ELSEVIER
Alzheimer's & Dementia 10 (2014) 328–335
Alzheimer's & Dementia

Cognition and gait show a distinct pattern of association in the general population

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Abstract

Background: With brain aging, cognition and gait deteriorate in several domains. However, the interrelationship between cognitive and gait domains remains unclear. We investigated the independent associations between cognitive and gait domains in a community-dwelling population.
Methods: In the Rotterdam Study, 1232 participants underwent cognitive and gait assessment. Cognitive assessment included memory, information processing speed, fine motor speed, and executive function. Gait was summarized into seven independent domains: Rhythm, Variability, Phases, Pace, Tandem, Turning, and Base of Support. With multivariate linear regression, independent associations between cognitive and gait domains were investigated.
Results: Information processing speed associated with Rhythm, fine motor speed with Tandem, and executive function with Pace. The effect sizes corresponded to a 5- to 10-year deterioration in gait.
Conclusions: Cognition and gait show a distinct pattern of association. These data accentuate the close, but complicated, relation between cognition and gait, and they may aid in unraveling the broader spectrum of the effects of brain aging.

Keywords: Cognition; Cognitive impairment; Epidemiology; Gait; Walking

1. Introduction

Age-related pathology of the brain may cause a decline in various cognitive domains, such as memory, executive function, and information processing speed [1,2]. Cognitive decline may ultimately lead to mild cognitive impairment and dementia [1].

Gait is a complex motor function that is also heavily affected by age-related brain pathology [3,4]. Gait is a strong indicator of health, and poor gait is associated with higher mortality, morbidity, and risk of falls [5–7]. Gait can be measured in several conditions, such as normal walking, turning, and tandem walking, and gait yields many parameters. These parameters in turn constitute fewer independent gait domains, such as Rhythm, Variability, Pace, Turning, and Base of Support, which together provide a comprehensive description of gait [8–10]. A few recent studies have shown associations of certain gait domains with different brain areas; for example, step width (part of Base of Support) is associated with the pallidum whereas step length (part of Pace) is associated with the sensorimotor- and dorsolateral prefrontal cortex [3,4].

Given that cognition and gait closely reflect brain functioning, several studies have studied the link between the two [9,11–13]. These studies did so by investigating global cognition or gait velocity, but they did not study separate domains [11–13]. It is conceivable that certain cognitive domains may associate with certain gait domains, both affected by a single corresponding brain area. The one study to investigate associations among specific cognitive and gait domains found Pace to be associated with attention and executive function [9]. Additionally, they found Rhythm, Variability, and Pace to associate with cognitive decline and incident dementia [9].

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1552-5260/$ - see front matter
http://dx.doi.org/10.1016/j.jalz.2013.03.009

Still, given that cognition and gait are broad concepts, it remains unknown how various other cognitive and gait domains are associated. Moreover, most previous studies did not consider correlations among cognitive and gait domains, making it difficult to discern their independent effects.

In a population-based study, we investigated the independent associations between cognitive domains and gait domains. To more comprehensively assess gait, we investigated normal walking, turning, and tandem walking.

2. Methods

2.1. Setting

This study was embedded in the Rotterdam Study, a prospective population-based cohort in the Netherlands aimed to investigate causes and determinants of chronic diseases in the middle-aged and elderly [14]. The cohort was initially defined in 1990 and expanded in 2000 and 2005. In 1990 and 2000, all inhabitants aged 55 years and older of Ommoord, a suburb of Rotterdam, were invited to participate in the study. In 2005, all inhabitants aged 45 years and older were invited. A total of 14,926 persons agreed to participate (response rates of 78, 67, and 65%). At study entry and during follow-up every 3–4 years, each participant underwent a home interview and extensive physical examination at the research center. At these assessments, height and weight were measured and self-reported chronic diseases were recorded. During the interview at study entry, the attained level of education was assessed according to the standard classification of education [14]. From March 2009 onward, gait assessment has been implemented in the core protocol of all subcohorts. The current study comprises all participants that completed gait assessment until March 2011. The study has been approved by the Medical Ethics Committee of the Erasmus Medical Center. All participants gave written informed consent.

2.2. Assessment of cognitive function

Cognitive function was assessed with the following neuropsychological test battery: the Mini-Mental State Examination (MMSE) [15], the Stroop test [16], a 15-word verbal learning test (based on Rey's recall of words [17]), the Letter-Digit Substitution Task (LDST) [18], a word fluency test (animal categories) [19], and the Purdue Pegboard test [20]. To obtain more robust measures, *z* scores were first calculated for all separate tests by subtracting the individual value by the population mean and dividing by the standard deviation (SD). Then, *z* scores for different tests were combined into compound scores for memory, executive function, information processing speed, global cognition, and fine motor speed as reported previously [21]. The *z* scores for the Stroop tasks were inverted for use in these compound scores because higher scores on the Stroop task reflect worse performance whereas higher scores on all other tests reflect a better cognitive performance. The compound score for memory was calculated as the average of the *z* scores for the immediate and delayed recall of the 15-word verbal learning test. Executive function was constructed by averaging the *z* scores for the Stroop interference subtask, the Word Fluency Test (number of animals in 1 minute), and the LDST (number of correct digits in 1 minute). Information processing speed was the average of the *z* scores for the Stroop reading and Stroop color naming test and the LDST. Fine motor speed was defined by the *z* score for the Purdue Pegboard test (both hands). For global cognition, we used the average of the *z* scores of the Stroop task (average of all three subtasks), the LDST, the Word Fluency Test, the immediate and delayed recall of the 15-word verbal learning test, and the Purdue Pegboard test (both hands). For each compound score, new *z* scores were calculated.

2.3. Gait assessment

A description of the gait assessment has been published previously [10]. Gait was assessed with a 5.79-m long walkway (GAITRite Platinum; CIR systems, Sparta, NJ: 4.88-m active area; 120-Hz sampling rate) with pressure sensors. This device is considered an accurate system to determine gait parameters [22–24].

Participants performed a standardized gait protocol consisting of three different walking conditions: normal walk, turning, and tandem walk. In the normal walk, participants walked over the walkway at their own pace. This walk was performed 4 times in both directions (eight recordings). In turning, participants walked over the walkway at their own pace, turned halfway, and returned to the starting position (one recording). In the tandem walk, participants walked tandem (heel-to-toe) over a line visible on the walkway (one recording).

In recordings of the normal and tandem walks, footsteps not falling entirely on the walkway at the start and at the end were removed before the analyses. The first recording of the normal walk was treated as a practice walk and was not included in the analyses. Recordings of individual walks were removed if instructions were not followed correctly or when fewer than four footprints were available for analyses. Spatiotemporal variables were calculated by the walkway software.

Consecutively, principal components analysis on 30 gait variables was used to derive summarizing factors, as previously reported [10]. Within the principal components analysis, varimax rotation was used to ensure that the factors were totally independent from each other. Factors were selected if their eigenvalue was 1 or higher, indicating that each factor explains at least as much variance as a single variable. We appointed variables to a certain factor if their correlation with the factor was 0.5 or higher. Although a gait variable could attribute to several factors, none of the gait variables had a correlation of 0.5 or higher with more than one factor. If necessary, factors were inverted so that lower values always represent "worse" gait. This applied to all factors except for Pace. Seven factors were derived from this principal components analysis, in which each factor represents a different independent gait domain: Rhythm, Variability, Phases, Pace, Tandem, Turning, and Base of Support [10]. Rhythm, Variability, Phases, Pace, and Base of Support have also been found in other studies, whereas Tandem and Turning recently were additionally identified from our study (Table 1) [8–10]. Similar to global cognition, we calculated a global gait score by summing all gait factors, dividing by the number of gait factors, and subsequently calculating a new *z* score.

2.4. Educational categorization

Education was divided into seven categories: 0 = primary education, 1 = lower vocational education, 2 = lower secondary education, 3 = intermediate vocational education, 4 = general secondary education, 5 = higher vocational education, and 6 = university.

2.5. Population for analysis

Between March 2009 and March 2011, 1905 participants were invited for gait assessment. Of these, 405 were excluded for various reasons: 196 participants were removed for technical reasons; 21 participants were excluded for use of walking aids, self-reported prosthesis, or Parkinson's disease; 113 participants were excluded because of too poor physical ability to walk; 41 participants were removed because they had fewer than 16 steps available for analyses, which lowers the validity of their gait parameters [25]; 14 participants refused to participate; 9 participants refused to perform all walks; 9 participants were removed because they did not follow instructions; and 2 participants did not perform the walks for other reasons. Of the remaining 1500 persons, an additional 248 participants were excluded because of missing cognitive data and another 20 participants because their educational level was unknown. In total 1232 participants were included in the analyses.

2.6. Statistical analysis

Linear regression analyses were used to determine the associations of MMSE and global cognition with the separate gait domains. We also investigated the association of global cognition (in quintiles) with global gait using univariate analyses of variance (ANOVA) and analyzed the *P* trend for linearity.

We subsequently investigated the associations of individual cognitive domains with the gait domains. First, we used linear regression analyses to investigate the associations for the separate cognitive domains with the gait domains. Given weak to strong correlations across cognitive domains (see Supplement Table 1), we consecutively used multivariate linear regression analyses including all cognitive domains. This way, we investigated the independent associations of the various cognitive domains with each independent gait domain.

All analyses were adjusted for the following potential confounders: age (at the time of the assessment of cognitive function), sex, height, weight, education, subcohort, and the interval between cognition and gait assessment in days. Analyses with Tandem were additionally adjusted for the step length and step count in the tandem walk. To address the robustness of our findings, Bonferroni correction was performed for all linear regression analyses involving cognitive domains (for 28 tests).

We note that all above-mentioned associations were tested against the null hypothesis of no association. For the multivariate analyses, we also directly compared effect sizes across associations with each other. We did this only for associations that were significantly different from the null after Bonferroni correction. The effect size of such association between cognitive domain and gait domain was compared to the effect sizes with other gait domains.

We also performed sensitivity analyses to investigate any effect of selective dropout of persons that were physically unable to walk. We did so by imputing global gait for these persons with the lowest global gait score among the available population. We subsequently compared results from linear regression before and after including these persons. Alternatively, we divided global cognition and global gait into quintiles and placed the persons unable to walk in the worst quintile of global gait. Consecutively, we calculated Spearman's correlations before and after including these persons.

Table 1
Description of the characteristics of the gait domains

Gait domain	Characteristic
Rhythm	A reflection of most temporal gait variables, such as cadence, stance time, and swing time. A lower value indicates a lower cadence.
Variability	A reflection of most variability gait variables, such as stride length variability and stance time variability. A lower value indicates higher variability.
Phases	A reflection of gait variables on the ratio between stable and instable walking time, such as the double support percentage of the gait cycle and the swing percentage of the gait cycle. A lower value indicates a higher double support percentage.
Pace	A reflection of distance-related gait variables, such as stride length and gait velocity. A lower value indicates a shorter stride length.
Tandem	A reflection of gait variables on the amount of errors in the tandem walk, such as the side steps and double steps. A lower value indicates more errors in the tandem walk.
Turning	A reflection of turn-related gait variables, such as the number of turn steps and turning time. A lower value indicates a slower turn.
Base of Support	A reflection of width-related gait variables, such as the stride width and the stride width variability. A lower value indicates a smaller stride width, but higher stride width variability.

Finally, adjustment for self-reported osteoarthritis and rheumatoid arthritis was performed to determine their influence on the investigated associations. All statistical analyses were performed using SPSS PASW version 17.0.2 for Windows.

3. Results

Population characteristics are presented in Table 2. The mean age was 66.3 years (SD 11.8), and 54.7% of the participants were women. The mean MMSE was 28.0 (SD 1.8) and the median educational level was intermediate vocational education. Excluded participants were more often female than the included participants and were significantly older ($P < .05$). After adjustment for age and sex, excluded participants also had shorter stature, a lower education, and a lower MMSE score compared with the included participants (all $P < .05$).

MMSE and global cognition were significantly associated with Variability and Pace (Table 3). In addition, global cognition was also significantly associated with Rhythm and Turning.

In Figure 1, a strong association between global cognition and global gait is seen (difference in z score of global gait per SD increase of global cognition: 0.26 [95% confidence interval: 0.19; 0.32]). When investigating cognition in quintiles, persons in the lower three quintiles had worse gait than persons in the highest quintile ($P < .05$). Moreover, this association demonstrated a significant P trend for linearity ($P < .001$).

Table 3 also shows that without adjustment for other cognitive domains, several cognitive domains were significantly associated with various gait domains.

In Table 4, the associations between cognitive domains and gait domains are shown after multivariable modeling, thereby exploring independent associations. Three associations were found to survive Bonferroni adjusted statistical thresholds: information processing speed was associated with Rhythm (difference in z score of Rhythm per SD increase of information processing speed: 0.15 [95% confidence interval: 0.07; 0.23]), fine motor speed was associated with Tandem (0.12 [0.05; 0.19]), and executive function was associated with Pace (0.15 [0.08; 0.23]). When using conventional limits of nominal significance ($P < .05$), five other suggestive associations emerged: memory became associated with Phases and Pace, information processing speed became associated with Turning, and fine motor speed and executive function became associated with Variability.

The effect size of the association between information processing speed and Rhythm was significantly larger than the effect size of information processing speed with Pace, but not that with Tandem (Supplement Table 2). The effect size of fine motor speed with Tandem did not differ significantly from the effect size of fine motor speed with Rhythm and Pace. Neither did the effect size of executive function with Pace differ significantly from the effect size of executive function with Rhythm and Tandem.

In the sensitivity analyses, after imputing gait values for the persons that were missing in the original analyses, the Spearman's correlation and the linear regression showed a stronger association between global cognition and global gait than in the original analyses (Spearman's correlation of 0.38 as opposed to 0.36, linear regression 0.32 [0.24; 0.40] compared with 0.26 [0.19; 0.32]).

Adjustment for self-reported osteoarthritis and rheumatoid arthritis did not change the results.

4. Discussion

Our study shows that cognitive domains and gait domains are tightly associated, with a putative pattern of certain cognitive domains with gait domains: information processing speed was associated with Rhythm, fine motor speed was associated with Tandem, and executive function was associated with Pace. Suggestive associations were also found for memory with Phases and Pace, for information processing speed with Turning, and for fine motor speed and executive function with Variability.

Table 2
Population characteristics

Characteristic	Total (n = 1232)	Men (n = 558)	Women (n = 674)	Nonparticipants (n = 673, of whom 398 women)
Age (y)	66.3 (11.8)	67.0 (12.0)	65.7 (11.5)	72.9 (11.8)†
Height (cm)	168.8 (9.4)	175.9 (7.0)	162.9 (6.6)	166.2 (9.6)‡
Weight (kg)	78.3 (14.7)	85.2 (13.9)	72.5 (12.7)	76.8 (14.5)
MMSE (score)	28.0 (1.8)	27.9 (1.8)	28.1 (1.7)	27.3 (2.5)‡
Education*	3 (1; 3)	3 (2; 5)	2 (1; 3)	2 (1; 3)‡
Self-reported movement disorders				
Osteoarthritis (n)	278 (22.6)	96 (17.2)	182 (27.0)	179 (26.6)
Rheumatoid arthritis (n)	34 (2.8)	10 (1.8)	24 (3.6)	34 (5.1)

NOTE. Values are mean (standard deviation) or number (%).
*For education, the median (interquartile range) is shown.
†Excluded participants were significantly older than the included population ($P < .05$).
‡Excluded participants differed significantly from the included population in these characteristics after adjustment for age and sex.

Table 3
Associations for the global cognition measures and separate cognitive domains with gait domains

Global cognition scores	Gait domains						
	Rhythm	Variability	Phases	Pace	Tandem*	Turning	Base of Support
MMSE	0.02 (−0.01; 0.05)	**0.06 (0.02; 0.09)**	0.00 (−0.03; 0.03)	**0.04 (0.01; 0.06)**	−0.03 (−0.06; 0.00)	0.02 (−0.01; 0.06)	−0.01 (−0.04; 0.02)
Global cognition	**0.19 (0.12; 0.25)**	**0.20 (0.13; 0.27)**	−0.01 (−0.07; 0.05)	**0.20 (0.14; 0.25)**	0.07 (0.00; 0.14)	**0.12 (0.05; 0.19)**	−0.07 (−0.14; 0.01)
Cognitive domains							
Memory	0.05 (−0.01; 0.11)	0.09 (0.03; 0.15)	−0.06 (−0.11; −0.01)	**0.10 (0.06; 0.15)**	0.00 (−0.06; 0.06)	0.08 (0.01; 0.14)	−0.06 (−0.13; 0.00)
Information processing speed	**0.19 (0.13; 0.24)**	**0.16 (0.10; 0.22)**	0.05 (0.00; 0.11)	**0.12 (0.07; 0.17)**	0.02 (−0.04; 0.08)	**0.11 (0.04; 0.17)**	−0.03 (−0.09; 0.04)
Fine motor speed	**0.10 (0.04; 0.16)**	**0.12 (0.05; 0.18)**	0.01 (−0.05; 0.07)	0.08 (0.02; 0.13)	**0.12 (0.06; 0.19)**	0.07 (0.00; 0.14)	0.00 (−0.06; 0.07)
Executive function	**0.16 (0.10; 0.22)**	**0.18 (0.11; 0.25)**	0.04 (−0.02; 0.10)	**0.18 (0.13; 0.23)**	0.05 (−0.01; 0.12)	0.08 (0.01; 0.15)	−0.03 (−0.10; 0.04)

Abbreviation: MMSE, Mini-Mental State Examination.

NOTE. Values represent the change in *z* scores (with 95% confidence intervals) of gait per point increase for MMSE or per standard deviation increase for global cognition and the cognitive domains. For MMSE and global cognition, results in bold represent significant findings against the null hypothesis of no association ($P < .05$). For the cognitive domains, results in bold represent significant findings against the null hypothesis of no association after Bonferroni correction for 28 tests ($P < .0018$). All analyses were adjusted for age, sex, height, weight, education, subcohort, and the interval between cognition and gait assessment in days.

*Additionally adjusted for step count and step size within the tandem walk.

The strengths of our study include the population-based design, the large sample size, the different walking conditions included, and the many independent gait domains investigated. Moreover, we also made our cognitive domains independent from each other by adjustment in a multivariable model.

However, our study also has some limitations. First, the cross-sectional design precluded the possibility to investigate the time-dependent relation between gait and cognition. Secondly, our population was selected to be relatively healthy, both cognitively and physically; hence, generalizability of our results may be restricted to a healthy population. However, our sensitivity analyses suggest that the exclusion of persons unable to walk has most likely led to an underestimation of the strength of association between cognition and gait. Thirdly, apart from normal walking, turning, and tandem walking, gait also comprises other walking conditions, such as running, backward walking, and backward tandem walking, which were not included in this study. Finally, several cognitive domains, such as attention, were also not tested in our study.

We demonstrated that better global cognition was associated with better global gait over the whole range of global cognition. This suggests that this association is not driven by persons at the lower end of the spectrum of cognitive ability. Instead, even in persons with average and good cognitive ability, cognition associates with gait.

MMSE and global cognition were most strongly associated with Variability, followed by Pace. Global cognition was also significantly associated with Rhythm and Turning. These results correspond with previous studies that found similar associations for global cognition with these gait domains or constituting variables [9,11,26].

Apart from their strong mutual association, gait variability and cognition are also associated with the risk of falls [5,27,28]. Thus, gait variability may be the most important gait-related intermediate in the association between cognition and risk of falls.

In a basic model with no adjustment for correlations among cognitive domains, we found that several cognitive domains associated with various gait domains. This demonstrates the close relationship between cognition and gait, but it also accentuates the correlation among the cognitive domains.

When investigating independent associations in multivariable models, a possible distinct pattern of associations emerged: information processing speed was significantly associated with Rhythm, fine motor speed was associated with Tandem, and executive function was associated with Pace. Suggestive associations were also found for memory with Phases and Pace, for information processing speed with Turning, and for fine motor speed and executive function with Variability. Because of the adjustment for other cognitive domains and the use of independent gait domains, these results suggest specific associations between cognitive domains and gait domains. However, direct comparison

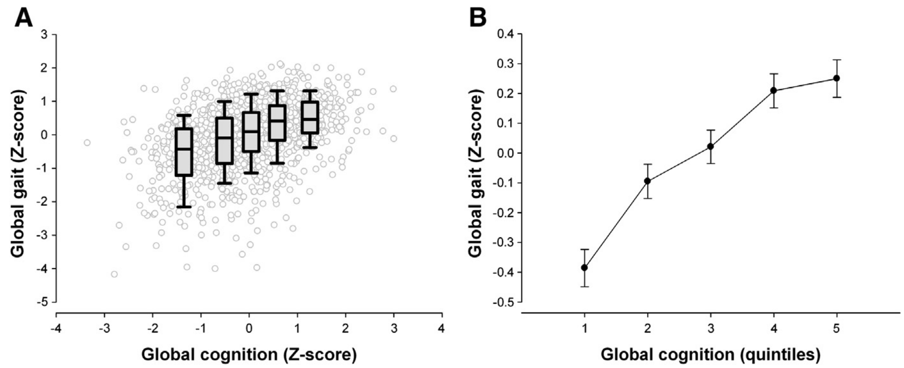

Fig. 1. The association between global cognition and global gait. (A) Scatterplot of global gait against global cognition, including a boxplot presenting the 90th, 75th, median, 25th, and 10th percentile of global gait within quintiles of global cognition (unadjusted values). (B) Plot of the adjusted means of global gait with their standard errors per quintile of global cognition. Each consecutive higher quintile of global cognition demonstrates higher global gait. A higher z score on global gait corresponds with better gait. Dots are means, adjusted for age, sex, height, weight, education, interval between gait and cognition measurements in days, and the subcohort. Error bars represent the standard errors of the mean.

showed few significant differences in effect size among the associations. Only the effect size of the association between information processing speed and Rhythm differed significantly from that with Pace. Therefore, we cannot be certain that the associations found between cognition and gait are indeed domain specific.

The only other study investigating associations between cognitive domains and gait domains found a significant association between executive function and Pace, but it did not find the suggestive associations for memory with Pace and executive function with Variability [9].

Most other studies on cognition and gait investigated gait with gait velocity, which was found to be associated with memory, information processing speed, and executive function [12,13]. However, gait velocity (= step length/ step time) is reflected by two gait domains: Rhythm (via step time) and Pace (via step length) [10]. Our results suggest that the Rhythm part of gait velocity is associated with information processing speed whereas the Pace part may be mainly associated with memory and executive function.

The association found between fine motor speed and Tandem is new and suggests that brain areas important for fine motor speed may also be important to maintain balance in gait.

It was surprising to note that the strong association found between global cognition and Variability was not reflected by a specific cognitive domain. Previous studies suggested that gait variability is foremost associated with executive function [29,30]. However, our results suggest that the association between cognition and Variability is not domain specific, but a global association distributed about equally over the cognitive domains, with only a suggestive predilection toward fine motor speed and executive function. Future studies are needed to validate the suggestive associations found in our study.

The relevance of the effect of these associations may be better interpreted when compared with the effect of age on gait, which has recently been reported from our study [10]: The effect of a 1 SD poorer performance in fine motor speed on Tandem corresponds to the effect of 5 years of aging whereas the effect of a 1 SD poorer performance in executive function on Pace corresponds to even 10 years of aging [10].

The strong associations between specific cognitive and gait domains demonstrate the close and intricate relationship between cognition and gait. This close relationship is likely explained by the effect of common underlying brain pathology. Indeed, previous studies have already shown pathologies in certain areas of the brain to be associated with specific cognitive and specific gait domains [1,3,4,31]. Nonetheless, an alternative explanation of poor cognitive functioning leading to gait disturbances because of impaired motor control should also be considered. However, although some studies did find that cognitive functioning was associated with a future decline in gait, other studies found poor gait to predict future cognitive decline whereas others found cognition and gait to deteriorate concurrently [9,11–13,32]. However, future studies are needed to further unravel the etiology of the associations between cognition and gait.

In conclusion, we found a distinct pattern in the associations between cognitive domains and gait domains: information processing speed was associated with Rhythm, fine motor speed was associated with Tandem, and executive function was associated with Pace. These results accentuate the close, but complicated, relationship between cognition and gait and may aid in unraveling the broader spectrum of the effects of brain aging. Future studies should also further explore the role of gait deterioration in incipient dementia and other neurodegenerative disease in old age.

Acknowledgments

The Rotterdam Study is sponsored by the Erasmus Medical Center and Erasmus University Rotterdam; the Netherlands

Table 4
Independent associations between cognitive domains and gait domains

Cognitive domains	Gait domains						
	Rhythm	Variability	Phases	Pace	Tandem*	Turning	Base of Support
Memory	0.00 (−0.06; 0.06)	0.04 (−0.02; 0.11)	−0.08 (−0.14; −0.03)	0.06 (0.01; 0.11)	−0.01 (−0.07; 0.05)	0.06 (−0.01; 0.12)	−0.06 (−0.13; 0.00)
Information processing speed	**0.15 (0.07; 0.23)**	0.07 (−0.02; 0.16)	0.06 (−0.01; 0.14)	0.00 (−0.07; 0.07)	−0.04 (−0.13; 0.05)	0.10 (0.00; 0.19)	−0.01 (−0.10; 0.09)
Fine motor speed	0.06 (−0.01; 0.12)	0.07 (0.00; 0.14)	0.00 (−0.06; 0.06)	0.04 (−0.02; 0.09)	**0.12 (0.05; 0.19)**	0.05 (−0.03; 0.12)	0.01 (−0.06; 0.08)
Executive function	0.04 (−0.05; 0.13)	0.10 (0.01; 0.19)	0.02 (−0.06; 0.10)	**0.15 (0.08; 0.23)**	0.06 (−0.04; 0.15)	−0.02 (−0.12; 0.08)	−0.01 (−0.11; 0.09)

NOTE. Values represent the change in z scores (with 95% confidence intervals) of gait per standard deviation increase in the cognitive domain. Results in bold represent significant findings against the null hypothesis of no association after Bonferroni correction for 28 tests ($P < .0018$). All analyses were adjusted for age, sex, height, weight, education, subcohort, the interval between cognition and gait assessment in days, and the other cognitive domains.

*Additionally adjusted for step count and step size within the tandem walk.

Organization for Scientific Research (NWO); the Netherlands Organization for Health Research and Development (ZonMW); the Research Institute for Diseases in the Elderly (RIDE); the Ministry of Education, Culture, and Science; the Ministry of Health, Welfare, and Sports; the European Commission (DG XII); and the Municipality of Rotterdam. J. N. van der Geest was supported by the Prinses Beatrix Fonds. The authors declare that they have no conflict of interest.

RESEARCH IN CONTEXT

1. Systematic review: W reviewed the literature using PubMed for articles describing the relationship of cognition with gait. We cite several studies that focused on either global measures or only a few preselected domains of cognition or gait. In our current study, we investigated how separate cognitive domains associate with separate gait domains.
2. Interpretation: We demonstrate a distinct pattern of association between specific cognitive domains with specific gait domains. For example, information processing speed associates with Rhythm, motor speed associates with Tandem, and executive function associates with Pace. This suggests that cognition and gait are more intricately linked than previously thought.
3. Future directions: Future studies should unravel the biological basis of these specific associations, which are possibly linked via corresponding brain regions. Also, the longitudinal and bidirectional relationship between cognition and gait should be investigated. This may possibly aid in identifying persons at increased risk of cognitive impairment or dementia.

References

[1] Ikram MA, Vrooman HA, Vernooij MW, den Heijer T, Hofman A, Niessen WJ, et al. Brain tissue volumes in relation to cognitive function and risk of dementia. Neurobiol Aging 2010;31:378–86.
[2] Euser SM, Schram MT, Hofman A, Westendorp RG, Breteler MM. Measuring cognitive function with age: the influence of selection by health and survival. Epidemiology 2008;19:440–7.
[3] Rosano C, Aizenstein H, Brach J, Longenberger A, Studenski S, Newman AB. Special article: gait measures indicate underlying focal gray matter atrophy in the brain of older adults. J Gerontol A Biol Sci Med Sci 2008;63:1380–8.
[4] de Laat KF, Reid AT, Grim DC, Evans AC, Kotter R, van Norden AG, et al. Cortical thickness is associated with gait disturbances in cerebral small vessel disease. Neuroimage 2012;59:1478–84.
[5] Maki BE. Gait changes in older adults: predictors of falls or indicators of fear. J Am Geriatr Soc 1997;45:313–20.

[6] Studenski S, Perera S, Patel K, Rosano C, Faulkner K, Inzitari M, et al. Gait speed and survival in older adults. JAMA 2011; 305:50–8.
[7] Watson NL, Sutton-Tyrrell K, Youk AO, Boudreau RM, Mackey RH, Simonsick EM, et al. Arterial stiffness and gait speed in older adults with and without peripheral arterial disease. Am J Hypertens 2011; 24:90–5.
[8] Hollman JH, McDade EM, Petersen RC. Normative spatiotemporal gait parameters in older adults. Gait Posture 2011;34:111–8.
[9] Verghese J, Wang C, Lipton RB, Holtzer R, Xue X. Quantitative gait dysfunction and risk of cognitive decline and dementia. J Neurol Neurosurg Psychiatry 2007;78:929–35.
[10] Verlinden VJA, van der Geest JN, Hoogendam YY, Hofman A, Breteler MMB, Ikram MA. Gait patterns in a community-dwelling population aged 50 years and older. Gait Posture 2013; 37:500–5.
[11] Tabbarah M, Crimmins EM, Seeman TE. The relationship between cognitive and physical performance: MacArthur Studies of Successful Aging. J Gerontol A Biol Sci Med Sci 2002; 57:M228–35.
[12] Soumare A, Tavernier B, Alperovitch A, Tzourio C, Elbaz A. A cross-sectional and longitudinal study of the relationship between walking speed and cognitive function in community-dwelling elderly people. J Gerontol A Biol Sci Med Sci 2009;64:1058–65.
[13] Watson NL, Rosano C, Boudreau RM, Simonsick EM, Ferrucci L, Sutton-Tyrrell K, et al. Executive function, memory, and gait speed decline in well-functioning older adults. J Gerontol A Biol Sci Med Sci 2010;65:1093–100.
[14] Hofman A, van Duijn CM, Franco OH, Ikram MA, Janssen HL, Klaver CC, et al. The Rotterdam Study: 2012 objectives and design update. Eur J Epidemiol 2011;26:657–86.
[15] Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–98.
[16] Golden CJ. Identification of brain disorders by the Stroop Color and Word Test. J Clin Psychol 1976;32:654–8.
[17] Bleecker ML, Bolla-Wilson K, Agnew J, Meyers DA. Age-related sex differences in verbal memory. J Clin Psychol 1988; 44:403–11.
[18] Lezak MD. Neuropsychological assessment. 4th ed. Oxford, United Kingdom: Oxford University Press; 2004.
[19] Welsh KA, Butters N, Mohs RC, Beekly D, Edland S, Fillenbaum G, et al. The Consortium to Establish a Registry for Alzheimer's Disease (CERAD). Part V. A normative study of the neuropsychological battery. Neurology 1994;44:609–14.
[20] Desrosiers J, Hebert R, Bravo G, Dutil E. The Purdue Pegboard Test: normative data for people aged 60 and over. Disabil Rehabil 1995; 17:217–24.
[21] Vernooij MW, Ikram MA, Vrooman HA, Wielopolski PA, Krestin GP, Hofman A, et al. White matter microstructural integrity and cognitive function in a general elderly population. Arch Gen Psychiatry 2009; 66:545–53.
[22] Menz HB, Latt MD, Tiedemann A, Mun San Kwan M, Lord SR. Reliability of the GAITRite walkway system for the quantification of temporo-spatial parameters of gait in young and older people. Gait Posture 2004;20:20–5.
[23] van Uden CJ, Besser MP. Test-retest reliability of temporal and spatial gait characteristics measured with an instrumented walkway system (GAITRite). BMC Musculoskelet Disord 2004;5:13.
[24] Bilney B, Morris M, Webster K. Concurrent related validity of the GAITRite walkway system for quantification of the spatial and temporal parameters of gait. Gait Posture 2003;17:68–74.
[25] Brach JS, Perera S, Studenski S, Newman AB. The reliability and validity of measures of gait variability in community-dwelling older adults. Arch Phys Med Rehabil 2008;89:2293–6.
[26] Brach JS, Studenski S, Perera S, VanSwearingen JM, Newman AB. Stance time and step width variability have unique contributing impairments in older persons. Gait Posture 2008;27:431–9.
[27] Hausdorff JM, Rios DA, Edelberg HK. Gait variability and fall risk in community-living older adults: a 1-year prospective study. Arch Phys Med Rehabil 2001;82:1050–6.
[28] Holtzer R, Friedman R, Lipton RB, Katz M, Xue X, Verghese J. The relationship between specific cognitive functions and falls in aging. Neuropsychology 2007;21:540–8.
[29] Hausdorff JM, Yogev G, Springer S, Simon ES, Giladi N. Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. Exp Brain Res 2005;164:541–8.
[30] van Iersel MB, Kessels RP, Bloem BR, Verbeek AL, Olde Rikkert MG. Executive functions are associated with gait and balance in community-living elderly people. J Gerontol A Biol Sci Med Sci 2008;63:1344–9.
[31] Benisty S, Gouw AA, Porcher R, Madureira S, Hernandez K, Poggesi A, et al. Location of lacunar infarcts correlates with cognition in a sample of non-disabled subjects with age-related white-matter changes: the LADIS study. J Neurol Neurosurg Psychiatry 2009; 80:478–83.
[32] Inzitari M, Newman AB, Yaffe K, Boudreau R, de Rekeneire N, Shorr R, et al. Gait speed predicts decline in attention and psychomotor speed in older adults: the health aging and body composition study. Neuroepidemiology 2007;29:156–62.