalence of dementia: a systematic review and meta-analysis. Alzheimers Dement. 2013;9(1):63-75. e62.
5. Verghese J, Wang C, Lipton RB, Holtzer R, Xue X. Quantitative gait dysfunction and risk of cognitive decline and dementia. J Neurol Neurosurg Psychiatry. 2007;78(9):929-935.
6. Feldman HH, Van Baalen B, Kavanagh SM, Torfs KE. Cognition, function, and caregiving time patterns in patients with mild-to-moderate Alzheimer disease: a 12-month analysis. Alzheimer Dis Assoc Disord. 2005;19(1):29-36.
7. Mazoteras Muñoz V, Abellan van Kan G, Cantet C, et al. Gait and balance impairments in Alzheimer disease patients. Alzheimer Dis Assoc Disord. 2010; 24(1):79-84.
8. Bruce-Keller AJ, Brouillette RM, Tudor-Locke C, et al. Relationship between cognitive domains, physical performance, and gait in elderly and demented subjects. J Alzheimers Dis. 2012;30(4):899-908.
9. Verghese J, Lipton RB, Hall CB, Kuslansky G, Katz MJ, Buschke H. Abnormality of gait as a predictor of non-Alzheimer’s dementia. N Engl J Med. 2002;347(22):1761-1768.
10. Scarmeas N, Albert M, Brandt J, et al. Motor signs predict poor outcomes in Alzheimer disease. Neurology. 2005;64(10):1696-1703.
11. Taylor ME, Delbaere K, Lord SR, Mikolaizak AS, Close JC. Physical impairments in cognitively impaired older people: implications for risk of falls. Int Psychogeriatr. 2013;25(1):148-156.
12. Savica R, Wennberg AM, Hagen C, et al. Comparison of gait parameters for predicting cognitive decline: the Mayo clinic study of aging. J Alzheimers Dis. 2017;55(2):559-567.
13. Feldman HH, Schmitt FA, Olin JT. Activities of daily living in moderate-to-severe Alzheimer disease: an analysis of the treatment effects of memantine in patients receiving stable donepezil treatment. Alzheimers Dis Assoc Disord. 2006;20(4):263-268.
14. Alzheimer’s Association. 2016 Alzheimer’s disease facts and figures. Alzheimers Dement. 2016;12(4):459-509.
15. Suh GH, Ju YS, Yeon BK, Shah A. Longitudinal study of Alzheimer’s disease: rates of cognitive and functional decline. Int J Geriatr Psychiatry. 2004;19(9):817-824.
16. Hulley SB, Cummings SR, Browner WS, Grady D, Newman TB. Designing Clinical Research: An Epidemiologic Approach. 4th ed. Lippincott Williams & Wilkins; 2013. Appendix 6C, page 79.
17. Back MJ, Kim K, Park YH, Kim S. The Validity and reliability of the mini-mental state examination-2 for Detecting mild cognitive impairment and Alzheimer’s disease in a Korean population. PLoS One. 2016;11(9):e0163792.
18. Muir-Hunter SW, Graham L, Montero Odasso M. Reliability of the Berg balance scale as a clinical measure of balance in community-dwelling older adults with mild to moderate Alzheimer disease: a pilot study. Physiother Can. 2015;67(3):255-262.
19. Telenius EW, Engedal K, Bergland A. Inter-rater reliability of the Berg Balance Scale, 30 s chair stand test and 6 m walking test, and construct validity of the Berg Balance Scale in nursing home residents with mild-to-moderate dementia. BMJ Open. 2015; 5(9):e008321.
20. Kim HJ, Park I, Lee HH, Lee O. The reliability and validity of gait speed with different walking pace and distances against general health, physical function, and chronic disease in aged adults. J Exerc Nutrition Bioc. 2016;20(3):46-50.
21. Leung SO, Chan CC, Shah S. Development of a Chinese version of the Modified Barthel Index – validity and reliability. Clin Rehabil. 2007;21(10):912-922.
22. Sekiya N, Nagasaki H, Ito H, Furuma T. The invariant relationship between step length and step rate during free walking. J Hum Mov Stud. 1996;30:241-257.
23. McDonough AL, Batavia M, Chen FC, Kwon S, Ziai J. The validity and reliability of the GAITRite system’s measurements: a preliminary evaluation. Arch Phys Med Rehabil. 2001;82(3):419-425.
24. Giebel CM, Sutcliffe C, Stolt M, et al. Deterioration of basic activities of daily living and their impact on quality of life across different cognitive stages of dementia: a European study. Int Psychogeriatr. 2014;26(8):1283-1293.
25. Volcker L, Harper DG, Manning BC, et al. Sundowning and circadian rhythms in Alzheimer’s disease. Am J Psychiatry. 2001; 158(5):704-711.
26. Chan WLS, Pin TW. Reliability, validity and minimal detectable change of 2-minute walk test, 6-minute walk test and 10-meter walk test in frail older adults with dementia. Exp Gerontol. 2019; 115:9-18.
27. Jayakody O, Breslin M, Srikanth V, Callisaya M. Gait characteristics and cognitive decline: a longitudinal population-based study. *J Alzheimers Dis*. 2019;71(s1):S5-S14. Pre-press:1-10.

28. Bahureksa L, Najafi B, Saleh A, et al. The impact of mild cognitive impairment on gait and balance: a systematic review and meta-analysis of studies using instrumented assessment. *Gerontology*. 2017;63(1):67-83.

29. Boripuntakul S, Lord SR, Brodie MA, et al. Spatial variability during gait initiation while dual tasking is increased in individuals with mild cognitive impairment. *J Nutr Health Aging*. 2014;18(3):307-312.

30. Verghese J, Robbins M, Holtzer R, et al. Gait dysfunction in mild cognitive impairment syndromes. *J Am Geriatr Soc*. 2008;56(7):1244-1251.

31. Choi JS, Oh HS, Kang DW, et al. Comparison of gait and cognitive function among the elderly with Alzheimer’s disease, mild cognitive impairment and healthy. *Int J Precis Eng Man*. 2011;12(1):169-173.

32. Nakamura T, Meguro K, Yamazaki H, et al. Postural and gait disturbance correlated with decreased frontal cerebral blood flow in Alzheimer disease. *Alzheimer Dis Assoc Disord*. 1997;11(3):132-139.

33. Drew T, Jiang W, Kably B, Lavoie S. Role of the motor cortex in the control of visually triggered gait modifications. *Can J Physiol Pharmacol*. 1996;74(4):426-442.

34. Armstrong DM, Drew T. Locomotor-related neuronal discharges in cat motor cortex compared with peripheral receptive fields and evoked movements. *J Physiol*. 1984;346:497-517.

35. Dawbarn D, Allen SJ. Neurobiology of Alzheimer’s Disease. Oxford University Press; 2007.

36. Bowen ME, Crenshaw J, Stanhope SJ. Balance ability and cognitive impairment influence sustained walking in an assisted living facility. *Arch Gerontol Geriatr*. 2018;77:133-141.

37. Maquet D, Lekeu F, Warzee E, et al. Gait analysis in elderly adult patients with mild cognitive impairment and patients with mild Alzheimer’s disease: simple versus dual task: a preliminary report. *Clin Physiol Funct Imaging*. 2010;30(1):51-56.

38. Persad CC, Jones JL, Ashton-Miller JA, Alexander NB, Giordani B. Executive function and gait in older adults with cognitive impairment. *J Gerontol A Biol Sci Med Sci*. 2008;63(12):1350-1355.

39. Petersen RC, Caracccio B, Brayne C, Gauthier S, Jelic V, Fratiglioni L. Mild cognitive impairment: a concept in evolution. *J Intern Med*. 2014;275(3):214-228.

40. Trzepacz PT, Hochstetler H, Wang S, et al. Relationship between the Montreal Cognitive Assessment and Mini-mental State Examination for assessment of mild cognitive impairment in older adults. *BMC Geriatr*. 2015;15:107.