Journal of Associated Medical Sciences 2021; 54 (1): 17-25

JAMS
Journal of Associated Medical Sciences

Thai-Journal Citation Index Centre (TCI) & ASEAN Citation Index (ACI)

Journal of Associated Medical Sciences

Journal homepage: https://www.tci-thaijo.org/index.php/bulletinAMS/index

Increased spatiotemporal variability during unplanned gait speed transition in older adults with mild cognitive impairment

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ARTICLE INFO

Article history:
Received 13 May 2020
Accepted as revised 22 September 2020
Available online 5 October 2020

Keywords:
Mild cognitive impairment, unplanned gait speed transition, gait variability, spatiotemporal parameters, motion analysis system.

ABSTRACT

Background: Walking in real-life situation requires an ability to rapidly change gait speed to achieve task goals or overcome environmental constraints. Gait speed transition may be compromised in older adults with Mild Cognitive Impairment (MCI) as it requires high demands on motor and cognitive integration to maintain gait stability. Gait variability is proposed to be a robust marker of cortical flexibility in regulating gait. Therefore, assessing gait variability during rapid increase in gait speed may hold promise in detecting deficits related to gait control among older adults with MCI.

Objectives: To investigate spatiotemporal parameters of gait variability during unexpected gait speed transition in older adults with and without MCI.

Materials and methods: Seventeen older adults with MCI (mean age=69.12±4.24 yrs.) and 17 cognitively intact controls (mean age=68.88±5.31 yrs.) participated in the study. The slow to fast speed transition was measured by asking participants to start walking at a slow pace and then instantaneously changing to fast pace in response to an unexpected auditory cue. Mean and coefficients of variation (CV) of step length, step width, step time and swing time were measured during slow to fast speed transition using 3-dimensional motion analysis. The Mann-Whitney U test was conducted to compare spatiotemporal gait parameters between the two groups. The statistical significance was set at $p<0.05$.

Results: Older adults with MCI demonstrated greater variability of step width (MCI group=38.81±9.44, Control group=31.45±7.67, $p=0.04$) and swing time (MCI group=16.02±5.11, Control group=12.14±3.52, $p=0.02$) than controls during fast speed transition. However, mean spatiotemporal parameters were similar between the two groups.

Conclusion: Older adults with MCI demonstrated increased step width and swing time variability during slow to fast gait speed transition. This finding suggests an impaired ability to regulate gait consistency which may predispose them to falls.

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doi: 10.14456/jams.2021.3
E-ISSN: 2539-6056

Introduction

The transitional cognitive state between expected cognitive decline of normal aging and early dementia has been designated as Mild Cognitive Impairment (MCI).[1] Several studies have found that older adults with MCI experience a decline in cognitive and gait functions that exceed the normal aging process.[2-4] Individuals with MCI demonstrate progressive deterioration both in cognitive and gait functions over time. As both impaired cognition and gait are recognized independent risk factors of falls,[5-7] it is essential to identify the cognitive and non-cognitive features among this population for providing an early detection and targeting specific interventions aiming to ameliorate risk of falling.

Walking in real-life situation requires the ability to rapidly increase gait speed to meet task goals and environmental demand such as crossing the street within a limited time allotted. Previous studies have demonstrated that pedestrians in several countries are often forced to walk at least 1.2 m/s when crossing a street, which is beyond the normal capabilities of many older adults.[8-10] In this situation, older adults reported that they experienced some walking difficulty when crossing the street that precludes them from full community engagement.[10,11] Several studies revealed that when walking at fast speed older people failed to achieve the same increases in speed and stride length compared to young adults, therefore it would be a barrier for them to engage in a physical environment.[12-14] There is evidence suggesting that when compared to usual walking, walking at a fast pace requires more neural control on gait regulation due to its needs a rapid postural response to control accelerations acting on the body and also involving several muscle groups activity, especially in older adults.[12,14,15] It has been demonstrated that walking requires cognitive resource, especially during complex walking tasks.[16-18] Therefore, people with MCI may have trouble regulating gait pattern when they encounter a challenging walking task. Given that increased gait speed places high demands on motor and cognitive integration to maintain stable periodic movement,[19,20] it could be anticipated that the ability to adapt gait speed in older adults with MCI would be compromised. However, to the best of our knowledge, no previous studies have investigated gait modulation in older adults with MCI during an unexpected increasing in gait speed. Previous studies have commonly investigated gait performance in individuals with MCI during steady-state of walking.[2,21,22] The evidence from a limit number of studies revealed that older adults with MCI showed significant decreases in gait performance during acceleration the body from a static to dynamic state as an initiation of walking compared to those non-MCI controls.[23]

There have been some studies that have investigated the changes of mean spatiotemporal parameters under a wide range of different walking speed among healthy adults. Consistent findings demonstrated that as walking speed increases, step length and swing time increase whereas step width and step time decrease in parallel.[24-28] To date, gait variability has been proposed to be a biomarker of cortical gait control efficiency among older adults with and without cognitive limitations.[18,29] Therefore, it may serve as a potential indicator in reflecting gait integrity under a gait speed transition. The present study aimed to examine the variability of spatiotemporal parameters during a rapid increase of walking speed in older adults with and without MCI. We hypothesized that variability of spatiotemporal parameters in individuals with MCI may be more pronounced than in the control group. This information would refine the understanding of gait speed modification in older adults with MCI during coping with unanticipated increasing in gait speed and may allow early intervention of a further functional decline.

Materials and methods

Participants

Thirty-four older adults (17 MCI and 17 cognitively intact controls) aged 60 years or older participated in the study. The diagnostic criteria for MCI including (i) subjective memory complaint from the patient and/or informant report, (ii) objective cognitive deficit in one or more cognitive domains, (iii) independence in functional activities, (iv) absence of clinical dementia (determined by The National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association [NINCDS-ADRDA] criteria[30]). Cognitively intact controls with similar age, gender, and body mass index (BMI) were recruited from the community settings. The inclusion criteria included being able to walk independently and safely without a walking device for at least 10 meters and being able to follow the assessment instructions. The exclusion criteria included having neurological condition, musculoskeletal disorder that affect balance and gait (e.g. Parkinson's disease, stroke, severe arthritis, hypertension, asthma), having depressive symptoms (determined by the score on the Thai Geriatric Depression Scale-15>6 points)[31] and having uncorrected visual and hearing impairment. The research protocol was approved by the Human Ethical Review Board of the principal investigator's institute (approved number: AMSEC-61EX-087). All participants provided written informed consent before participation.

Apparatus

Spatiotemporal gait parameters during gait speed transition were evaluated using the 3-dimensional (3D) Motion Analysis® system with 10 Eagle-4® infrared cameras (Motion Analysis Corporation, Santa Rosa, California, USA) and analysed using a custom written programs in MATLAB programs (The MathWorks, Inc., Natick, Massachusetts, USA). The sampling rate of the motion analysis system was set at 120 Hz. The raw coordinate data was filtered with Butterworth low-pass filter using a fourth order with a cut-off frequency at 6 Hz.

Procedures

All participants were interviewed about the co-morbidities, medical conditions, medication usage, and history of fall in the previous 12 months. Moreover, participants were examined for the risk of falling by using the Timed Up and Go test (TUGT). The time taken to complete TUGT more than 14.5 seconds is considered as a high risk of falling.[32]

With respect to the cognitive function, participants completed standard neuropsychological tests by trained assessors including Mental State Examination T10[33] and Montreal Cognitive Assessment (general cognitive function)[34], Verbal Paired Associates Test[35] and Rey Auditory Verbal Learning Test[36] (memory), Digit Span Test[37] and Trail Making Test A (attention)[38], Trail Making Test (B-A)[38] and Stroop Color and Word Test (executive function).[39]

The reflective markers (2.0 cm of diameter) were bilaterally placed on the lateral and medial sides of the knee and ankle based on anatomical landmark that included lateral-medial femoral epicondyle, head of fibula, medial-lateral tibial malleolus, 2nd metatarsal head and calcaneus.[40] In addition, one reflective marker was placed on the participant's second sacral vertebrae (S_2), which is the approximate centre of gravity (COG) of the whole body.[41]

Prior to data collection, participants were asked to walk at their self-determined pace along 10-meter walkway over 3 walking conditions which included usual, fast, and slow speed conditions, respectively. An average value over 2 trials per condition was calculated to use as a baseline data. Following the gait testing protocol, participants were instructed to start walking at their self-determined slow speed and had to increase their gait speed as fast as possible upon the presence of the auditory cue, and then continue walking to the stopping line (10-metre). The auditory cue ('Fast') was activated in a random time point during walking. Each participant performed 4 walking trials. To discourage any response anticipation, four gait speed transition trials were randomly included within the 16 slow pace trials (1 gait speed transition trial per 4 slow pace trials, in a total of 20 walking trials). The starting and stopping lines were marked on the floor at 2 meters from the capture volume zone to eliminate the effect of gait initiation (Figure 1).

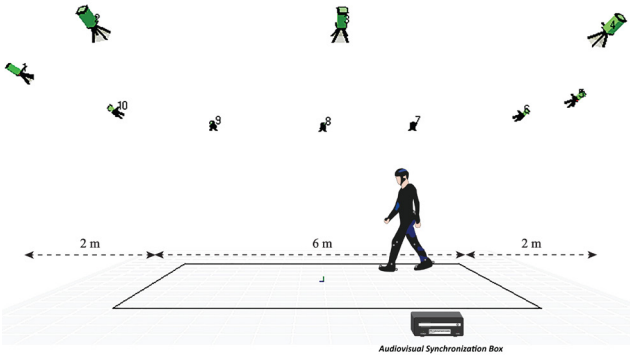

Figure 1. *Experimental setup of gait speed transition assessment.*

Gait measure definitions

The transitional gait speed phase was defined as a transient period between the presence of auditory cue using audiovisual synchronization box to reach a steady-state of fast walking speed. Spatiotemporal parameters were investigated during slow to fast speed transition including step length, step width, step time, and swing time. These spatial (i.e. step length, step width) and temporal (i.e. step time, swing time) parameters have generally been recognized as an indicator for reflecting different components of gait control including rhythmic and dynamic postural control.[42-44] Mean and variability of spatiotemporal gait parameters were calculated by averaging across the 4 slow to fast speed transition walking trials. Gait variability was quantified using coefficient of variation (CV) by the equation CV = (standard deviation/mean) x 100%. Step length (cm) was defined as the distance between the heel markers on the two feet at the time of a heel-strike event of the leading leg.[45] Step width (cm) was defined as a lateral distance between the centres of the two feet, where the centre of each foot was approximated as the midpoint between the toe and the heel markers.[45] Step time (sec) was determined as the time elapsed from the first contact of heel marker of the concurrent footstep to the first contact of heel marker of the next footstep on the opposite extremity.[40,46] Swing time (sec) was defined as the time elapsed from the last contact of toe marker of the concurrent footstep to the first contact of heel marker of the next footstep on the same extremity.[40,46]

Statistical analyses

All statistical analyses were conducted using SPSS software (version 21.0, IBM Corporation, Chicago, IL, USA). An independent sample t-tests was used to compare the demographic data between the two groups. All spatiotemporal parameters during gait speed transition were tested for normality using the Shapiro-Wilk test. The Mann-Whitney U test was used to compare spatiotemporal parameters during gait speed transition between the two groups. The statistical significance threshold was set at $p<0.05$.

Previous study suggested that a sufficient number of steps needed for acceptable valid and reliable measures of gait variability were at least 10-12 steps.[47] Therefore, in the present study, variability of spatiotemporal parameters during gait speed transition was calculated from at least 12 steps to ensure the stability of gait variability measures.

Results

Demographic characteristics of the participants are illustrated in Table 1. Participants in the MCI group had a significantly lower education attainment than those in the control group ($p=0.001$). There was no significant difference between the two groups for baseline gait speed including slow, usual, and fast-pace walking ($p>0.05$). With respect to the cognitive tests, the MCI group was worse performance on the MSET10 ($p=0.01$), MoCA ($p=0.001$), RAVLT ($p=0.01$), DST ($p=0.01$), and TMT B-A ($p=0.04$) than the control group.

Table 1 Demographic characteristic of the participants.

Variables•	Control group (n=17)	MCI group (n=17)	*p* value
Age (yrs)	68.88±5.31	69.12±4.24	0.89
Height (cm)	155.12±0.90	156.23±0.90	0.68
Weight (kg)	56.58±8.59	58.24±6.87	0.54
BMI (kg/m^2)	23.44 ± 2.66	23.90±2.46	0.60
Male: Female	2:15	2:15	
Educational level	13.70±2.87	8.76±4.59	0.001*
Falls in the past year (n)	0.47±0.72	0.53±0.80	0.17
Number of drugs taken daily (types)	0.94 ± 1.09	1.53±1.37	0.82
TUGT (sec)	7.10±0.92	7.88±1.35	0.06
Gait speed (m/s)			
Slow gait speed	0.96±0.13	0.97±0.22	0.94
Usual gait speed	1.10±0.14	1.09±0.18	0.85
Fast gait speed	1.44±0.24	1.39±0.21	0.47
TGDS-15 (score, total score =15)	1.35±1.41	1.59±1.58	0.65
MSET10 (score, total score=29)	27.47±1.33	25.65±2.09	0.01*
MoCA (score, total score=30)	25.53±1.94	20.23±1.89	0.001*
VPAT (words, total score=24 words)	17.18±4.10	14.41±3.86	0.05
RAVLT (words, total score=75 words)	52.47±7.15	43.88±10.52	0.01*
DST (score, total score=28)	15.76±3.90	12.47±2.62	0.01*
TMT A (sec)	50.38±24.26	59.18±17.98	0.24
TMT B-A (sec)	40.82±23.18	92.80±92.90	0.04*
SCWT (interference score)	-4.30±6.50	-4.60±6.43	0.89

Note: *•Data are shown as mean±SD, *Independent t-test, significant difference at p<0.05. MSET10: Mental State Examination T10, MoCA: Montreal Cognitive Assessment, TGDS-15: Thai Geriatric Depression Scale-15, VPAT: Verbal Paired Associates Test, RAVLT: Rey Auditory Verbal Learning Test, DST: Digit Span Test, TMT A: Trail Making Test Part A, TMT B-A: subtracting Part B from Part A, SCWT: Stroop Color and Word Test.*

Spatiotemporal gait parameters during gait speed transition

Mean, median, quartiles, and variability of spatiotemporal parameters during gait speed transition are shown in Table 2. The Mann-Whitney U Test showed no significant differences for all mean spatiotemporal measures between the two groups. However, there was a statistically significant difference between the two groups for variability of spatiotemporal parameters. Specifically, variability of the step width (p<0.04) and swing time (p<0.02) were significantly greater in the MCI group compared with the control group under slow to fast speed transition.

We further explored the number of steps, total distance and total time during gait speed transition. The results demonstrated that there was no statistically significant difference between the two groups for all gait parameters. With respect to gait speed before and after a transition phase, gait speed at slow pace prior to changing to fast pace (MCI group =0.85±0.18 m/s, Control group =0.80±0.12 m/s) and during reaching to fast pace (MCI group =1.69±0.31 m/s, Control group =1.66±0.26 m/s) was not different between the MCI and control groups (p<0.05).

Variability of spatiotemporal parameters during steady-state of walking

The variability of spatiotemporal parameters during steady-state of walking are presented in Table 3. The Mann-Whitney U Test showed no significant difference between the two groups for variability of spatiotemporal parameters across the 3 walk conditions including slow, usual, and fast-pace walking (p>0.05).

Table 2 Spatiotemporal parameters during gait speed transition of the MCI and control groups.

Parameters	Control group (n=17)			MCI group (n=17)			*p*-value
	Mean±SD	Median	Q25 - Q75	Mean±SD	Median	Q25 - Q75	
Mean spatiotemporal							
Step length (cm)	62.78±9.62	63.70	53.50-71.05	62.62±7.74	63.70	57.00-68.05	0.88
Step width (cm)	6.98±2.31	6.93	4.93-9.44	7.10±2.65	6.37	5.09-9.33	0.93
Step time (sec)	0.52±0.05	0.52	0.50-0.54	0.52±0.04	0.51	0.49-0.55	0.76
Swing time (sec)	0.46±0.03	0.46	0.44-0.48	0.46 ± 0.05	0.47	0.41-0.49	0.80
Coefficient of variation							
Step length variability (%)	9.97±3.08	9.31	7.44 -12.51	12.49±6.30	10.32	8.17-15.31	0.38
Step width variability (%)	31.45±7.67	30.62	24.42-37.29	38.81±9.44	39.34	32.35 -43.04	0.04*
Step time variability (%)	12.77±2.64	12.49	10.62-14.60	14.39±4.70	12.30	10.85-18.33	0.48
Swing time variability (%)	12.14±3.52	10.54	9.35-14.82	16.02±5.11	16.79	11.52-19.41	0.02*
Other parameters							
Number of steps	4.22±0.70	4.25	3.88-4.50	3.96±0.89	3.75	3.13-4.38	0.34
Total distance (cm)	261.43±45.98	274.40	231.45-289.80	246.86±60.57	230.70	204.60-268.40	0.44
Total time (sec)	2.17±0.42	2.08	1.91-2.38	2.03±0.49	1.98	1.66-2.19	0.39

***Note**: * Mann-Whitney U Test revealed significant difference at p<0.05.*

Table 3 Variability of spatiotemporal parameters during steady-state of walking of the MCI and control groups.

Parameters	Control group (n=17)			MCI group (n=17)			*p*-value
	Mean±SD	Median	Q25 - Q75	Mean±SD	Median	Q25 - Q75	
Slow gait speed							
Step length variability (%)	4.78±1.31	5.11	3.51-5.53	4.56±1.14	4.72	3.59-5.30	0.50
Step width variability (%)	26.81±8.61	27.13	17.23-34.05	32.07±8.81	33.85	24.33-38.91	0.10
Step time variability (%)	7.43±3.18	6.53	4.70-10.11	6.70±2.61	6.35	4.81-8.67	0.72
Swing time variability (%)	7.78±3.01	8.06	6.05-8.68	6.12±2.93	5.35	3.78-7.67	0.07
Usual gait speed							
Step length variability (%)	4.79±1.41	4.57	3.76-5.46	4.48±1.32	4.36	3.10-5.33	0.69
Step width variability (%)	27.23±6.99	26.74	21.90-32.96	33.19±9.40	30.98	25.11-41.84	0.08
Step time variability (%)	5.88±1.76	6.11	4.32-6.64	6.09±2.27	5.82	3.97-7.38	0.89
Swing time variability (%)	7.58±3.24	6.58	5.37-9.53	5.92±1.85	5.67	4.37-6.83	0.16
Fast gait speed							
Step length variability (%)	4.51±1.28	4.65	3.44-5.31	4.14±1.34	4.27	2.81-5.06	0.34
Step width variability (%)	24.40±5.78	25.65	18.92-28.89	23.25±4.29	22.54	19.98-27.18	0.70
Step time variability (%)	4.40±1.28	4.08	3.06-5.51	4.89±1.77	5.01	2.95 -6.35	0.66
Swing time variability (%)	6.31±2.06	6.39	4.49-8.33	5.25±2.60	4.83	3.02-6.97	0.15

***Note**: * Mann-Whitney U Test revealed significant difference at p<0.05.*

Discussion

The main goal of this study was to investigate gait parameters in older adults with MCI during a transition gait speed task when compared to those cognitively intact controls. Our findings showed that older adults with MCI increased their variability of the step width and swing time during slow to fast speed transition compared with controls. However, the effect of gait speed transition on means of spatiotemporal parameters was similar between the two groups. Our findings are in agreement with previous studies that have suggested that an increased challenge in stability was not captured by means but by the variability of parameters.[48,49] Therefore, gait changes in older adults with MCI can be revealed during coping with a challenging walking condition and by using gait variability as the assessment measure.

As expected, older adults with MCI performed worse on general (i.e. MSET10 and MoCA) and specific cognitive tests (i.e. RAVLT, DST, and TMT B-A) than those controls. Consistent findings have revealed that deficits in general and specific cognitive domains including memory, attention, and executive function can be detected early in the course of MCI.[50-53] With respect to educational level, the present study found that the MCI group had a lower

educational level than the control group. Previous study has reported that there was no significant difference in gait speed between the low and medium education elderly and high education elderly.[54] Our results are in agreement with a previous report that gait speed of participants in the MCI group whose lower education was similar to those of the control group. Therefore, the difference of educational status between the two groups would not influence our findings.

Previous studies have extensively investigated gait performance in older adults with MCI during steady-state of walking compared to non-cognitive impaired persons and the findings were still inconsistent.[2,21,22,55,56] Consistent with previous studies,[55,56] gait speed under steady-state when walked at slow, usual, and fast pace in older adults with MCI was similar to those of healthy older adults. There was an evidence that usual walking speeds for community-dwelling older adults who are healthy generally ranged from 0.90 to 1.30 m/s.[57-59] Moreover, variability of spatiotemporal parameters during steady-state of walking at self-selected slow, usual, and fast paces did not differ between the two groups (as shown in Table 3). Therefore, it would be suggested that older adults with MCI in the present study appeared to be healthy and low risk of falling (as determined by their gait speed and variability of gait under steady-state of walking, performance on TUGT, and their fall history, Table 1 and 3).

Walking in real life situation requires cognitive resources and postural control for maintaining optimal walking task. Therefore, an instantaneous and non-volitional change in walking speed would be considered because it can determine the individual's ability to maintain safe gait in response to environmental constraint. A previous study supported that the ability to adapt gait pattern reactively had been identified as a critical feature of community ambulation.[60] To the best of our knowledge, this paper is the first to study spatiotemporal gait variability during gait speed transition in older adults with and without MCI. The relevant studies demonstrated that assessing gait variability under challenging situations such as walking at different speeds may represent cortical flexibility in controlling gait.[61,62] Findings demonstrated that despite similar gait speed, participants in the MCI group had greater gait variability than those cognitively intact controls during gait speed transition. It is possible that compared to steady-state walking, transitional accelerate of gait speed, both rapidly and unexpectedly, may require more demand on neuromuscular and balance control for adapting gait pattern in response to time-constraints. As we found, the variability of swing time and step width was significantly increased in older adults with MCI. Frenkel-Toledo et al[63] suggested that variability of swing time was a robust marker of gait dysrhythmicity and instability that was independent of gait speed. In addition, step width variability was proposed to be a determinant of balance control ability and closely related to fall risk in relatively healthy older adults who did not walk slowly (gait speed ≥1.0 m/sec).[42,64] Moreover, previous studies reported that variability in centre of mass (COM) mediolateral that reflect dynamic balance stability appeared to increase with advancing age whereas other gait dynamic stability (i.e. anteroposterior and vertical) was similar across ages.[65,66] Therefore, an increased swing time and step width variability in older adults with MCI in our study may reflect a neural control problem on regulation of balance control when coping with challenging walking task as fast speed transition. Together, evidence from the present work suggests that gait impairment in older adults with MCI would be detected by using sensitive measure as variability of gait and challenging walking condition as unexpected fast speed transition task. The clinical implication that arises from this study is an assessment of spatiotemporal parameters of gait variability during gait speed transition may be used as a potential approach for unveiling walking-related cortical changes among older adults. If gait changes can be identified at early stage, an early intervention aims to prevent future fall may be achieved.

The present study has some limitations. Our sample size was small that might not be detecting to the changes of some gait parameters. Therefore, the larger sample sizes should be enhanced the power analysis and external validity in future study. Another limitation is concerning the use of a laboratory setting rather than real life situations. Given that the demanding of the walking task in everyday life is highly complex. Therefore, the assessment of gait speed transition in real world situations, where individuals require unplanned rapid changes in gait speed under a range of environmental stimuli or concurrent task, is needed. Further study should also investigate gait adaptation in older adults with MCI under various walking speeds such as fast to slow speed transition. Finally, a longer walk-way length would yield greater consistency among measures of gait variability and also allow a wider range of distance to randomly activate an auditory cue.

Conclusion

Older adults with MCI demonstrated a significant increase in the variability of swing time and step width as compared to cognitively intact controls. These findings suggest that older adults with MCI had an impaired ability to regulate their gait consistency during attempt to increase walking speeds rapidly which may predispose them to falls.

Conflict of interest

The authors report no conflicts of interests in this study.

Acknowledgement

Funds for this research were provided by the Thailand Research Fund (grant numbers MRG 6180220). The data was collected at the Motion Capture Laboratory, College of Arts, Media and Technology (CAMT), Chiang Mai University.

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