ORIGINAL RESEARCH

Guidelines for Gait Assessments in the Canadian Consortium on Neurodegeneration in Aging (CCNA)

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ABSTRACT

Background

Motor and cognitive impairments are common among older adults and often co-exist, increasing their risk of dementia, falls, and fractures. Gait performance is an accepted indicator of global health and it has been proposed as a valid motor marker to detect older adults at risk of developing mobility and cognitive declines including future falls and incident dementia. Our goal was to provide a gait assessment protocol to be used for clinical and research purposes.

Methods

Based on a consensus that identified common evaluations to assess motor–cognitive interactions in community-dwelling older individuals, a protocol on how to evaluate gait in older adults for the Canadian Consortium on Neurodegeneration in Aging (CCNA) was developed.

Results

The CCNA gait assessment includes preferred and fast pace gait, and dual-task gait that comprises walking while performing three cognitively demanding tasks: counting backwards by ones, counting backwards by sevens, and naming animals. This gait protocol can be implemented using an electronic-walkway, as well as by using a regular stopwatch. The latter approach provides a simple manner to evaluate quantitative gait performance in clinics.

Conclusions

Establishing a standardized gait assessment protocol will help to assess motor–cognitive interactions in aging and neurodegeneration, to compare results across studies, and to feasibly implement and translate gait testing in clinics for detecting impending cognitive and mobility decline.

Key words: consensus, gait, cognition, aging, neurodegenerative diseases

TABLE 1.
Canadian Gait and Cognition Network institutions and members

Canadian Gait and Cognition Network			
Province	*City*	*Institution*	*Member*
Ontario	London	Gait and Brain Lab, Schulich School of Medicine & Dentistry. University of Western Ontario	Manuel Montero-Odasso
		Schulich School of Medicine & Dentistry. University of Western Ontario	Robert Bartha
		Schulich School of Medicine & Dentistry. University of Western Ontario	Michael Borrie
		Regional Mental Health Care-London. University of Western Ontario	Amer Burhan
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		Pharmacy department. St Joseph's Health Care	Leanne Vanderhaeghe
		Department of Psychiatry. University of Western Ontario	Akshya Vasudev
	Ottawa	Faculty of Health Sciences, Interdisciplinary School of Health Sciences. University of Ottawa	Sarah Fraser
	Waterloo	The Sun Life Financial Movement Disorders Research and Rehabilitation Centre. Wilfrid Laurier University	Quincy Almeida
		Faculty of Applied Health Sciences, Department of Kinesiology. University of Waterloo	William McIlroy
		Faculty of Applied Health Sciences, Department of Kinesiology. University of Waterloo	Laura Middleton
Québec	Montréal	Department of Medicine, University of Montreal, Montreal Heart Institute and Institut universitaire de gériatrie de Montréal	Louis Bherer
		Division of Geriatric Medicine. McGill University / Université McGill	Olivier Beauchet
		McConnell Brain Imaging Center, Montreal Neurological Institute, McGill University.	Julien Doyon
		Department of Psychology. Concordia University	Karen Li
		Division of Geriatric Medicine. McGill University / Université McGill	José Morais
	Quebec City	Department of Rehabilitation. Université Laval	Bradford McFadyen
Alberta	Edmonton	Glenrose Rehabilitation Hospital. University of Alberta	Richard Camicioli
British Columbia	Vancouver	Aging, Mobility, and Cognitive Neuroscience Lab, Department of Physical Therapy. University of British Columbia	Teresa Liu-Ambrose
New Brunswick	Fredericton	Faculty of Kinesiology and Institute of Biomedical Engineering. University of New Brunswick	Chris A. McGibbon
Pennsylvania	Pittsburgh	Department of Biomedical Informatics. University of Pittsburgh	Ervin Sejdic

INTRODUCTION

As people age, they are more susceptible to mobility and cognitive impairments. These impairments often coexist early on the pathway to age-associated disability, leading to future mobility decline, falls, and dementia.[1] Epidemiological evidence on slow gait has demonstrated associations with early cognitive decline and future dementia, which draws attention to the coexistence of motor and cognitive impairments in older adults.[1-4]

The complex interplay between gait motor control and cognitive processes is thought to be related to common brain regions and networks shared.[1,5,6] The prevalence of motor and cognitive impairment in vulnerable populations, such as in those at risk of neurodegenerative diseases, increases with age[7-12] and increases the risk of future motor disability and falls.[1,13-17] Gait disorders are commonly present at an early stage of dementia syndromes.[18] Deficiencies in attention, executive function, and working memory co-exist with gait abnormalities in pre-dementia states like mild cognitive

impairment (MCI).[19,20] Mounting evidence shows that these motor changes start even before cognitive changes, and that a slowing of gait may precede the development of MCI by a decade.[21] Taken together, these studies suggest that there is a transition period whereby gait slowing occurs concurrently or even before cognitive loss.[16,22]

The Role of Cognition in Gait

Cognitive function plays a key role even in the regulation of routine walking, particularly in older adults.[23] Since the seminal "stops walking while talking" study[24] demonstrated that the inability to maintain a conversation while walking is a marker for future falls in older adults, observing people walking while they perform a secondary task ("dual-task paradigm") has become an accepted way to assess motor–cognitive interaction and risk of mobility decline and falling.[1,24, 23]

In the dual-task paradigm, participants' performance on each task alone (single-task walk, single-task cognitive) is compared to their performance during dual-task (walk and cognitive task performed simultaneously). Dual-task gait performance isolates the role of attention and executive function deficits in neural control of locomotion.[1,19,20,25] The underlying hypothesis is that two simultaneously performed tasks interfere and compete for brain cortical resources.[26,27] Therefore, dual-task gait testing can act as a "brain stress test" to detect mobility problems and risk of fall. Dual-task studies have also revealed that the cognitive demands while walking increase in the face of oligosymptomatic and covert neurologic disorders,[19,20,24,28] providing a rationale to use this "brain stress test" to detect individuals at higher risk of progression to dementia syndromes.[7]

METHODS

Integrating Gait Assessments in Aging and Cognitive Research

In 2008, our group proposed that motor and cognitive assessments should be part of the research and clinical evaluation for falls risk and mobility decline, and also for cognitive decline and dementia.[29] Since then, we have worked to advance the integration of both motor and cognitive assessments within aging research in Canada as a means to evaluate the motor–cognitive interface for the prediction of falls and cognitive decline. Our first successful attempt was in 2012 at a provincial level with the incorporation of a standardized gait and balance assessments in the cohort of the Ontario Neurodegenerative Research Initiative (ONDRI).[30] The ONDRI cohort finished recruitment in March 2017 and more than 500 older adults across the spectrum of five neurodegenerative diseases have been assessed for their gait and balance. In 2013, with the creation of the Canadian Consortium on Neurodegeneration in Aging (CCNA), we assembled the CCNA team:[12] Mobility, Exercise, and Cognition (MEC) team. We proposed a standardized and comprehensive gait assessment protocol to be used in the CCNA cohort, to investigate the interaction between mobility and cognition in neurodegenerative processes and aging across Canada. CCNA is currently recruiting a national cohort of 1,600 older adults with subjective cognitive impairments (SCI), mild cognitive impairment (MCI), vascular cognitive impairment (VCI), Alzheimer's disease (AD), and frontotemporal dementia (FTD), with the goal of having a comprehensive medical, cognitive, and imaging assessment.

Finally, in 2015 a consensus meeting that included CCNA members specializing in mobility in aging and an international advisory board of experts (list of attendees and program available at www.gaitandbrain.com/resources/) agreed on gait measurements that would test both mobility and cognition. The resultant gait protocol is presented herein below.

RESULTS

Measurements and Procedures for the Gait Assessments (Note: A CCNA gait assessment instructional video can be found at www.gaitandbrain.com/resources/.)

Environmental Conditions

Regarding the area dedicated to gait assessment, we recommend the use of a well-lit environment with intensity-controlled artificial light to adjust for changing daylight conditions. The assessment area should be also quiet and, preferably, a closed room with no auditory or visual interference.

People to be assessed should wear comfortable and non-restrictive clothes and wear their own footwear. Appropriate types of footwear include closed walking shoes (no slippers), with heel height not exceeding 3 cm. For follow-up gait analyses, it is highly recommended that participants use the same footwear as was worn at the baseline assessment. Depending on participants' fall risk, we recommend safety measures be used such as a safety-belt around the participant's waist for easy grabbing by an observer in case of an imminent fall. When using electronic walkways, it is recommended that the edges should be attached to the floor to avoid any slipping of the equipment.

Clinical Assessments

In the CCNA cohort, clinical assessments are conducted by a physician certified in geriatric medicine, neurology, psychiatry or family medicine. The clinical gait assessment includes the observation of walking to detect clinically evident gait disturbances that are being classified in the following categories: normal gait, ataxic gait, antalgic gait, cautious gait, frontal gait, hemiparetic gait, spastic gait, and shuffling gait, per CCNA cohort protocol.

Walking Testing Path

Distance over which to measure the test should be based on the characteristics of the population evaluated.[31] In older adults without mobility disability, a distance between 6 and 10 meters is needed to include at least three walking cycles to ensure that the steady-state gait velocity is measured.[16,31-34]

In the proposed protocol, participants will walk a total of 8 meters, of which the middle 6 meters is recorded and timed. Gait assessments will thus be performed along a 6-meter path or using a 6-meter electronic walkway. One meter before and after the 6-meter pathway will be added in order to avoid recording acceleration and deceleration phases, as described in Figure 1. A 6-meter distance was chosen based on previous cohort studies, due to the feasibility to implement in laboratory environments, and to capture at least 12 steps in steady-state walking.

Walking times can be recorded with a stopwatch, and assessors must begin timing as the participant's foot first crosses the start of the 6 meter path and terminate when their foot first crosses the end of the 6 meter path. When available, electronic walkways such as GAITRite® or the Zeno Walkway System® are placed in the described walking path to measure additional gait parameters during walking and dual-task walking.

Gait and Cognitive Task Assessment

The proposed gait assessment protocol is divided into three main walking conditions: 1) preferred or usual gait velocity, 2) dual-task gait at usual gait velocity, and 3) fast gait (Table 2).

For preferred gait velocity, participants will be instructed to walk at a comfortable and secure pace. A total of three walks are performed. If possible, we recommend that all gait trials consist of walking in the same direction. Participants with a slow gait velocity, less than 0.6m/s, or participants with lower limb disability, will be allowed to complete one walk if they are not able to perform the three trials. A minimum of approximately 12 steps is required to allow measurement of step-to-step variability during the preferred gait velocity.[35] For example, an individual who walks at 1.5 m/s would usually only have 4-5 steps per walk; therefore, we would need at least three trials of walking at preferred gait velocity. For those walking less than 1.0 m/s, two trials is commonly necessary and for those walking less than 0.5 m/s, a single walk is sufficient.

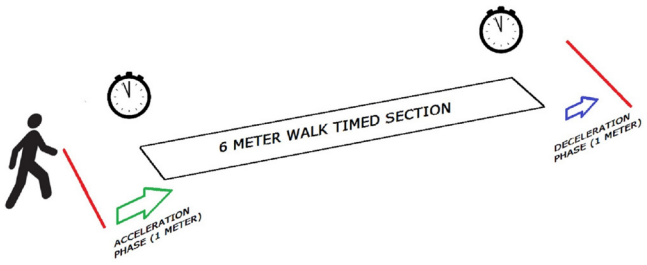

FIGURE 1. View of the 6-meter path for gait assessments in the Canadian Consortium on Neurodegeneration in Aging; the start and end marks are outlined in red, indicating where participants should start and stop their walking to avoid recording acceleration and deceleration events

The second walking condition consists of a dual-task gait and includes three walks, each with a designated cognitively demanding task, completed at their preferred gait velocity. Commonly used and validated cognitive tasks include counting backwards by 1's from 100 out loud, counting backwards by 7's, and a verbal fluency task such as enumerating as many animal names as possible.[20,36-38] Each of these walks will be performed once.

As part of the "Gait Pre-Assessment", the performance in the arithmetical and verbal fluency cognitive tasks used while walking will be evaluated individually 1 hour prior to any walks for a total of 10 s each while participants are in a seated position. This will provide single-task cognitive data for comparison to the verbal output during the dual-task gait testing. The number and accuracy of the responses will be recorded. Cognitive performance will be reported as number of responses per second, calculated as (number of responses)/10. Accuracy of responses will be accounted for through the use of a corrected response rate (CRR). The CRR will be calculated as: response rate per second × percent correct.[39]

The first dual-task test administered will consist of the participant walking while simultaneously counting backward by 1's from 100 (100-99-98…) out loud. The second dual-task test will require the participant to repeat the walk, but this time while naming animals out loud (category fluency test). In the third dual-task, the participant will be asked to walk while subtracting 7's from 100 (100-93-86…) out loud. For subsequent assessments, it is recommended to start with a different three-digit number randomly chosen between 100 and 150. During all dual-task trials, participants are encouraged to keep walking even if the cognitive task is difficult for them (i.e., if they cannot do the subtractions or name animals). The assessor must record how many numbers were subtracted, any counting errors, or if the participant did not complete any subtractions, as well as record the number of animals listed and any animals that were repeated. These different dual-task conditions were selected based on previous research which demonstrated that subtractions depend more on working memory and attention, while naming animals out loud is more related to verbal fluency, which relies on semantic memory.[40,41]

The last walking condition is the fast gait, which is a single-task walk at a pace that is faster than the participant's preferred gait velocity. Participants will be instructed to walk as fast as they can, as safely as they can, but without running.

Standardized Walking Instructions

We recommend the use of standardized walking instructions to explain the various tasks to participants. Details on instructions used in the CCNA cohort can be found in Table 3.

TABLE 2.
Summary of gait assessments and gait variable outcomes collected in each task and used in the CCNA study

Gait Task	*Description*	*Gait Variables Used as Outcomes*	*Limitations of Task*
Preferred or usual gait	Participant walks at their normal speed along the path	Gait velocity Gait variability "Slow gait" categorization (<1.0m/s)	For variability calculations a minimum of 12 steps are required
Arithmetic dual-task	Participant walks while counting backwards by 1's and then while counting backwards by 7's out loud, starting from 100 or 150	Gait velocity Gait variability Number of subtractions performed Number of mistakes Dual-Task Cost	Arithmetic cognitive challenges are dependent on participant's education level
Category fluency dual-task	Participant walks while naming animals out loud	Gait velocity Gait variability Number of animals named Number of repetitions Dual-Task Cost	Verbal cognitive challenge are dependent on verbal and semantic skills
Fast gait	Participant walks as fast as they can, safely and without running	Maximum capacity of gait velocity	Participants may not feel comfortable walking at maximum speed; may not capture true capacity of each participant

TABLE 3.
Detailed instructions for gait assessment in CCNA cohort

Walking Task	*Instructions*
Preferred or usual gait	"When I say GO, please walk at your usual pace in a comfortable and safe way until you cross this line [INDICATE END LINE]."
Counting backwards	"When I say GO, please walk at your usual pace and at the same time count backwards from 100 by 1s, out loud, until you cross this line [INDICATE END LINE]. Remember that it is important that you do not stop your walking or counting." If participant have difficulties understanding, evaluators are allowed to clarify by providing a verbal example: "For example 100, 99, 98, ... and so on". Evaluators are allowed to prompt the tasks if participants tend to stop during the walk. If walk needs to be repeated, ask participant to start from 200 or 300.
Naming animals	"When I say GO, please walk at your usual pace and at the same time try to name as many different animals as you can think of, out loud, until you cross this line [INDICATE END LINE]. Please do this out loud. Remember that it is important that you do not stop your walking or talking."
Serial sevens	"When I say GO, please walk at your usual pace and at the same time count backwards from 100 by 7s, out loud, until you cross this line [INDICATE END LINE]. Remember that it is important that you do not stop your walking even if you can't think of the numbers." Evaluators are allowed to prompt the tasks if participants tend to stop during the walk. If walk needs to be repeated, ask participant to start from 200 or 300.
Fast gait	"When I say GO, please walk as fast as you can, as safe as you can, and without running, until you cross this line [INDICATE END LINE]."

Assistive Devices

Individuals to be tested should wear their own glasses and hearing aids. Assistive walking devices are allowed, if needed. We recommend first asking the participant if they are comfortable performing one trial without the assistive walking device, to assess if the participant is able to walk without assistance. If they are able to do this, then all trials should be done without the device and an additional member of the research team should shadow the participant as they walk down the electronic walkway in case the participant loses balance. If the person is uncomfortable without the device or if they cannot safely ambulate without it, the device should be used for all trials. If devices are used

during gait testing, the type of device (e.g., cane, walker) should be recorded and it should be noted that the device was used for all trials. (Gait Cost of Using a Mobility Aid in Older Adults with Alzheimer's Disease. Muir-Hunter SW, Montero-Odasso M. J Am Geriatr Soc. 2016 Feb;64(2):437-8. doi: 10.1111/jgs.13973.)

The attentional demands of ambulating with an assistive device in older adults with Alzheimer's disease. Muir-Hunter SW, Montero-Odasso M. Gait Posture. 2017 May;54:202-208. doi: 10.1016/j.gaitpost.2017.03.011. Epub 2017 Mar 10

Prioritization

Instructions for prioritization of tasks while dual-task testing will depend on the main research question or if gait is evaluated in a clinical encounter. For the purposes of the CCNA cohorts, participants will be instructed to pay equal attention to both gait and the cognitive task; if a participant stops either task during the trial, they will be prompted to resume. Providing no instruction to prioritize gait over cognitive task or vice-versa allows both gait and cognitive task to vary and has previously been shown to provide a better representation of what happens naturally.[42, 27] On the other hand, if the effect of cognitive load on gait is the main question, the participants should be instructed to prioritize the cognitive task over walking, in order to see the outcome that this has on their gait.[42] In clinics, allowing both gait and cognitive tasks to vary, without giving clear prioritization instructions, provides a better representation of mobility performance while doing daily living activities.

Rationale for the Minimum Set of Variables to be Analyzed in the CCNA Cohort

Gait Velocity

Gait velocity provides important information on the risk of future adverse events, as a slowing in gait velocity has been associated with future falls, hospitalizations, disability, cognitive impairment, progression to dementia, and mortality.[33,43-45] It can be measured, as described above, in the preferred gait velocity condition, dual-task condition and fast gait condition. Fast gait velocity has been proposed to be an indicator of gait velocity reserve and predict disability, and thus we have incorporated this modality in our protocols.[46] Finally, we also analyze dual-task velocities as overall measures of the motor-cognitive interaction.

Spatiotemporal Quantitative Gait Variables

When electronic walkways are available, we recommend measuring six gait variables that have previously been shown to be sensitive to cognitive changes and associated with future cognitive and mobility decline.[5,47,48] Besides gait velocity as described above, these variables are cadence (steps/min), stride time (milliseconds), stride length (cm), step width (cm), and double support time (milliseconds) (Table 4).

Gait Variability

A sensitive measure of dynamic stability during walking is gait variability, defined as the stride-to-stride variation in time or distance of the quantitative variables listed above.[49] This measure quantifies the temporal automaticity of gait, with greater variability indicating reduced consistency and a more unstable gait pattern. Evaluating gait variability is an accurate methodology to identify subtle changes in walking due to pathological conditions or disease. For instance, cognitively normal older adults have low gait variability; however, high gait variability has been described in Parkinson's disease and Alzheimer's disease, and has been associated with high risk of future falls and mobility decline.[47,48,50-52] Gait variability may serve as a clinically relevant parameter in the evaluation of mobility and as a responsive measure for different interventions in fall prevention.[53]

Dual-Task Gait Cost

The dual-task gait cost (DTGC) provides a measure of the mobility "cost" that an individual incurs when walking and performing a simultaneous cognitive task, compared to only walking. This DTGC can be assessed using the following formula: DTGC = [(usual gait - dual-task gait) / usual gait] × 100. DTGC can be calculated using usual and dual-task values from any of the six quantitative variables listed above, as well as for variability. Dual-task gait cost has been demonstrated to correlate with the measures of cognitive ability (i.e., low cognitive performance is associated with high DTGC), and helps to detect older adult at risk of future mobility and cognitive decline, including progression to dementia.[7,36,54-56]

Dual-Task Cognitive Cost

The dual-task cognitive cost (DTCC) provides a measure of the effect of the walking task over cognitive performance. Commonly, older adults prioritize gait (motor performance) over cognitive performance to maintain the posture first strategy.[57] As such, DTCC may be larger than DTGC, but would be missing information without the calculation of costs in both domains. The formula to calculate the DTCC is: DTCC = [(Single-task cognition - dual-task cognition) / Single-task cognition] × 100, if the dependent measure is accuracy or number of items completed. However, if reaction times are measured, the subtraction would be reversed (Dual-task cognition - Single-task cognition) to indicate the slow-down relative to the denominator, Single-task cognition.

DISCUSSION

This is the first pan-Canadian protocol guideline to standardize gait assessments as a means to assess the motor–cognitive interaction. A common protocol for gait assessment will provide a wealth of data that can be compared across many research sites in Canada, helping to increase the applicability of gait testing in both research and clinical settings. The gait assessment protocol described here is used in the ONDRI

TABLE 4.
Definitions of quantitative spatiotemporal gait variables analysed in CCNA cohort

Variable	*Units*	*Definition*
Velocity	meters/second	Distance covered by the time to ambulate
Cadence	steps/minute	Number of steps by the time to ambulate
Stride length	meters	Distance between heel points of two consecutive footfalls of the same foot
Step length	meters	Anterioposterior distance between the heel points of two consecutive footfalls of the opposite foot
Step width	meters	Mediolateral distance between the heel points of two consecutive footfalls of the opposite foot
Stride time	seconds	Duration to ambulate one stride length
Step time	seconds	Duration to ambulate one step length
Double support time	seconds	Duration of when both limbs are in contact with the ground

cohort, the CCNA cohort, and in the Gait and Brain Study, thus potentially reaching more than 2,500 older research participants across Canada in these three different longitudinal studies.[7,30] The prospective assessment of quantitative gait performance under preferred and fast velocity, and dual-task conditions in the targeted neurodegenerative diseases included in the CCNA cohort will expand our understanding about the relationships between gait and cognition which, in turn, will help to identify modifiable factors or mechanisms to prevent falls in older adults with and without neurodegenerative conditions, and to detect older individuals at higher risk of cognitive decline and dementia incidence.

More importantly, our protocol can be applied using a simple stopwatch and having a known distance, like a corridor, which facilitates its clinical applicability in non-research settings. Given the growing recognition of the importance of gait as a mobility marker of overall health and function in aging and disease, establishing a common gait assessment protocol will assist in the development of standardized mobility assessments, and allow for comparisons across disease states. While gait may well serve as the sixth vital sign[33,34,58,59] and a motor biomarker for neurodegenerative diseases,[60] a standard approach used to assess gait and the cognitive-motor interface (e.g., dual-tasking) in research and clinical settings is critically important to advance its use in routine clinical care.

The protocol is also compatible with other portable measurement systems besides instrumented walkways. For example, accelerometer-based wearable sensors can be utilized to quantify common clinical parameters of gait, including gait speed and step-to-step variability.[61] Although relatively new in the clinical setting, these inexpensive and highly portable technologies have been proven reliable and valid in a controlled setting, and are showing great promise for separating the effects of mobility and cognitive impairments on gait function.[62]

Finally, the guidelines presented here are intended to facilitate collaborations across groups and networks in research in aging and to also provide guidance to clinicians who wish to implement quantitative and spatiotemporal gait analysis in clinical settings.

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CONFLICT OF INTEREST DISCLOSURES

The authors declare that no conflicts of interest exist.

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