Unplanned Stopping Strategy in Individuals with Mild Cognitive Impairment

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Abstract

Individuals with Mild Cognitive Impairment (MCI) demonstrate changes in cognitive and gait functions. Gait termination requires higher cognitive integration compared to steady-state walking due to the increased stability needed during a transient period. It is possible that the capability to terminate gait in older adults with MCI would be compromised. Therefore, this study aimed to compare gait termination parameters between older adults with MCI and without MCI. Gait termination parameters (i.e., the number of steps taken to stop, total stopping distance, and total stopping time) were assessed in 30 older adults with MCI and in 30 cognitively intact controls. The Mann-Whitney U test revealed that the MCI group required more steps to stop compared to the control group (MCI group = 2.02 ± 0.40 steps; control group = 1.91 ± 0.36 steps, $p = 0.05$). These findings suggest that older adults with MCI adopt a more conservative strategy by employing additional steps for terminating gait. Poor executive function may affect gait termination performance in older adults with MCI.

Keywords: Mild Cognitive Impairment, gait termination, unplanned stopping, gait impairment, executive function

Introduction

Falls and fall-related injuries are important public health problems and significant contributors to morbidity and mortality in older people. This is particularly so for people with cognitive impairment who have an annual incidence of approximately 60 %, about twice that of cognitively intact older adults [1]. The consequences of falls in this population are often serious, including hospitalization, institutionalization, and mortality [2].

Gait impairment is evident at the early stages of cognitive decline [3], in that slow gait speed precedes the onset of clinically demonstrable cognitive impairment [4]. Mild cognitive impairment (MCI) is a term given to the transitional state between normal aging and dementia [5]. Older adults with MCI have impairments in cognitive function and gait performance [6,7]; both of these are known independent risk factors for falls [3,8]. Although causal relationships between impaired cognition and gait disorders are not well elucidated, there is strong evidence indicating a close association between specific cognitive domains (compromised attention and executive function) and gait impairment [9,10].

Previous studies have revealed that about 50 % of falls in elderly people occur during transitional movements, especially when starting and stopping walking, turning, and avoiding obstacles [11]. Gait termination is a challenging task, as the body must change from a dynamic to a static state. This transition

gait phase requires accurate control to arrest the forward momentum of the body and minimize the possible loss of balance and subsequent fall [12,13]. Compared to steady walking, gait termination requires higher sensorimotor and cognitive integration in order to adjust the stepping pattern to comply with changing environmental and task demands, such as avoiding obstacles, negotiating uneven surfaces, and changing speed and direction [11]. Previous studies have shown that elderly people require 2 or more steps to stop, which results in an increased total stopping time and distance, compared to young adults, who usually require only 1 step to stop [14,15]. An increase of total stopping time and distance may increase the risk of collisions, as well as increase the possibility of stepping beyond a safe boundary, resulting in an increased risk of falls.

Given the high demand on postural stability and the complex cognitive processes involved in gait termination, it could be expected that the capability to terminate gait in older adults with MCI would be compromised. The present study aimed to compare the number of steps taken to stop, the total stopping time, and the total stopping distance between older adults with MCI and cognitively intact controls. We hypothesized that older adults with MCI would adopt a more conservative gait termination strategy in order to maintain balance compared with cognitively intact controls. Specifically, we hypothesized that they would take more steps, with longer stepping times and distances to stop, than the controls. Furthermore, the present study evaluated specific cognitive domains previously found to co-exist with gait impairment and falls. This information may provide insight into the interplay between cognition and gait termination.

Materials and methods

Sixty older adults (30 MCI, 30 cognitively intact controls) aged 60 years or older participated in the study. MCI was diagnosed by an experienced neurologist using Petersen's criteria [5], including (i) memory complaint, preferably corroborated by an informant, (ii) objective memory impairment for age (determined by CDR score on memory domain = 0.5), (iii) preserved general cognition for age (determined by Mini-Mental State Examination; MMSE score $\geq$ 24 points), (iv) essentially intact activities of daily living, and (v) not suffering from dementia (determined by NINCDS-ADRDA criteria). In addition, the inclusion criterion for participants with MCI included having a Montreal Cognitive Assessment (MoCA) score of less than 26 points. These criteria are similar to those used in a previous study, for which participants with MCI had normal MMSE scores but low MOCA scores [16]. Cognitively intact controls with similar age, gender, and educational levels were recruited from the local community. Participants were excluded if they had neurological conditions, unstable acute and/or chronic disease, depressive symptoms (Geriatric Depression Scale; GDS >12 points) [17], uncorrected visual or hearing impairments, consumed alcohol < 6 h before testing, or used medications that may have affected gait performance. The study protocol was approved by the Human Ethical Review Board of the principal investigator's institute. All participants gave written informed consent prior to participation.

For data collection, the number of steps taken to stop and the total stopping distance were measured using the GAITRite® system (CIR system, USA) computerized walkway. Total stopping time was obtained using a custom-made footswitch system. The system incorporated a lightweight polymer force sensitive resister (FSR) (Interlink Electronics Incorporate, Camarillo, CA, USA), synchronized with a stopping cue, embedded inside a flexible inner sole which could be attached to the sole of the shoe. Voltage changes corresponding to heel strikes and toes being taken off were digitized at 100Hz by a portable data acquisition card (NI USB 6008; National Instruments, Austin, TX 78759) and stored on a PC for offline processing. Control of data acquisition and post processing of temporal parameters of gait was performed using the Data Acquisition Toolbox for MATLAB [18].

Procedures

Before testing, participants were interviewed about co-morbidities, medication usage, and fall incidences within the previous 12 months. Confidence in performing Activity of Daily Living (ADL) without fear of falling was examined with the Fall Efficacy Scale (FES) [19]. Participants were asked to rate their confidence level (range from 1 - 10) while performing a range of ADLs. Moreover, participants

were examined for the risk of falling using the Timed Up and Go Test (TUGT). Time taken to complete TUGT > 14.5 seconds is defined as being of a high risk for future falls [20]. Each participant's cognitive profile (i.e., memory, attention, language ability, and executive function) was evaluated using 5 standard neuropsychological tests; namely, Logical Memory-Delayed Recall (memory), Digit Span forward-backward (attention), Animal Naming Test (language ability), Trail Making Test B-A, and Block Design test (executive function) [21-25].

Following gait testing protocol, participants were instructed to walk along a 4.6 m. gait mat walkway at their usual, comfortable speed. To discourage anticipation of a stopping response, 3 stopping trials were randomly included within 18 non-stopping walking trials (one stopping trial per 6 walking trials). For the stopping trials, participants were required to stop walking as soon as possible upon the giving of an auditory signal (presented at a random time point during the trial). To control the influence of the stopping cue's timing on the stopping pattern during the gait cycle, the stopping cue was activated only upon a right heel strike at a random time point during walking [26]. Two practice trials were given to familiarize participants with the walking task.

Gait measure definitions and statistical analysis

Gait termination parameters, namely, the number of steps taken to stop, the total stopping time, and the total stopping distance, were analyzed. The number of steps taken to stop was determined by the overall steps taken to completely stop after the stopping cue. The total stopping time (sec) was determined by the time taken from the stopping cue to come to a complete stop. The total stopping distance (cm) was determined by the distance from the heel at the stopping cue to the last heel at a complete stop.

SPSS for window version 17.0 was used for data analysis. Data of all variables during gait termination were tested for normality, using the Shapiro-Wilk test. An independent sample t-test was used to compare the demographic data between the MCI and the control groups. A Mann-Whitney U test was used to compare the average gait termination parameters from 90 walking trials (3 stopping trials for each participant) between the 2 groups. A probability level of 0.05 was set to denote significance.

Results and discussion

Participant characteristics

The demographic characteristics of the participants are illustrated in **Table 1**. As expected, the MCI group performed significantly worse in the MMSE and MoCA than the control group ($p = 0.001$). Older adults with MCI also took more medications, walked at slower speeds, and took more time to perform the TUGT than the control group ($p < 0.05$). Other variables were not significantly different between the 2 groups.

Table 1 Demographic characteristics of the participants.

Variables[a]	Control group (n = 30)	MCI group (n = 30)	*p*-value
Age (yr)	70.97 (7.64)	70.60 (7.96)	0.86
Height (cm)	157.60 (7.42)	154.90 (7.58)	0.17
Weight (kg)	56.08 (7.95)	57.67 (8.59)	0.46
Educational level (yr)	10.27 (4.14)	10.93 (5.35)	0.59
Male: Female	10 : 20	10 : 20	-

Variables[a]	Control group (n = 30)	MCI group (n = 30)	*p*-value
At least 1 fall in the past 1 yr	0.33 (0.61)	0.47 (0.68)	0.43
Drugs (type)	1.10 (1.16)	1.80 (1.42)	0.04*
FES (score)	87.77 (16.33)	81.10 (22.40)	0.19
Preferred gait speed (m/s)	1.22 (0.20)	1.08 (0.21)	0.01*
TUGT (sec)	7.09 (0.98)	8.15 (1.60)	0.003*
Global cognitive function:			
MMSE (score)	29.07 (0.98)	27.63 (1.47)	0.001*
MoCA (score)	27.37 (1.22)	21.90 (2.67)	0.001*
Specific cognitive function:			
LM-Delayed Recall (score)	41.70 (5.45)	23.07 (8.94)	0.001*
DS (score)	16.07 (3.41)	13.63 (2.61)	0.001*
WF (word)	20.77 (3.89)	19.20 (4.55)	0.16
TMT (B-A) (sec)	76.33 (38.99)	105.27 (64.78)	0.04*
BD (score)	19.43 (6.93)	16.67 (7.28)	0.13

[a]Data are shown as mean (SD). FES, Fall Efficacy Scale; TUGT, Timed Up and Go Test; MMSE, Mini-Mental State Examination; MoCA, Montreal Cognitive Assessment; LM-Delayed Recall, Logical Memory-Delayed Recall; DS, Digit Span forward-backward; WF, Word Fluency; TMT (B-A), Trial Making Test subtracting part B from part A; BD, Block Design
*Independent samples t-test revealed significant difference at $p \leq 0.05$

Gait termination parameters

The Mann-Whitney U test revealed that the MCI group required more steps to stop compared to the control group ($p = 0.05$). Both groups mainly used a 2-step strategy to terminate gait (MCI group = 84.44 %, control group = 86.67 %). The MCI group used 1- and 3-step strategies at 6.67 and 8.89 %, respectively, while the control group used 1- and 3-step strategies at 11.11 and 2.22 %, respectively. There was no statistically significant difference between the 2 groups for total stopping time or stopping distance (**Table 2**).

Table 2 Gait termination parameters of participants in the control and MCI groups.

Variables[a]	Control group (n = 30)	MCI group (n = 30)	*p*-value
Total stopping time (sec)	1.17 (0.41)	1.24 (0.46)	0.24
Total stopping distance (cm)	66.90 (22.20)	67.57 (22.96)	0.84
Number of steps taken to stop	1.91 (0.36)	2.02 (0.40)	0.05*
Stopping strategies, number of trials [b] (%)			
• One-step	10 (11.11 %)	6 (6.67 %)	
• Two-step	78 (86.67 %)	76 (84.44 %)	
• Three-step	2 (2.22 %)	8 (8.89 %)	

[a]Data are shown as mean (SD).
[b]Percentage from ninety walking trials
*Mann-Whitney U test revealed significant difference at $p \leq 0.05$

Cognitive performance

With respect to cognitive performance, the MCI group demonstrated a significantly poorer performance on the Logical Memory-Delayed Recall ($p = 0.001$), Digit Span forward-backward ($p = 0.001$), and Trial Making Test (B-A) ($p = 0.04$) than the control group (**Table 1**). In the present study, the number of 3-step strategies was higher for the MCI group than the control group. Therefore, we further explored the cognitive performance of these participants by looking at their performance on each cognitive test. The results showed that the 4 participants with MCI who employed a 3-step strategy to terminate gait had relatively low scores on the Block Design test (Subject A, score = 3, Subject B, score = 8, Subject C and D, scores = 12) when related to the average score of the MCI group [Mean (SD) = 16.67 (7.28)].

Previous studies have usually examined the gait performance of cognitive impaired persons under steady state walking [6,31]. Consistent with previous research [7], older adults with MCI walked with significant slower gait speeds than cognitively intact controls. Compared with normal walking tasks, gait termination demands greater control of postural stability and complex integration of the neuromuscular system [27]. To the best of our knowledge, this is the first study that has determined the gait characteristics during gait termination of older adults with MCI. Findings revealed that participants in both groups mainly employed a 2-step strategy to terminate gait. Tirosh and Sparrow reported that older adults used significantly more 2-step stopping strategies compared to young adults [14]. They suggested that the second step response in older adults was employed to ensure mediolateral stability rather than to decelerate forward momentum for terminating gait. Therefore, the additional steps, evident in older people with and without MCI, may be a compensation strategy used to deal with inherent instability during gait termination.

In everyday situations, termination of gait, both rapidly and unexpectedly, may be associated with avoiding obstacles or boundaries, prior to which forward momentum must be arrested. Stopping is a great challenge to the body, as the nervous system must effectively change the body from steady state walking to quiet stance [28]. To safely terminate gait, the Center of Mass (COM) must be maintained within a base of support (BOS). However, if the COM exceeds the upper boundary regions, the body may not provide sufficient time to decelerate the COM, and an additional step would be required to maintain stability [29]. In the present study, despite slower gait speeds, participants in the MCI group employed 2 or more steps to stop than cognitively intact controls did. The increase in the numbers of steps taken to stop walking was, however, without an increase in the total stopping time and distance, indicating a shorter length for each step taken to stop in older adults with MCI. Substantial evidence indicates that older adults adopt a more conservative walking pattern, especially in a reduction in step length compared to young adults [30,31]. One explanation is that reduction in step length is a strategy to maintain stability,

as the COM being kept close to the moving BOS reduces the displacement of the COM relative to BOS [32].

In the present study, participants with MCI were generally high functioning and at relatively low risk of falling (as determined by their performances on TUGT and FES and their fall history, **Table 1**), suggesting a preserved control of balance. Therefore, an increase in the number of steps taken to stop accompanied by a simultaneous decrease in step length could reflect a cautious gait strategy in older adults with MCI, employed to ensure gait stability during termination of gait.

With respect to cognitive ability, the present study found that the MCI group demonstrated poorer performance in the LM-Delayed Recall (memory), DS (attention), and TMT (B-A) (executive function) tests than the control group. A previous study demonstrated that memory, attention, and executive functions are the cognitive components affected early in the course of the MCI syndrome [33]. There is evidence that decline in these 3 specific cognitive domains is associated with poor gait performance during dual-tasking (i.e., slower walking speed and shorter stride length) in older adults with MCI [34,35]. Our findings are consistent with, and help confirm, the previous findings, that walking is not an automatic motor task, but involves specific cognitive function. Compared to steady walking, successful unplanned gait termination requires more complex cognitive control, especially attention and executive function, for adapting and executing movements, as well as for responding to any time-constraints or unanticipated events. Given the cognitive processes involved in gait, we were interested to look closer into the cognitive performances of the 4 participants with MCI who required a 3-step strategy to stop. Besides poorer performances on the LM-Delayed Recall, DS, and TMT (B-A) tests, the 4 older adults with MCI had lower scores on the Block Design test compared to their group. Executive function covers a variety of skills that are involved in complex cognitive integration, such as solving novel problems, modifying behavior in response to incoming information, generating strategies, or sequencing complex actions [36]. The Block Design test is commonly used to assess aspects of executive function, including visual spatial organization, speed of mental and visual-motor processing, and planning ability [37]. A previous study demonstrated that slow gait speed during steady state walking was associated with poor scores on the Block Design test among cognitively normal older adults [38]. Together, our findings suggest that poor performance on Block Design test not only contributes to gait performance during steady state of walking, but also affects performance during gait termination.

We acknowledge our study has certain limitations. The main limitation concerns the external validity of laboratory study of gait termination. The requirement to stop may be different from the demands of real life situations. Therefore, gait termination undertaken in real world environments, where there may be less opportunity to pre-plan responses across a range of walking speeds, is needed. In addition, a study design that includes biomechanical variables such as Ground Reaction Force (GRF) and COM displacement would provide insight into the postural control of individuals with MCI during gait termination. Finally, a long-length gait mat walkway would allow a wider range of distances in which to randomly activate the stopping cue.

Conclusions

The present study demonstrated that, compared to those cognitively intact controls, older adults with MCI required more steps to come to a complete stop. These findings suggest that individuals with MCI adopt a more conservative gait pattern when they encounter an unplanned stopping condition. The present study also suggested that poor specific cognitive domains, mainly executive function, may affect gait termination performance in older adults with MCI.

Acknowledgements

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