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Variance Between Walking Speed and Neuropsychological Test Scores During Three Gait Tasks Across The Irish Longitudinal Study on Aging (TILDA) Dataset

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Abstract— This study investigated the relationship between neuropsychological test scores and gait speed in three gait tasks using baseline cross-sectional data from 4694 healthy adults (54% women, age (mean±sd) 62.4±8.2) from The Irish Longitudinal study on Aging (TiLDA). Global cognition, short term memory, speed of processing, executive function and sustained attention were measured by a detailed battery of neuropsychological tests. Gait speed was recorded from a GaitRite™ pressure sensing mat during a single walk and two dual walking tasks; dual cognitive walk (alternate letters) and dual motor walk (carrying a glass of water). Correlations between neuropsychological test scores and the three gait speed outcomes were investigated using univariate and multiple linear regressions models; firstly adjusting for age, gender, height, education and depression only and then including all neuropsychological test scores in the same regression model and adjusting as previously. It was found that short term memory, speed of processing and attention were significantly correlated with gait speed in all three gait conditions, with global cognition and executive function also significantly correlated with gait speed in the dual cognitive walk. The nature and complexity of the task performed affected gait speed with the addition of the cognitive task while walking causing a larger reduction in gait speed than the addition of the motor task. This indicates that for this healthy nationally representative population sample there is a link between neural processes involved in movement and cognition and this association differs depending on the gait task performed.

I. Introduction

The link between gait and cognitive function is being increasingly recognized. Global cognition has been shown to predict longitudinal gait speed decline[1]. In turn, slow gait speed has been shown to predict survival rate [2]and those at risk of falling[3]. However, there is limited knowledge on the specific contributions of each cognitive subdomain to gait speed. Some studies have found global cognition, short term memory and executive function to play the biggest part [1, 4], others also including attention[5], however not all studies probe speed of processing or attention domains. Further understanding of the relationship between gait and cognitive sub-domains might inform clinical assessments and rehabilitation strategies, in addition to contributing to the understanding of underlying pathology.

Locomotion is a complex task engaging the motor cortex, cerebellum, basal ganglia, and involving feedback to the proprioceptive, visual, and vestibular sensors producing precise motor commands and resultant coordinated muscle firing and limb movements in a healthy person. However, aging and pathology change higher neurological areas of movement control.

Mild cognitive impairment (MCI) refers to slight cognitive disturbances that do not meet the criteria for dementia and can be measured using global cognitive scales. Patients with MCI have cognitive impairments beyond that expected for their age and education[6] but without interfering severely with their activities of daily living. People with MCI have a significant rate of conversion to Alzheimer's disease, but also a slower walking speed and a higher risk of falling than healthy controls.

More specifically speed of processing and executive function have been thought of as the main mediators of age related cognitive decline[7]. Slowing of processing speed as we age is thought to be due to global deterioration in white matter integrity, whereas declines in executive function are thought to be due to functional and structural declines in the frontal cortex. Executive function is required for effective, goal orientated actions and for control of attentional resources needed for activities of daily living[8]. Executive function measures have been linked to slower walking speed, disruptions of gait and balance and to higher risk of falls [9]. Attention is a subcategory of executive function and it is seen to play a central role in gait[10]. Sustained attention refers to the ability to maintain attention to a task over a period of time and has been linked to higher risk of falls[11] but has not been examined in relation to gait speed. Memory is also an important factor as it is one of the first cognitive domain to be affected by aging, however good memory has been shown to have an influence on recording of falls[12].

Research is needed to determine the relationship between attention, task complexity, task prioritization, awareness of limitation and gait speed in an older cohort to investigate pre-pathological signs within gait. Studies to date have focused on a small set of neuropsychological batteries or based findings on small subject numbers. The aim of this study was to probe the relationship between six pertinent neuropsychological test scores and gait speed in three gait

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conditions in a large nationally representative community dwelling older population sample.

II. PROCEDURE

This study used baseline cross sectional data from 4694 healthy adults (54% women, age (mean±sd) 62.4±8.2) who participated in The Irish Longitudinal study on Aging (TiLDA), a nationally representative study.

A. Methods

Gait and neuropsychological data were investigated from the TILDA health assessment. A 4.88m GAITRite™[CIR Systems Inc., NJ, USA] pressure sensing mat recorded gait speed during two walks at normal pace for a single walk and two dual walking tasks: motor and cognitive. The dual motor walk involved walking while carrying a glass filled one inch from the top with water. The dual cognitive walk involved walking while reciting alternate letters of the alphabet. The walking tasks began 2.5 meters before the start of the mat and continued for 2 meters at the end of the mat to facilitate acceleration, deceleration and turning.

The Mini Mental State Examination (MMSE) and Montreal Cognitive Assessment (MOCA) are two types of 0 to 30-point global cognitive screening scales with memory, visuoconstructional, attention, concentration, memory, language and orientation components. MOCA, in addition, includes a larger executive function component and has been shown to have greater sensitivity at detecting MCI than MMSE[13]. A cut-off test score in MMSE of 26 is commonly used as healthy cognition, under 24 as severe cognitive impairment and in MOCA under 26 for MCI.

Sustained attention was measured using the Sustained Attention to Response Task (SART) coefficient of variation[14]. Repeated digits were presented sequentially from '1' to '9' on a screen in front of participants (300 ms inter-stimulus interval, 207 numbers) while participants pressed a button for every digit except for the digit '3'.

Short term Memory was assessed using a ten word recall which tested immediate and delay recall.

The Color Trail Test (CTT)[15] consists of two parts. Part 1 involves connecting numbers in ascending order with a pencil as quickly as possible, and part 2 additionally requires alternating between pink and yellow numbers. Both parts were timed and the difference in time between part 1 and part2 (ΔCTT) was the executive function measure used.

Speed of Processing was measured using the Choice Reaction Time test (CRT) mean reaction time. A yes/no stimulus appeared on the screen and participants responded by pressing a corresponding yes/no button (100 repetitions).

Data was analyzed using Stata 12 [StataCorp LP, Texas, USA]. Paired t-tests were used ($p<0.05$) to investigate the effect of task on gait speed. Correlations between neuropsychological test scores and gait speed for each gait condition were investigated using univariate and multiple linear regressions models. Statistical Model 1 investigated correlations between gait speed and each neuropsychological test scores using univariate regression, Statistical Model 2 also adjusted for age, gender, depression, height and level of education. Statistical Model 3, included all

TABLE I. SUMMARY OF PARTICIPANT CHARACTERISITCS, (N=4694)

Characteristics	*Description*	*Value*
Gender	Female [n,%]	2557 54%
Age	Mean±sd [years]	62.4±8.2
Height	Mean±sd [m]	1.66±0.09
Education	Participants achieving Primary, Secondary, Tertiary Education [n]	1045,1940, 1707
Depression	Short Centre for Epidemiological Studies Depression Scale, CES-D: Mean±sd, n ≤ 16 (%)	4.39±4.02 113 (3%)
Falls	Self-reported falls in the last year: None, One, Two or more [n,%]	3759, 616, 317 80%, 13%, 7%
Walking Speed	Single Walk [m/s]	1.35±0.20
	Dual Walk (Cognitive) [m/s]	1.11±0.26
	Dual Walk (Motor) [m/s]	1.33±0.21
Global Cognition	MMSE: Mean±sd, n < 26, 24 (%)	28.60±1.85 (6, 2)
	MOCA: Mean±sd, n < 26 (%)	25.20±3.26 (48)
Short Term Visual Memory	Ten Word Recall Test: Immediate Recall (Range, IQR Median)	1-10, 4-8, 5
	Ten Word Recall Test: Delayed Recall (Range, IQR Median)	1-10, 3-9, 5
Speed of Processing	CRT Mean Reaction Time [s]	0.815 ±0.27
Executive Function	ΔCTT [s]	54.4±27.2
Sustained Attention	SART Coefficient of Variation [%]	0.31±0.16

neuropsychological test scores in the same regression model, while adjusting as previously. In order to compare the relative contributions of the most statistically pertinent neuropsychological test scores Statistical Model 4 only included the most statistically significant ($p<0.3$) neuropsychological test scores from Statistical Model 3 and adjusted as previously. Significance values can be seen in Table II (Statistical Model 1, 2 and 3) and beta coefficients and standard errors in Table III (Statistical Model 4) to indicate their relative contribution. No variables were omitted due to collinearity (variance inflation factor >10).

III. RESULTS

Characteristics from 4694 participants included in the analysis can be seen in Table I. Gait speed was found to be significantly different for all gait conditions (two tailed paired t-test: $t<0.05$). All neuropsychological test scores were highly statistically significant correlated with gait speed for all gait conditions in Statistical Model 1 and 2 (Table II), with the exception of ΔCTT for the single walk (Statistical Model 2).

In Statistical Model 3, 23%, 17% and 24% of the variance associated with gait speed for the single walk, dual cognitive and dual motor walks respectively can be explained by personal (age, gender, height, depression and education) and neuropsychological factors (global cognition, short term memory, speed of processing, executive function and attention) with MOCA, immediate recall, ΔCRT and SART coefficient of variation statistically significantly correlated

TABLE II. CORRELATIONS OF NEUROPSYCHOLOGICAL TEST SCORES WITH GAIT SPEED DURING THREE WALKING TASKS

Predictor	Single Walk			Dual Cognitive Walk			Dual Motor Walk		
	p value			p value			p value		
	Statistical Model 1	Statistical Model 2	Statistical Model 3	Statistical Model 1	Statistical Model 2	Statistical Model 3	Statistical Model 1	Statistical Model 2	Statistical Model 3
	p	p	p	p	p	p	p	p	p
Global Cognition: MOCA	<0.005	0.021	0.046	<0.005	<0.005	0.055	<0.005	<0.005	0.258
Global Cognition: MMSE	<0.005	0.013	0.766	<0.005	0.011	0.593	<0.005	<0.005	0.799
Short Term Memory: Immediate recall	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Short Term Memory: Delayed recall	<0.005	0.008	0.722	<0.005	<0.005	0.601	<0.005	<0.005	0.518
Speed of Processing: ΔCRT	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Executive Function: ΔCTT	<0.005	0.217	0.466	<0.005	<0.005	0.046	<0.005	<0.005	0.673
Sustained Attention: SART Coefficient	<0.005	<0.005	0.005	<0.005	<0.005	0.046	<0.005	<0.005	0.002

Statistical Model 1 used univariate linear regression. Statistical Model 2 also adjusted for age, height, gender, education and depression. Statistical Model 3 used a multiple linear regression including all neuropsychological test scores and adjusting as per Statistical Model 2: n= 4431, 4403 and 4402 and R2 = 0.23, 0.17 and 0.23 for single, dual cognitive and dual motor gait speed.

(<0.3) with gait speed in all gait conditions, but MMSE and delayed recall were not. ΔCTT was significantly correlated with gait speed in the cognitive gait task only. In Statistical Model 4 (Table III) 23%, 17% and 23% of the variance associated with gait speed for the single, dual cognitive and dual motor walks were explained by personal and neuropsychological factors with immediate recall, ΔCRT SART coefficient of variation statistically significantly correlated with gait speed in all gait conditions. MOCA and ΔCTT were significantly correlated with gait speed in the dual cognitive walk also.

IV. DISCUSSION

This study examined the relationship between measures of cognitive function and gait speed. Short term memory, speed of processing and sustained attention were found to be the most significant cognitive factors affecting gait speed for all gait conditions, with global cognition and executive function significantly correlated with gait speed for the dual cognitive walk also. The nature and difficulty of the task performed affected gait speed with the addition of the cognitive task while walking causing a larger reduction in gait speed than the addition of the motor task. These results indicate that for this healthy nationally representative older population sample, even a simple gait task may involve many cognitive processes with different processes recruited depending on that nature and difficulty of the task.

All cognitive domains were statistically significantly correlated to gait speed for all gait conditions in Statistical Model 1 and in Model 2 after adjusting for confounding factors (age, height, gender, education and depression). The effect of confounding factors can be seen in the reduced statistical significance of most cognitive domains from Statistical Model 1 to 2. However, immediate recall, speed of processing and SART coefficient remain highly statistically significant throughout all regression models. This shows the importance of adjusting for confounding factors to aid in highlighting variables of most interest.

When comparing the relative statistical significance of all cognitive domains in the same regression model (Statistical Model 3), MMSE and delayed recall are no longer statistically significantly correlated with gait speed for any gait condition. This indicates that any statistical significant variance in gait speed can be explained by the other cognitive test scores included in Statistical Model 3 such as MOCA and immediate recall. In addition, MMSE scores (28.60±1.85) were very high with reduced variance compared with MOCA scores (25.20±3.26). These findings support literature which shows MMSE to be a less appropriate scale than MOCA to assess a healthy cohort due to its lower sensitivity to MCI.

Percentage variance (R-squared) associated with gait speed for all gait conditions from Statistical Model 3 to Statistical Model 4 are very similar, indicating that the neuropsychological test scores included in Statistical

TABLE III. CORRELATIONS OF NEUROPSYCHOLOGICAL TEST SCORES WITH GAIT SPEED DURING THREE WALKING TASKS: STATISTICAL MODEL 4

Predictor	Single Walk			Dual Cognitive Walk			Dual Motor Walk		
	β	S.E.	p	β	S.E.	p	β	S.E.	p
Global Cognition: MOCA	-0.203	0.110	0.065	-0.303	0.142	0.033*	-0.06	0.110	0.581
Short Term Memory: Immediate recall	0.598	0.195	0.002*	1.145	0.262	<0.005*	0.9	0.195	<0.005*
Speed of Processing: ΔCRT	-0.008	0.001	<0.005*	-0.015	0.002	<0.005*	-0.01	0.001	<0.005*
Executive Function: ΔCTT				-0.034	0.016	0.040*			
Sustained Attention: SART Coefficient	-5.259	1.968	0.008*	-5.41	2.703	0.046*	-6.43	2.03	0.002*

Statistical Model 4 shows results for a multiple linear regression including neuropsychological variables that had a p value of <0.03 in Statistical Model 3 and adjusting as per Statistical Model 2. n=4431, 4403 and 4402 and R2=0.24, 0.17 and 0.23 for single, dual cognitive and dual motor gait speed.

Model 4 explain almost all of the variance in gait speed for each gait condition.

Statistical Model 4 found short term memory, speed of processing and sustained attention to be the most statistically significant cognitive contributors to gait speed variance for all gait conditions. Walking requires multiple cognitive processing tasks such as multi-sensory integration, spatial awareness and proprioception. Therefore, it follows that speed of processing and attention, an executive function, are therefore important for gait speed. Memory, the first cognitive domain to be affected by aging, is also highlighted here as an important factor in the walking speed of this healthy older adult sample.

In addition, in Statistical Model 3 and 4 executive function was found to be statistically significantly correlated to the dual cognitive walk only. This was reflected in reports from participants who found this dual walk more difficult than the single walk or dual motor walk. This result indicates that participants recruited executive function resources when performing the dual cognitive walk. Global cognition (MOCA) also affected gait speed when performing the dual cognitive walk and this may also be due to the large executive function component within MOCA.

This study found short term memory, speed of processing and sustained attention to be the most statistically significant cognitive contributors to gait speed for all gait conditions. These findings support similar studies by Mielke et al[4] and Watson et al[1] who found memory and executive function or attention to contribute to gait speed variance, however these studies did not probe speed of processing or sustained attention contributions. Future research should be undertaken to calculate percentage of variance that each cognitive subdomain contributes to gait speed using standardized beta coefficients. This increased understanding of the links between neurocognitive function and gait activity may aid in the diagnosis of motor cognitive dysfunctions and allow effective pre-emptive actions to be taken.

In addition, we hypothesize that for this healthy nationally representative population sample there is a link between neural processes involved in movement and cognition and this association differs depending on the gait task performed.

V. Conclusion

In this study it has been shown that memory, attentional and speed of processing capacity are statistically significantly correlated to the gait speed at which a person walks during simple and more complex gait tasks. Global cognition and executive function also play a role when simultaneously performing a motor and cognitive task. The nature and difficulty of the gait task affects the speed at which a person walks: the addition of a cognitive task causing a much larger reduction in gait speed than the addition of a motor task. This indicates that for this healthy nationally representative population sample there is a link between neural processes involved in movement and specific cognition sub-domains and this association and the neural resources involved differ depending on the gait task performed.

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