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Original Article

Association between Gait Time and Cognitive Function in Various Walking Conditions

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SUMMARY

Introduction: Walking ability has been emerges as a significant predictor of future cognitive impairment and dementia in elderly. This study aimed to investigate the association between gait time and cognitive function in various walking conditions, and to find out which walking conditions are the most associated with cognitive function.

Methods: This is a study with a cross-sectional design and convenience sampling. The study participants were 86 elderly people aged > 65 years with cognitive intact or mild cognitive impairment. Cognitive function was measured using Mini-mental state examination (MMSE), and two examiners measured walking time according to six different walking conditions. Pearson's correlation analysis and multiple regression analysis were used to compare the association between gait time and cognitive function in six walking conditions.

Results: There are significantly correlated between gait time and MMSE (cognitive function) in all walking conditions ($p < 0.05$). According to multiple linear regression, all of the gait time in six different walking conditions was associated with the cognitive function ($p < 0.05$). However, age, sex, body mass index (BMI), and leg lengths did not associated with the cognitive function. The walking condition that had highest adjusted R^2 (%) coefficient and satisfied the homoscedasticity of residuals was the 4-Meter Walking Test (4MWT) while holding a water cup ($r = 0.483$, $p < 0.001$) and the Groningen Meander Walking Test (GMWT) ($r = 0.473$, $p < 0.001$).

Conclusion: Among the six walking models, the 4MWT while holding a water cup and GMWT were the most effective walking models to explain the cognitive function.

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1. Introduction

As symptoms of the dementia develop over many years or even decades, interest in its early detection and effective strategies for the prevention is increasing.¹ Mild cognitive impairment (MCI) highly at risk of conversion to dementia and is modifiable, with the possibility of reversion to a cognitive intact status.^{2,3}

Deficits in cognitive functions can affect motor functioning, and subtle changes in motor functioning could be an early indicator of cognitive decline.^{4,5} Among several motor functions, gait speed is proposed as a screening criterion for cognitive decline in MCI.⁶ A recent study revealed that gait speed seems to have early detection abilities for cognitive impairment.⁷ Longitudinally, gait speed emerges as a strong and significant predictor of future cognitive impairment and dementia in older adults.⁸ Identifying patients in pre-dementia states, such as MCI, is an important clinical need because treatment may be more effective in early stages.⁹

Increasing the complexity of the gait environment is another means of evaluating the effect of cognition on performance.¹⁰ Simple straight path walking provides a low cognitive challenge and may

not be related to walking in more complex real-world environments, whereas curved path walking reflects real-life situations involving dynamic stability that requires individuals to navigate through their environments such as around a furniture.¹¹ Curved path walking involves planning and greater motor skills and controls than straight path walking, tapping into higher function demands.^{12,13} Therefore, curved path walking may effectively assess not only gait speed deficits but also motor control deficits in people with Alzheimer's disease (AD), providing a better understanding of the relationship between cognition and functional gait deficits.¹⁴

The use of a dual-task paradigm is a good way to screen for gait abnormalities in MCI.¹⁵ Dual tasking relies on dividing attention between two distinct tasks: a motor task such as walking and a cognitively demanding task such as counting backward. Patients with MCI and AD typically show more pronounced decrements in gait when performing two tasks simultaneously compared to healthy elderly people.^{16–18} Generally, increasing cognitive effort in the dual task increases the gait assessment sensitivity; however, an attention-demanding arithmetic task such as counting backward seems to be more appropriate for gait analyses in older adults.¹⁹

As described above, gait ability has been proven to be highly related to cognitive function in various types of walking methods. This study aimed to investigate the association between gait time

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and cognitive function in various walking conditions, and to find out which walking conditions the most associated with cognitive function. Based on these results, we expect to develop a gait evaluation method that considers the walking environment as an alternative to cognitive tests for the elderly people who have cognitive ability difficulties and screening test for early detection in the future.

2. Patients and methods

This is a study with cross-sectional design and convenience sampling. A total of 90 elderly people were screened by the staff in facilities, including two elderly welfare care centers and one dementia prevention care center in Gyeonggi-do from October 2018 to December 2019. After the consent of the facility manager, a notice was posted on the bulletin board of the facility. For the elderly who voluntarily applied for research, one physical therapist at the facility performed primary screening according to the inclusion and exclusion criteria.

After the primary screening, each physical therapist from the facility and the research team performed a secondary screening through walking observation and the survey questionnaire consisting of general information, including gender, height, weight, leg length, educational level, medical history, and dosing information. A psychiatrist confirmed the final participants after conducting a cognitive test (CERAD-K, The Consortium to Establish a Registry for Alzheimer's disease) from the second screened participants. Finally, four participants dropped out of the study because of personal reasons, such as health problems. A total of 86 elderly people were finally included in this study. Inclusion criteria were (1) able to walk independently without using aids, (2) able to hear and understand directions sufficiently to participate in tests without severe cognitive impairment, and (3) aged ≥ 65 years. (4) Participants with normal cognition and diagnosed with MCI. Exclusion criteria were (1) vascular stroke with motor deficits, (2) Parkinson's disease, and (3) neurological disorder that can affect the gait.

Therefore, this study was explained to all participants or their guardians, and they provided consent to participate in this study. The project was approved by the Institutional Review Board of Eulji University (EUIRB2019-19).

2.1. Outcome measurement

The tester trained by the clinical counselor performed the cognitive test. The results of the cognitive test were not shared with the tester measuring the walking time. Mini-mental state examination – Korean Version (MMSE-K): Global cognitive function test consisting of orientation, learning, working memory, object naming, understanding simple instructions, and copying drawing were conducted to assess the general cognitive function. This score was used as reference test to analyze the correlation. If participants have severe cognitive problem, they were ruled out based on this score and general information after identifying a psychiatrist.

We used the time taken to walk (gait time) as a comparator test. The tester gave verbal instructions to each participant. Subsequently, they performed a demonstration if the participant did not understand the instructions well. After practicing two or three times according to the standardized instructions of the tester, two testers measured the time taken to walk in six different gait conditions, namely (1) walking 4-metres in a straight path according to the 4-Meter Walking Test (4MWT), (2) 4MWT while counting backward from 20, (3) 4MWT while holding a water cup, (4) walking 6-metres in a curved path according to the Groningen Meander Walking Test

(GMWT), (5) GMWT while counting backward from 20, and (6) GMWT while holding a water cup.

The 4MWT was used to assess the straight path by instructing each participant to walk a 4-m distance at a comfortable walking speed, and the outcome measurement is the walking time. The reliability (0.85) is high. Curved path used the GMWT, i.e., each participant is instructed to walk along a 6-m line with four curves. The time taken to walk was measured. The reliability (0.99) is high.²⁰

The walkway distance was marked on the walkway to assess the gait performance. Time was measured using a digital stopwatch. The participants were asked to walk on this walkway while looking at a visible target on the wall. The test sequences of six different gait conditions were performed at random.

2.2. Statistical analysis

Data were analyzed using R software 3.6.0 (R Foundation for Statistical Computing), and participants' general characteristics were analyzed using the frequency analysis. Pearson's correlation coefficient was used to identify the relationship between the comparators and reference test. The intraclass correlation coefficient (ICC) was calculated to verify the agreement between examiners. The high Pearson's coefficient and ICC score were considered to be highly correlated with the reference test of MMSE, and to be high reproducibility of comparators.

The gait time (second) was changed using the inverse transformation method to indicate a positive correlation by fitting the statistical model of ICC. Each comparator test was also standardized to minimize the bias of comparator tests.

Pearson correlation and multiple regression analysis were used to determine the relationship between the cognitive function and gait time. Independent variables were the time taken to perform gait in six walking conditions, and dependent variables were the MMSE-K score. Regression coefficients were compared among six walking conditions. The common covariates with gait time were leg length, gender, age, and BMI. All statistics were two-tailed, and p-values < 0.05 were considered significant.

3. Results

3.1. General characteristics and gait test

The general characteristics of the participants and the results of the gait test were shown in Table 1.

3.2. Correlation between MMSE-K and gait time

There are significantly correlated between gait time and MMSE-K (cognitive function) in all walking conditions ($p < 0.05$). The highest correlation coefficient was 0.488 in the 4MWT while counting backward from 20 among six different walking conditions, followed by 4MWT while holding a water cup ($r = 0.483$), and the difference in all conditions was significant (Table 2) (Figure 1).

The ICC was analyzed to identify coincide with the standard test (MMSE-K). The highest ICC was found to be 0.656 (the 4MWT while counting backward from 20), followed by 0.651 (the 4MWT while holding a water cup) (Table 2).

3.3. Regression analysis between MMSE-K and gait time

Age, sex, BMI, and leg lengths were not associated with MMSE-K (the global cognitive function) ($p > 0.05$). However, all of gait time

Table 1
Participant characteristics and cognitive function and walking time measurement result.

	Mean (SD)
Age, years	77.73 (5.41)
Sex, %	
Male	20 (23.3)
Female	66.6 (76.7)
BMI, kg/meter ²	23.59 (2.53)
Average leg size, cm	78.42 (4.68)
Reference test	
MMSE	22.81 (4.15)
Comparator tests, sec	
4MWT	6.40 (2.00)
4MWT while counting backward from 20	9.62 (10.17)
4MWT while holding a water cup	6.23 (2.18)
GMWT	12.74 (7.58)
GMWT while counting backward from 20	15.15 (8.04)
GMWT while holding a water cup	11.88 (5.04)

SD, standard deviation; BMI, body mass index.

Table 2
Association between MMSE-K and gait time in different walking conditions.

Walking conditions ^a	r ^b	p ^c	ICC	p ^d
4MWT	0.438	< 0.001	0.609	< 0.001
4MWT while counting backward from 20	0.488	< 0.001	0.656	< 0.001
4MWT while holding a water cup	0.483	< 0.001	0.651	< 0.001
GMWT	0.473	< 0.001	0.642	< 0.001
GMWT while counting backward from 20	0.472	< 0.001	0.642	< 0.001
GMWT while holding a water cup	0.410	< 0.001	0.582	< 0.001

^a The gait time (sec) was changed by the inverse transformation method.

^b Correlation coefficient.

^c p-value for correlation; ^d p-value for ICC (intraclass correlation coefficient).

in six different walking conditions was associated with MMSE-K ($p < 0.05$). The highest adjusted R^2 (%) was the 4MWT while holding a water cup (Model 3), followed by the 4MWT while counting backward from 20 (Model 2) and GMWT (Model 4). However, only Models 3 and 4 satisfied the homoscedasticity of residuals (Table 3). Therefore, the best model for explaining a cognitive function was Model 3 and 4.

4. Discussion

This study was conducted to identify the association between gait time and cognitive function in various walking conditions, and to find out which walking conditions the most associated with cognitive function. Among six walking conditions, the 4MWT while holding a water cup and GMWT were the most effective walking condition for explaining cognitive function.

Lee has recommended the use of 4MWT and GMWT as valid gait assessment tools for predicting dementia.²¹ Quantitative gait measurements, such as 4MWT, are useful for the early prediction of cognitive decline and dementia risk in non-demented elderly people.²² Dynamic walking ability measurement methods such as GMWT are an optimized tool for measuring dementia patients characterized by executive function, gait speed, and stride length reduction.²³ In addition, gait is more clearly related to the test such as the total MMSE score that estimates the degree of overall cognitive area rather than the importance of individual cognitive areas because walking is a movement completed by appropriately interacting with various cognitive areas rather than a problem of one or two cognitive areas.²⁴ Based on this evidence, this study used 4MWT and GMWT for gait evaluation and MMSE-K for cognitive evaluation.

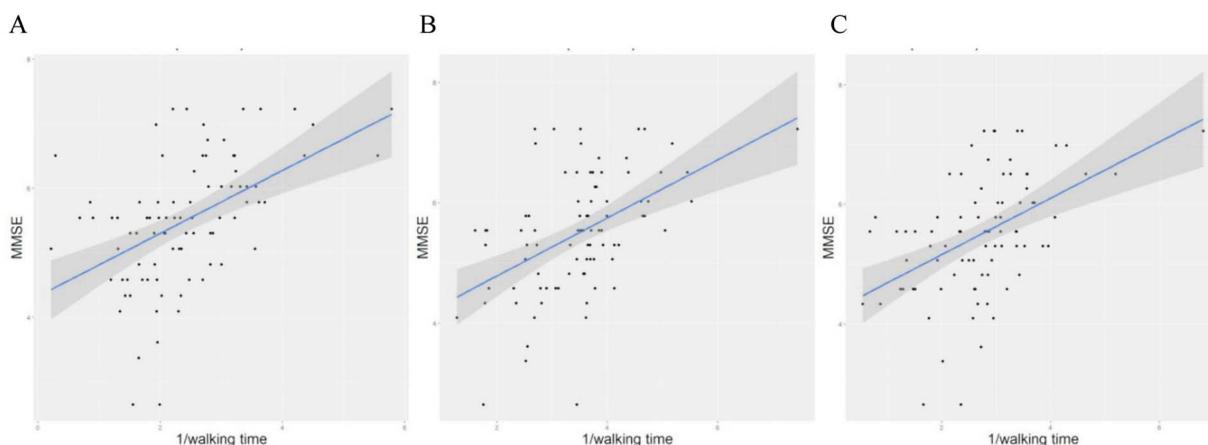


Figure 1. Correlation between global cognitive function (MMSE-K) and gait time. A, walking while counting backward from 20 in a straight path ($r = 0.488$); B, walking while holding a water cup in a straight path ($r = 0.483$); C, walking in a curved path ($r = 0.473$). The shaded area is 95% confidence interval.

Table 3
Multiple linear regression analysis of MMSE-K and gait time according to different gait condition.

Model	Regression coefficient of gait time	SE	p ^a	Adjusted R ² (%)	p ^b
Model 1: 4MWT	0.379	0.112	0.001	18.64	0.456
Model 2: 4MWT while counting backward from 20	0.433	0.111	< 0.001	21.91	0.025
Model 3: 4MWT while holding a water cup	0.451	0.108	< 0.001	23.58	0.061
Model 4: GMWT	0.415	0.115	< 0.001	20.04	0.342
Model 5: GMWT while counting backward from 20	0.407	0.117	< 0.001	19.21	0.202
Model 6: GMWT while holding a water cup	0.321	0.122	0.010	14.32	0.130

Model calculated by independent variable (gait time, age, sex, BMI, leg size) and dependent variable (MMSE-K). Regression coefficients for age, gender, BMI, and leg size are not displayed because they not significant for all regression models.

The gait time (s) was changed by the inverse transformation method.

^a p-value for regression coefficient; ^b p-value for homoscedasticity using Breusch-Pagan test.

SE, standard error.

Gait speed is emerging as an important early indicator of risk for cognitive decline and cognitive impairment.²⁵ However, the usual pace gait speed measured at a single time point in higher functioning older adults may not predict cognitive decline,²⁶ thereby limiting its clinical utility. In addition, gait speed during the usual pace and narrow walk conditions was not associated with cognitive outcomes after adjustment.²⁷ Complex walking tests challenge the over-learned task of walking and could serve as stress tests of central motor control. Previous studies have indicated that there is an overlap in the brain regions responsible for central motor control and those involved in cognitive impairment.^{26,28,29} In other words, these complex walking tests may uncover latent pathology that puts individuals at increased risk for cognitive impairment and dementia. Therefore, this study confirmed the relationship between gait time and cognitive function by adding dual tasks such as holding water cups and counting backward while applying the 4MWT and GMWT to set various walking environments.

In this study, participants were verbally explained on the six walking methods first, and then the examiner showed a walking demonstration. All straight and curved path walks require attention and executive factors, as they understand the instructions and complete the walk with or without additional tasks. Walking with a cup of water requires a higher level of visuospatial attention because the walking must be done with the utmost care to avoid spilling the water inside the cup. As a result of this study, the 4MWT while holding a water cup and GMWT were the most relevant walking tasks with cognitive function. This suggests that an appropriate level of walking task is more effective in explaining cognitive function than the dual task added to walking task, i.e., simple or too complicated and difficult task.

In a previous study, significant associations among executive function, working memory, and gait slowing were found in older people with MCI, which were better detected under dual-tasking conditions. Poor working memory was strongly associated with dual-task decrement on gait velocity, which was expressed an early phenomenon in people with MCI. Therefore, the quantitative examination of gait under dual tasking could be a complementary way to evaluate brain function during the preclinical onset of dementia.³⁰ As gait can be more easily and quantifiably measured than psychometrics, quantitative gait assessment can be used as a complementary measure for neuropsychological assessment in older adults with MCI. The 4MWT while holding a water cup and GMWT are a minimal quantitative examination setup, easy to manage, and has the advantage of being safely performed at home or in a clinical setting. Therefore, the 4MWT while holding a water cup and GMWT are considered a useful walking method for explaining cognitive function in the early stages of dementia.

The explanatory power of gait time to explain cognitive function in the present study is only 23.58% in model 3. It is considered that the explanation power in this study was low because the selection of variables was inappropriate. Therefore, if more variables such as age, sex, BMI, leg size, as well as complication (hypertension, diabetes, cardiovascular disease, etc.), surgery, trauma, etc., are added, the explanatory power will surely increase.

In this study, we tried to identify general characteristics and select participants through the questionnaire, but the reliability of the questionnaire was insufficient in the elderly people who had decreased cognitive level. Because of the difficulty in recruiting elderly people with reduced cognition, only three facilities in the area were recruited, and the number of participants was small, making it difficult to generalize the study results. In addition, because it is a cross-sectional study, the fact of how the correlation between cog-

nitition and gait changes over time could not be analyzed.

5. Conclusion

This study identified the gait conditions most related to cognitive function among various gait tasks and to determine the gait evaluation method to explain the cognitive function in the elderly people. As a result, among the six walking models, the 4MWT while holding a water cup and GMWT were the most effective walking models to explain the cognitive function. The 4MWT while holding a water cup and GMWT are a simple quantitative gait test, which is thought to be an easily managed and safe gait test performed at home or in a clinical setting.

Conflict of interest statement

The authors declare no conflict of interest.

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