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Review article

Cognition and gait in older people

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ABSTRACT

Cognitive difficulties and gait abnormalities both increase with age. We review normal and pathologic changes in both gait and cognition in older adults. Gait performance in older individuals is linked to specific cognitive changes, in particular in executive function. Structural and functional assays highlight the shared anatomic control of cognitive and gait function, mostly in the prefrontal cortices. Cognitive impairment can be used to predict incident gait difficulties. Changes in gait, especially decreased gait velocity, may be a harbinger of impending cognitive decline. The combination of slow gait and cognitive complaints (the Motoric Cognitive Risk syndrome) is a powerful new clinical tool to identify those at high risk of developing dementia and therefore may be used to target interventions. Evidence is limited, but cognitive training and targeted physical activity may be useful to mitigate or prevent gait and cognitive decline with age.

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1. Introduction

The world's population is aging, and the incidence of age-related impairments in gait and cognition are expected to increase dramatically. Understanding these impairments in gait and cognitive domains, and the relationships between them, may have broad public health implications and may also elucidate underlying neural mechanisms, which may lead to novel therapies.

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Table 1
Gait abnormalities and risk of negative health outcomes.

Population	Gait Abnormality	Outcome	RR or HR (95% CI)
Community-based sample, age ≥ 70 [3]	Abnormal gait, mild	Institutionalization or mortality	HR 1.76 (1.01–2.84) ^a
Community-based sample, age ≥ 70 [3]	Abnormal gait, moderate to severe	Institutionalization or mortality	HR 3.18 (1.94–5.21) ^a
Community-based sample, age ≥ 65 [4]	Slow gait	Hospitalization	RR 1.48 (1.02–2.13) ^b
Community-based sample, age ≥ 65 [4]	Slow gait	Mortality	RR 1.64 (1.14–2.37) ^b
Convenience sample, age ≥ 65 [5]	Worsening gait	Mortality	RR 1.19 (1.07–1.34) ^c

Notes: Abnormal gait defined by clinical inspection. Those with mild gait abnormalities were able to walk without assistance, whereas those with moderate or severe abnormalities needed assistance to walk or stand. Slow gait defined as <1 m/s. Worsening gait defined as an increased score on the gait/postural reflex subscale of the modified Uniform Parkinson's Disease Rating Scale (UPDRS).

^a Adjusted for age and sex.

^b Adjusted for health and demographic factors.

^c Adjusted for age, sex, and education. RR per one-point increase in UPDRS subscale.

A 2013 UN report [1] found that almost all countries around the world have increasing aging populations due to a combination of decreasing mortality and fertility. The percent of the world's population over 60 increased from 1990 to 2013 (9.2%–11.7%), and is expected to almost double by 2050 (21.1%) [1]. Aging is the primary risk factor for cognitive decline. An estimated 46.8 million people worldwide were living with dementia in 2015, and this number is expected to almost double every 20 years [2].

Abnormalities of gait are also common, and increase with aging. Gait may be assessed by self-report, visual inspection, or quantitative computer analysis; there is no gold standard. Depending on the criteria used to define gait abnormalities and population studied, the estimated prevalence can vary widely. In one community-dwelling sample of non-bedbound older adults, 35% had prevalent abnormal gaits diagnosed by clinicians [3]. Gait disorders are associated with a diverse array of negative health outcomes, including hospitalization [4], institutionalization [3], and death [3–5] (see Table 1). Whether this increased risk is due to shared causative mechanisms between gait and health changes or gait changes are a direct result of cardiovascular and other health risk factors, gait is a useful marker of systemic disease burden and can inform prognosis.

In this paper, we present a review of the literature regarding the associations between gait and cognition in aging. We discuss shared anatomic and functional substrates, and their shared decline in pathological and non-pathological aging. The use of gait as a biomarker of cognitive decline is discussed. Finally, interventions targeting both gait and cognitive decline in aging are reviewed.

2. Methods

We performed an expert review of the literature by searching PubMed for English-language papers in humans published within the last five years with the following search term:

((“Gait”[Mesh] OR “Gait Apraxia”[Mesh] OR “Gait Ataxia”[Mesh] OR “Gait Disorders, Neurologic”[Mesh]) AND (“Cognition”[Mesh] OR “Cognition Disorders”[Mesh] OR “Dementia”[Mesh] OR “Dementia, Multi-Infarct”[Mesh] OR “Dementia, Vascular”[Mesh] OR “Alzheimer Disease”[Mesh] OR “Mild Cognitive Impairment”[Mesh]))

Articles were reviewed, and bibliographies were used to identify other potentially relevant sources.

3. Results

3.1. Gait in older adults

Changes in gait may be due to neurologic and non-neurologic causes, and may be part of the normal aging process or can be due to underlying pathologies. Muscle mass and strength both decrease with age (i.e., sarcopenia and dynapenia) [6]. Mild declines in pro-

prioception (joint position sense) without overt neuropathy are present in older adults [7]. Arthritis and joint deformities become more common [8]. As a result of these and other biomechanical changes in aging, stride shortens, stance widens [8], and velocity decreases, even in robust, healthy older samples (e.g. [9]).

Pathologic changes at almost any point in the neuroaxis can cause gait dysfunction, and almost all have increased frequency with age. Clinical patterns of neurologic gait dysfunction include neuropathic (characterized by a foot drop), hemiparetic (unilateral increased muscle tone with weakness), spastic (bilateral increased tone with weakness), Parkinsonian (slow, flexed posture, short steps, difficulty with gait initiation), and frontal gaits (slow, wide-based, short steps) [8]. Methods of gait assessment, gait parameters measured, and populations studied vary; however, many findings related to gait changes in older adults are consistent in the literature.

3.2. Cognition in older adults

Cognition is a construct that represents a spectrum of higher order cerebral function, from normal to subjective complaints without evidence of decline, to evidence of decline without change in function (mild cognitive impairment syndrome [MCI]), to dementia. Dementia represents the stage where daily activities are impeded due to decline in cognitive function. People with MCI are able to employ compensatory mechanisms to maintain basic functions but are at high risk to develop dementia. Depending on the population studied, between 5 and 20% of individuals with MCI progress to dementia annually [10,11]. Older age is a significant risk factor for progression from MCI to dementia [10], in addition to risk factors such as lower education, diabetes and other vascular risk factors, depression, and genetic polymorphisms [12].

Not all changes in cognition with age are considered pathologic, and not all cognitive domains change with “healthy” aging. Vigilance, semantic memory, and procedural knowledge do not decline in the absence of pathology [13]. In contrast, processing speed, divided attention, working memory, and episodic memory all decline regardless of neurodegeneration [13]. Therefore, to the extent that gait performance relies on various cognitive domains, even non-pathologic changes to the nervous system cause gait dysfunction with age.

3.3. Cognition and gait in older adults

3.3.1. Shared cognitive domains

Close associations have been found between cognitive performance and gait in older adults. While walking is largely an automatic task, cognitive faculties orchestrate control over axial musculature and balance/posture with bilateral upper and lower extremity movements and integration of visual, vestibular, proprioceptive, and other sensory feedback. Executive function (EF)

is the domain most commonly associated with gait dysfunction. EF is an umbrella term for the management of cognitive processes, including working memory, reasoning, task flexibility, and problem solving, which is central to planning, goal-directed action, coordination of complex locomotion, and other daily activities. EF and processing speed are associated with gait speed, step time, step length, absolute and relative amounts of time spent in double support phase, and other gait parameters [14]. Decline in EF over time is associated with decline in gait speed (in both those with and without baseline cognitive impairment) [15], and improvement in EF is associated with improved gait speed [16]. This latter point is crucial due to its implications in primary and secondary prevention.

When walking becomes a less automatic process, such as walking over uneven terrain, walking while performing a concurrent task, or walking in the presence of various pathologies, allocation of additional cognitive resources becomes necessary. For instance, the dual-task costs, that is, the relative decline in motor and cognitive performance while performing a second task while walking, are lower while walking at a slightly slow pace compared to normal or very slow walking [17]. The type of dual task can tax various cognitive resources to varying degrees, though EF is one of the key determinants of dual-task ability (e.g., [18]). Dual-task performance can predict various health outcomes, including incident frailty, disability, and mortality in older adults [19].

3.3.2. Shared anatomy

Anatomically, similar brain regions mediate gait and cognition, in particular EF. A greater burden of subcortical white matter (WM) hyperintensities on MRI is related to increased dual-task costs while walking, and this effect is greater among those with dementia (i.e., those with decreased cognitive resources) compared to those without dementia [20]. In another study, overall WM burden and WM changes in specific frontal pathways were associated with slow gait, and this was attenuated by controlling for EF and global cognition [21]. While these changes are most pronounced in older adults, even middle-aged adults accumulate WM changes and silent infarcts that are associated with worse EF and gait [22]. Gait and specific cognitive domains are also mediated by shared cortical regions. Cerebellar gray matter volume is associated with both gait performance and EF, and when EF is controlled for, there is no longer an association with gait [23]. Smaller cortical gray matter volumes and smaller hippocampal volumes are associated with slower gait velocity, and these associations are also attenuated by controlling for cognitive performance [24].

Shared anatomic control of gait and cognition can also be explored in real time. While not yet used clinically, certain laboratory-based techniques have provided significant insights into complex tasks such as walking. Functional near-infrared spectroscopy (fNIRS) uses light to measure concentrations of oxy-hemoglobin, and thus brain activation, in cortical and subcortical regions. It has high temporal resolution and can be measured online in freely mobile individuals, thus allowing more ecologically valid assessments of gait and cognition. Using fNIRS, it has been shown that activation of the prefrontal cortex (PFC) mediates both normal walking and walking under dual-task conditions [25]. There is increased PFC activation with dual-task compared to normal walking, and increased activation in younger participants, who had improved dual-task performance [26]. Transcranial direct current stimulation (tDCS) can non-invasively modulate cortical activity. Depending on the polarity used, it can temporarily increase or decrease excitability in a small region of cortex. Augmentation of function at the PFC by tDCS can improve dual-task cognitive and gait performance [27], and reduce dual-task costs [28]. Reduced function at the PFC by tDCS worsens both cognitive and gait performance under dual-task locomotion [27]. Finally, imagining oneself walking or walking while performing a dual task seems to involve

Table 2
 Motoric Cognitive Risk syndrome and risk of negative health outcomes.

Population	Outcome	HR (95% CI)
Community-based sample, age ≥ 70 [39]	Dementia	3.27 (1.55–6.90)
Community-based sample, age ≥ 70 [39]	Vascular dementia	12.81 (4.98–32.97)
Pooled international cohort [40]	Dementia	1.93 (1.59–2.35)
Community-based sample, age ≥ 60 [40]	Alzheimer's disease	2.21 (1.49–3.28)
Convenience sample, age ≥ 65 [40]	Alzheimer's disease	1.97 (1.41–2.74)
Pooled international cohort [42]	Mortality	1.69 (1.46–1.96)

Notes: Motoric Cognitive Risk syndrome defined as presence of cognitive complaint and gait velocity ≥ 1 standard deviation below age- and sex-matched peers. All analyses adjusted for age, sex, and education.

similar brain areas and share other characteristics as actual walking, and can be done under circumstances where actual walking is impossible, such as in an MRI scanner [29]. Functional MRI imaging revealed increased activity in the PFC and several other brain regions during dual-task walking in a study of older adults [29]. These techniques may help circumvent limitations of standard imaging technology to provide new insights into gait and cognition.

3.3.3. Shared pathology

Both cognition and gait are affected by neurodegenerative disease. Those with MCI and Alzheimer's Disease walk more slowly and have more variability in their gait (a marker of poor gait control) under single and various dual-task conditions [30,31] than those without cognitive impairment. People with cognitive impairment display higher dual-task costs while walking [32]. Cognitive and gait decline in aging may have common genetic underpinnings. The presence of the e4 allele of the apolipoprotein E (APOE) gene, the best known genetic risk factor for cognitive decline, was reported to be also associated with faster decline in gait speed, though this effect was only seen in men [33].

Changes in gait can also be used to predict incident cognitive pathology, and indeed may be a useful early biomarker of dementia. Slow gait is associated with the presence and incidence (over many years of follow-up) of cognitive decline and dementia in diverse patient populations around the world (e.g. [34,35]). Neurologic gait abnormalities [36], especially "high risk" neurologic gait abnormalities such as hemiparetic, frontal, and unsteady gaits [37], predict incident dementia, in particular vascular or non-Alzheimer's dementia. The predictive power of gait abnormalities for dementia, especially vascular dementia, was confirmed in a meta-analysis of 12 cohort studies [38].

3.3.4. Motoric cognitive risk syndrome

Capitalizing on the predictive power of gait abnormalities for incident cognitive decline, a pre-dementia state called the Motoric Cognitive Risk (MCR) syndrome has been proposed. MCR is defined as the presence of cognitive complaints and slow gait (one standard deviation below age- and sex-matched peers) in older adults without disability or dementia [39]. As opposed to a diagnosis of MCI, diagnosis of MCR does not rely on formal neuropsychological assessment, thus requires fewer resources and is independent of language and level of education. Pooled prevalence of MCR across 17 countries and more than 26,000 older participants was 9.7%, and the prevalence increases with advancing age [40]. Incidence of MCR ranged from 51 to 80 per 1000 person-years in older adults. It was associated with age and several potentially modifiable risk factors, including stroke, depressive symptoms, sedentariness, and obesity [41]. Presence of MCR predicts incident dementia (all-cause)

[39,40], Alzheimer's disease [40], vascular dementia [39], and mortality, even after accounting for several recognized mortality risk factors [42] (see Table 2). These effects are significant beyond what is predicted based on slow gait or cognitive complaints alone, and hold even if those individuals who meet criteria for both MCR and MCI syndromes are excluded [40]. MCR may therefore be a useful clinical tool to target interventions to those at highest risk of cognitive decline.

3.4. Targeting physical activity to improve cognition

Using physical activity to prevent or slow cognitive decline is alluring as it may have direct benefits through shared pathways (above) and indirect benefits through reduction of shared cardiovascular risk factors. Evidence of positive effects on reducing dementia risk, however, is limited. In longitudinal observational studies, for example, increased rates of physical leisure activity participation did not decrease the risk of incident dementia in older adults [43], whereas cognitively-stimulating leisure activities did. Several individual studies on aerobic exercise and effects on executive function in older adults looked favorable (see [44], for a review). In meta-analyses, however, exercise does not appear to improve cognitive function in either cognitively normal [45] or demented [46] older adults, though larger trials are needed as the quality of the evidence was low. Multi-modal interventions, for instance combining physical activity with cognitive stimulation or training, may hold greater promise for improving cognition than exercise alone.

3.5. Targeting cognition to improve gait

Adherence to exercise regimens is limited, and regular exercise may be particularly difficult for older adults with frailty, pain, or other conditions that impair mobility. Cognitive training has been studied as a tool to improve gait in older adults. Most studies to date had very small sample sizes and described themselves as pilot projects, but results are promising: cognitive training programs have been shown to improve balance [47], gait velocity [48] (but see [49,50]), dual-task costs [49], and a composite gait task (timed up and go) [50]. Per ClinicalTrials.gov (<https://clinicaltrials.gov/>), a number of such trials are in progress using a range of interventions with anticipated larger sample sizes, including healthy older adults, those with MCI, Parkinson's Disease, stroke, and other conditions (accessed: Mar 7, 2016). Such trials will hopefully inform wide-scale clinical interventions in the coming years.

4. Conclusions

In an aging society, prevalence of impaired gait and impaired cognition are both expected to increase dramatically. Impairments in the two are linked, and understanding these connections may allow new insights into the disease processes. Screening tools using gait and cognition can identify those at high risk of decline, and interventions capitalizing on shared anatomical substrates hold promise for future treatments, though additional research is needed.

Author contribution

JAC participated in the design, writing, and editing of the manuscript, and saw and approved the final version.

JV participated in the conception, design, and editing of the manuscript, and saw and approved the final version.

JLZ participated in the conception, writing, and editing of the manuscript, and saw and approved the final version.

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