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Original Article

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Correlation Between Executive Function and Walk While Crossing Over an Obstacle Under Different Gait Phases

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ABSTRACT

Background and Purpose: Dual walking task such as crossing over an obstacle may serve as an excellent tool for predicting early cognitive decline. Thus, this study aimed to investigate correlation between walking while crossing over an obstacle and executive functions under different gait phases to validate the use of walking with an obstacle for predicting early cognitive decline.
Methods: A cross-sectional study was conducted on 48 elderly individuals from 2 day-care centers and 3 welfare-centers in Seoul and Gyeonggi, Korea. Executive function tests (Trail Making Test, Stroop test) and dual walking tests (gait speed, cadence, stance time, gait cycle time) were performed and compared using partial correlation analysis.
Results: There were significant correlations between executive function and most of the gait variables (stance time, cadence, and gait cycle time) ($p<0.05$) when crossing over an obstacle while walking. Especially, stance time exhibited significant correlations with most executive functions ($p<0.05$).
Conclusions: When evaluating executive function during walking with an obstacle, post-obstacle-crossing phase and stance time need to be observed.

Keywords: Walking; Elderly; Executive Function; Cognitive Dysfunction

INTRODUCTION

In the field of cognitive health research, memory and executive function assessments have become vital for identifying early-stage Alzheimer's dementia risk.[1] Recent studies have also highlighted the importance of walking tests in predicting cognitive decline and dementia risk.[2] The dual-task walking test, compared to single task walking, stands out as a better tool for detecting cognitive decline due to its increased demand for attention and reliance on executive function.[3-6]

Walking while navigating an obstacle, a type of motor dual-task walking, places a significant cognitive demand on individuals. It involves the prefrontal cortex,[7,8] advanced sensory processing, and motor information processing to navigate gait patterns while responding to environmental constraints.[9] Consequently, the dual-task walking test while crossing over an

This work is based on the Seung Min Lee's MS thesis.

obstacle imposes significant cognitive demands, places emphasis on physical factors such as balance, and relies heavily on executive functions including attention attributes, making it a potential alternative for assessing and predicting cognitive decline.

Interestingly, studies have revealed an association between lower Trail Making Test (TMT) score, a common measure of executive function, and decreased walking speed during crossing over an obstacle.[10,11] This finding suggests that walking tests involving obstacle may hold promise as a proxy measure of executive function. However, previous research has mainly focused on walking speed, overlooking other critical variables and phases of obstacle crossing. This raises the question of whether executive function test, like the Stroop test, could correlate with walking tests and if different obstacle crossing phases might impact results.

Aging present unique gait challenges, with older adults often showing hesitance during obstacle crossing due to increased reaction time.[12] These individuals tend to adopt safer strategies characterized by prolonged stance time when approaching obstacle. Certain cognitive assessments such as Montreal Cognitive assessment and Wechsler memory scale-revised logical memory test correlate with specific aspects of obstacle negotiation, such as clearance of a trailing limb when tripping over obstacles.[13] These observation have led us to hypothesize that gait characteristics in older individual might vary across obstacle crossing phases influenced by cognitive demands such as executive function. Despite the potential significance of this relationship, it has received limited exploration.

Hence, our research focused on investigating the correlation between walking test while crossing over an obstacle and executive functions across various gait phases, with an aim of laying the groundwork for cognitive enhancement programs targeting older adults with cognitive decline.

METHODS

Participants

This study utilized a cross-sectional design. Participants were recruited from 2 day-care centers and 3 welfare-centers in Seoul and the Gyeonggi area between October 1, 2018 and October 15, 2022. We targeted 48 participants aged 65 years or older who met the following inclusion criteria: (1) ability to walk independently, and (2) ability to communicate with the tester. Exclusion criteria were: (1) Parkinson's disease, (2) stroke, (3) history of artificial joint surgery, (4) dizziness, and (5) recently history of falls.

We explained the study protocol to all participants and obtained their consent to participate. This study was approved by the Institutional Review Board of Eulji University (study approval number: EU18-72, EU19-19, EUIRB2020-007, EU22-60). During the first visit, we collected general information of participants and conducted executive function tests including TMT and Stroop test. Subsequently, a psychiatrist reviewed and confirmed test results for interpretation. A walking test was administered during the second visit. It was scheduled within one week after the first visit. Results of both the cognitive test and walking tests were kept blinded from testers.

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Measures

Walking test

Participants were instructed to walk comfortably at their normal pace, first without an obstacle and then while navigating a 6-meter path with a plastic obstacle that was 10 cm in height. We used a Tekscan® F-Scan® system (2010; Tekscan Inc., South Boston, MA, USA) equipped with pressure-sensing insoles to measure gait variables. Gait variables including cadence, gait cycle time, and stance time were analyzed using the F-scan software program (2021; Tekscan Inc.). The validity of F-scan system was high, as indicated by an intraclass coefficient of 0.91.[14]

During walking test while crossing over an obstacle, gait variables were assessed in 3 distinct phases: approaching phase (prior to reaching the obstacle), crossing phase (while navigating the obstacle), and post-crossing phase (after successfully crossing the obstacle) (**Fig. 1**).

Executive function test

1) TMT

The TMT required participants to connect randomly positioned numbers and letters in an ascending sequence as quickly as possible. TMT has 2 parts to test: TMT-A and TMT-B. TMT-A part involves connecting 25 numbers from 1 to 25. TMT-B part consists of connecting 13 numbers from 1 to 13 and 12 letters alternately.

The time taken to complete each task was measured. If a participant could not complete TMT-A and TMT-B within 360 seconds and 300 seconds, respectively, the test was concluded. A lower score indicated a better cognitive function. The maximal score was 360 for TMT-A and 300 for TMT-B based on the maximal time allowed for task completion.[15]

2) Stroop test

The Stroop test comprises 3 subtasks: Stroop word, Stroop color, and stoop color-word. Participant was initially instructed to read the words (Stroop word) and then say the color name (Stroop color). Finally, they read the name of the ink color that each word was printed

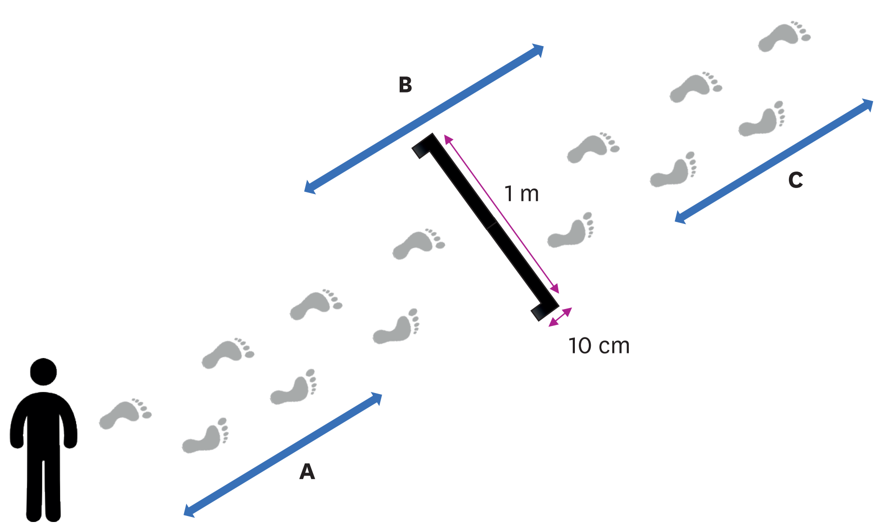

Fig. 1. Example of walking test while crossing over an obstacle. The blue line represents 3 distinct phases. (A) Approaching phase (prior to reaching the obstacle). (B) Crossing phase (while navigating the obstacle). (C) Post-crossing phase (after successfully crossing the obstacle phase). Black bar-sticky picture illustrates the obstacle.

in (Stroop color-word). The number of words to read without error within 45seconds was counted as the final score, with a higher score indicating a better cognitive function.[16,17]

Statistical analysis

All data were analyzed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Participants' general characteristics were subjected to frequency analysis. To assess the relationship between executive function (TMT, Stroop test) and gait variables (gait speed, cadence, stance time, gait cycle time), we employed partial correlation analysis after adjusting for age, education level, and height. All statistics were 2-tailed and significance level was set at $p<0.05$.

RESULTS

Table 1 displays characteristics of 48 participants who completed this study (average age: 76.68±5.22 years). The proportion of women (71%) was higher than that of men. Additionally, the average Korean version of Mini-Mental State Examination score was 24.29±5.19 (**Table 1**).

In general walking, gait variables (stance time, cadence, and gait cycle time) significantly ($p<0.05$) correlated with the Stroop color test, but not with TMT-A, TMT-B, or Stroop word.

In obstacle-crossing walking, stance time exhibited significant ($p<0.05$) correlations with all executive function tests except for TMT-B. Cadence showed a significant correlation only with TMT-A, while gait cycle time showed significant correlations only with the Stroop color and Stroop word-color test ($p<0.05$). Interestingly, the TMT-B did not exhibit a significant correlation with any of the gait variables in either gait condition (**Table 2**).

Table 1. General characteristics of participants

Category	Subjects (n=48)
Gender (Men/Women)	14/34 (29/71)
Age (yr)	76.68±5.22
Education (yr)	8.79±5.51
Weight (kg)	58.45±9.43
Height (cm)	155.76±9.21
BMI (kg/m^2)	24.03±2.76
Mini-Mental State Examination	24.29±5.19
Trail Making Test (score)	
A	106.04±90.63
B	233.88±89.05
Stroop test (score)	
Word	59.98±24.24
Color	50.06±17.40
Word-color	29.98±11.83
General walking speed (m/s)	0.84±0.28
Crossing over obstacle walking speed (m/s)	0.83±0.28
Underlying disease	
Diabetes	16
High blood pressure	15
Hyperlipidemia	15
Spinal stenosis	7
Lumbago	11
Other diseases	10

Values are mean ± standard deviation or number (%).

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Table 2. Correlation between executive function and gait variables in both walking conditions

Gait variables	Executive function				
	TMT-A	TMT-B	SW	SC	SWC
GG_ST	0.098	0.014	−0.231	−0.412*	−0.305*
GG_CA	0.007	−0.126	0.228	0.334*	0.259
GG_GCT	0.018	0.043	−0.271	−0.427*	−0.295*
OG_ST	0.383*	0.117	−0.482*	−0.589*	−0.427*
OG_CA	0.341*	0.029	0.039	−0.159	−0.105
OG_GCT	0.080	0.141	−0.207	−0.385*	−0.458*

TMT: Trail Making Test, SW: Stroop word, SC: Stroop color, SWC: Stroop word-color, GG_ST: general gait stance time, GG_CA: general gait cadence, GG_GCT: general gait cycle time, OG_ST: obstacle gait stance time, OG_CA: obstacle gait cadence, OG_GCT: obstacle gait cycle time.
*$p<0.05$.

Table 3. Correlation between gait variables and executive functions while crossing over an obstacle based on gait phase

Phase	Gait variables	Executive function				
		TMT-A	TMT-B	SW	SC	SWC
Approaching an obstacle	Stance time	0.354*	0.103	−0.473*	−0.573*	−0.409*
	Cadence	−0.207	−0.092	0.350*	0.286*	0.211
	Gait cycle time	0.143	0.104	−0.244	−0.141	−0.086
During crossing over an obstacle	Stance time	0.383*	0.142	−0.489*	−0.596	−0.444*
	Cadence	0.416*	0.052	−0.062	−0.269	−0.181
	Gait cycle time	0.044	0.129	−0.149	−0.339*	−0.436*
After crossing over an obstacle	Stance time	0.351*	0.084	−0.403*	−0.502*	−0.361*
	Cadence	−0.324*	−0.110	0.476*	0.558*	0.403*
	Gait cycle time	0.330*	0.139	−0.509*	−0.600*	−0.427*

TMT: Trail Making Test, SW: Stroop word, SC: Stroop color, SWC: Stroop word-color.
*$p<0.05$.

In analysis of gait phase during crossing over an obstacle, there were significant ($p<0.05$) correlations between gait variables and executive functions after crossing obstacle phase except for TMT-B test. Specially, the stance time exhibited a significant correlation with most executive functions among gait variables (**Table 3**).

DISCUSSION

The main finding of this study was that executive functions showed relationships with gait variables during walking test while crossing over an obstacle in comparison with general walking. Notably, stance time exhibited significant correlations with most executive function tests.

The walking test while crossing over an obstacle offers advantages in identifying participants' walking strategies besides assessing executive functions.[18] It also provides information about physical factors such as balance.[19] Therefore, the walking test while crossing over an obstacle was selected in this study among various dual-tasks. We found a strong correlation between the walking test while crossing over an obstacle and overall executive function assessments compared to single task walking. This might be attributed to the increasing demand for prefrontal cortex activation when the elderly cross over an obstacle.

Elderly individuals experience an increasing load on executive functions during dual-task walking involving crossing over an obstacle or additional tasks compared to single-task walking, leading to prominent gait impairments.[20-22] The dorsolateral prefrontal cortex (DLPFC) is activated due to damage to the neural system or decreased automatic movement as attention and executive functions' demands increase during walking.[23-25] Consequently,

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older adults heavily rely on executive functions to compensate for decreased gait automaticity.[8,23,25] For this reason, increased activation of the DLPFC can serve as a predictive clinical indicator of gait impairments and the risk of falling in older adults.[26]

Normal walking for older adults is subconscious and automatic. However, when encountering an obstacle, walking becomes a conscious task.[18] Older adults utilize cognition processes[9] and motor control processes involving somatosensory systems[27] to safely cross over an obstacle. Furthermore, older adults adopt more conservative strategies to compensate for age-related physical and cognitive decline while crossing obstacles,[20] resulting in slower speed and shorter steps with higher step clearance. The extent of change depends on diminution of their motor and cognitive abilities.[12,20]

The ability to successfully handle obstacles is associated with executive functions related to visual-spatial processing and motor planning because prefrontal cortex activity is increased during crossing over an obstacle compared to walking without obstacle.[8,22,28]

Elderly individuals with a decline in executive function tend to recruit more brain activity to perform takes compared to younger adults.[29,30] However, this brain activity pushes older adults closer to limits of their cognitive resources, leading to slower processing speed and reduced task performance.[31] The reason why executive function test is correlated with gait variables during walking with an obstacle is that additional demands for executive functions during crossing over an obstacle bring them closer to their resource limits.

Cadence refers to the number of steps taken per minute. The better the intention and initiation of movement, the faster the cadence. Martin has reported that cadence is also associated with executive function.[32] Executive function is not only associated with temporal parameters such as step time, but also associated with spatial parameters such as step length and rhythmic aspects such as cadence.[33,34]

Bovonsunthonchai et al.[35] have reported that decreased cognitive function is associated with decreases of support base, gait speed, and step length and increases of double support time and step time.

Cognitive frailty is related to gait parameters such as cycle time. Assessing gait performance offers benefits for early diagnosis of cognitive decline.[36] Poor executive function is related to adverse gait parameters including double stance time and step time.[33] Additionally, the variability of gait is related to the decline of executive function.[33,37] The variability of gait can be calculated using the standard deviation of measures of gait parameters.[33] In our study, we analyzed stance time, which is similar to double stance time and step time in terms of the timing of foot contact during walking. However, we did not calculate gait variability. Similar to a previous study, we found that stance time was significantly related to most executive function tests among gait parameters. Hence, evaluating temporal gait variables such as stance time might be useful for predicting cognitive and executive function decline.

According to analysis of phases during crossing over an obstacle, there were significant correlations between gait variables and executive function tests in the post crossing phase compared to the approaching phase. Individuals with lower executive function tend to exhibit longer stance time. It is possible to adopt a new strategy during walking with an obstacle.

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Older adults tend to have longer reaction time due to aging when approaching an obstacle.[12] They adopt a more cautious and slow approach with increased attentional demands.[20,38] Additionally, the cognitive cost required for safe walking can be reduced by decreasing their walking speed since additional cognitive demands caused by obstacles increase the task cost.[7] Maidan et al.[22] have noticed that people with better executive function exhibit longer distance between the leading foot and an obstacle after crossing over an obstacle and greater clearance between the trailing foot and the obstacle during crossing over an obstacle. Namely, individuals may adopt an adaptation strategy to avoid the risk of tripping over obstacles. Consequently, individuals would select a new gait strategy that can increase their stance time.

Moreover, we found that a longer gait cycle time was associated with lower executive function. A longer gait cycle time implies slower walking, indicating a correlation between lower executive function and slower walking speed. Furthermore, our finding reveals that lower cadence is linked to decreased executive function.

In summary, the elderly tends to exhibit longer stance time, slower cadence, and reduced walking speed after crossing over an obstacle. This result might be attributed to the adoption of a new gait strategy aimed at compensating for post-obstacle instability. Another possible reason could be the shared neural substrate between executive function and gait variables.[39]

Our study has several limitations. First, it had a small sample size, thus having limitation when generalizing results of this study. Another limitation was that this study did not include various measurements such as electromyography for muscle activity assessment, kinematic analysis for spatial variables, or brain imaging. In future studies, these measures of muscle strength, kinematic variables, and assessments of brain function and anatomy should be considered for a more comprehensive investigation.

In conclusion, this study highlights the critical connection between executive functions and stance time parameter in dual walking test, especially when crossing over an obstacle. Furthermore, in the analysis of gait phases, there were mostly significant correlations between gait variables and executive function in the phase of post- crossing over an obstacle. Thus, we may reasonably conclude that observation according to the phase of walking and stance time is necessary to assess the executive function.

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