Do Differences in Spatiotemporal Gait Parameters Predict the Risk of Developing Depression in Later Life?

Robert Briggs, MB, BCh, BAO,† Daniel Carey, PhD,* Paul Claffey, MB, BCh, BAO,† Triona McNicholas, MB, BCh, BAO,*† Orna Donoghue, PhD,* Sean P. Kennelly, PhD,* and Rose Anne Kenny, MD*†*

BACKGROUND/OBJECTIVES: There is growing interest in the association between gait disturbance and depression in later life. The aim of this study is to clarify the longitudinal relationship between specific gait parameters and incident depression within a population-representative sample of older people.

DESIGN: Longitudinal analysis of spatiotemporal gait parameters at baseline (wave 1) and incident depression at 2 and 4 years (waves 2/3). Logistic regression models were used to assess the relationship between tertiles of gait parameters and incident depression.

SETTING: The Irish Longitudinal Study on Aging.

PARTICIPANTS: Over 3600 nondepressed community-dwelling people aged 50 years or older.

MEASUREMENTS: A score of 9 or greater on the eight-item Center for Epidemiological Studies Depression Scale at wave 2 or 3 was indicative of incident depression. The GAITRite system was used to measure gait speed, step length, step width, and double support phase during usual speed walking and under dual task conditions.

RESULTS: Participants with incident depression (344/3615) had slower gait speed (129.9 [95% confidence interval {CI} = 127.2-132.6] cm/s vs 134.1 [95% CI = 133.0-135.1] cm/s; F = 8.82; P = .003) and shorter step length (68.0 [95% CI = 66.9-69.2] cm vs 70.3 [95% CI = 69.9-70.7] cm; F = 13.99; P < .001) at baseline than those who did not develop depression. Logistic regression models demonstrated that those within the slowest tertile for gait speed and shortest tertile for step length had significantly increased likelihood of incident depression in fully adjusted models, with odds ratios of 1.54 (95% CI = 1.08-2.19) and 1.54 (95% CI = 1.01-2.35), respectively. Measures of step width and double support time were not associated with depression.

CONCLUSIONS: This study demonstrates that older people with incident depression have significantly slower gait speed and shorter step length at initial assessment. These findings are clinically significant given the impact both conditions have on functional status in later life, as well as the possibility that gait problems may represent a potentially modifiable risk factor for depression. **J Am Geriatr Soc 67:1050–1056, 2019.**

Key words: gait; depression; aging

Gait disorders affect around one third of community-dwelling older people aged 60 years or older, with prevalence increasing significantly with advancing age.[1] Given the wide range of processes that integrate to maintain gait and balance, there are multiple potential underlying causes of gait disturbance and these causes are generally defined as lower, middle, or higher level, depending on the level of the sensorimotor deficit involved.[2]

Causes of lower-level gait problems include osteoarthritis and peripheral neuropathy, while conditions associated with focal neurological deficits, such as stroke, Parkinson disease, or multiple sclerosis, cause middle-level deficits.[3] Higher-level gait disorders are those that cannot be explained by demonstrable deficits in the pyramidal, extrapyramidal, sensory, or cerebellar systems, and are related to cerebrovascular disease, particularly frontal white matter disease.[3]

Decline in gait is a consistent and reliable predictor of future functional status and mortality in later life.[4–6] Gait problems, particularly higher-level gait problems, are also closely linked with poorer brain health outcomes, increasing the risk of incident dementia, particularly vascular dementia.[7,8]

From the *The Irish Longitudinal Study on Ageing Trinity College Dublin, Dublin, Ireland; and the †Mercer's Institute for Successful Ageing, St James's Hospital, Dublin, Ireland.

Address correspondence to Robert Briggs, MB, BCh, BAO, The Irish Longitudinal Study on Ageing, Mercer's Institute for Successful Ageing, St James's Hospital, Dublin, Ireland. E-mail: briggsr@tcd.ie

DOI: 10.1111/jgs.15783

0002-8614/19/$15.00

There is also growing evidence linking gait disturbance with depression in later life.[9] Elevated late-life depressive symptoms are associated with slower gait velocity and shorter stride length,[10] and older adults with major depression have also been shown to have higher swing time variability than healthy controls.[11] In a cohort of depressed older people, slower gait speed was associated with an increased chance of persistent depressive symptoms.[12]

Late-life depression is associated with an increased risk of falls, which may be related to gait disturbance.[13] Importantly, cerebral white matter disease has also been shown to predict incidence of depression in later life, as well as poorer prognosis.[14]

To date, most work examining gait patterns in late-life depression is cross-sectional and longitudinal studies have not yet examined the role of specific gait characteristics as markers of risk. The aim of this study, therefore, is to clarify the longitudinal relationship between spatiotemporal gait parameters and incident depression within a large population-representative sample of community-dwelling older adults. Our hypothesis was that we could identify specific gait patterns, particularly slower walking speed and shorter step length, as both are seen in higher-level gait disorders, as a marker of an increased risk of incident depression.

METHODS

This is a longitudinal study examining the relationship between spatiotemporal gait parameters at baseline (wave 1) and incident depression at 4-year follow-up.

Ethics

The study was approved by the Faculty of Health Sciences Research Ethics Committee at Trinity College Dublin, and all participants gave informed written consent. All experimental procedures adhered to the Declaration of Helsinki. All health assessments were carried out by trained research nurses.

Study Design

This study is embedded within The Irish Longitudinal Study on Aging (TILDA), a large population-based study of a nationally representative sample of community-dwelling adults aged 50 years or older. The TILDA design has been outlined previously[15] but in short; participants were recruited using a stratified clustered procedure to randomly sample postal addresses from the Irish Geo-Directory (a listing of all residential addresses in the Republic of Ireland). All postal addresses in Ireland were assigned to 1 of 3155 geographic clusters; using RANSAM (a random sampling design for Ireland), a sample of 640 of these clusters was selected, stratified by socioeconomic group and geography, where all household residents aged 50 years or older were eligible to participate.

We analyzed data from the first, second, and third waves of TILDA collected between 2009 and 2015. Participants were included in this analysis if they were aged 50 years or older with no preexisting diagnosis of dementia at wave 1, completed screening for depression during the computer-assisted personal interview, and underwent a health assessment at wave 1, with complete data for gait assessment. Preexisting dementia was based on a prior physician's diagnosis of dementia only, so it is possible that some patients with clinical dementia who had not yet received a formal physician's diagnosis of same were included at wave 1.

Participants were excluded if they did not complete both 2- and 4-year follow-up, including assessment for depression at both waves 2 and 3.

Depression

Depressive symptoms were assessed at wave 1 using the 20-item Center for Epidemiological Studies Depression Scale (CES-D-20). A score of 16 or greater was used to define cases of depression.[16] Participants with depression at wave 1 were excluded from the study (n = 332).

At waves 2 and 3, the eight-item Center for Epidemiological Studies Depression Scale (CES-D-8) was used to screen for depression. Previous work has confirmed its reliability in comparison to the CES-D-20 in terms of internal consistency and factor structure within the TILDA cohort.[17] Therefore, the CES-D-8 was used to reduce the time taken to conduct participant assessments, as well as to reduce respondent burden and fatigue. Participants with a CES-D-8 score of 9 or greater at either wave 2 or 3 were defined as having incident depression.[18]

Scales were administered in participant's own home by a trained interviewer.

Gait

Spatiotemporal gait analysis was provided by the GAITRite system, a computerized mat with pressure sensors.[19] Participants started walking 2.5 m before the mat and stopped 2 m after the mat to allow for acceleration and deceleration. They completed two walks in each of three conditions: at usual walking pace; walking while carrying out a manual task (holding a glass of water); and walking while carrying out a cognitive task (reciting alternate letters of the alphabet [ie, A-C-E]). Data from the two walks in each condition were averaged (eg, the two "normal" walks were combined to yield one overall variable for normal walking); similarly, the two manual task walks were averaged and so on, and the following gait variables were obtained: gait speed, step length, step width, and double support phase.

Gait speed is defined as the distance covered by the body per unit time and is measured in cm/s. Step length is the distance between corresponding successive points of heel contact of the opposite foot. Step width is the side-to-side distance measured between the midline midpoint of one foot to the midline midpoint of the opposite foot. Double support phase is the time spent with both feet in contact with the floor, expressed as a percentage of the total gait cycle. Figure 1 shows details.

Other Measures

Further detailed social and biological data, including age, sex, educational attainment, smoking status, and body mass index (BMI), were also collected at wave 1. Blood pressure (BP) was measured twice in a seated position using the

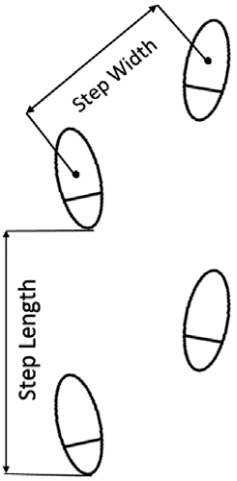

Figure 1. Step length and step width.

OMRON digital automatic BP monitor, and the mean value was used for analysis. Alcohol use was assessed using the CAGE (Cut Down, Angry, Guilty, Eye Opener) questionnaire.[20] Cardiovascular disease was defined as self-reported physician diagnosis of arrhythmia, angina, myocardial infarction, or cardiac failure. Cognitive status was assessed with the Montreal Cognitive Assessment (MOCA). Medication records were also examined for antidepressant use, specifically those with Anatomic Therapeutic Chemical (ATC) Classification N06A and benzodiazepine use (ATC N05BA).

Statistical Analysis

Data were analyzed using Stata (StataCorp).

Analysis was weighted for attrition. These weights corrected for the systematic difference in attrition rates over subgroups, reduced the bias caused by this difference in attrition rates, and were calculated based on the reciprocal of the probability of a wave 1 respondent taking part in wave 2 or wave 3. This probability was calculated using a logistic regression model. Factors in the model that were shown to affect attrition included measures of cognitive and behavioral health, marital status, and several health measures.

Normally distributed continuous variables were compared across groups using Student's *t*-test with adjusted Wald test and used postestimation. Proportional estimation was used for categorical variables, with Z score calculated postestimation.

Multilevel models with CES-D-8 score as the dependent variable nested within participant were used to compare data across specific time points by gait abnormalities, specifically tertiles of gait speed, and average marginal effects were calculated and graphed.

Logistic regression models, presenting odds ratios, were used to assess the longitudinal relationship between tertiles of gait parameters (gait speed, step length, step width, and double support time) and incident depression (developed depression/-did not develop depression at either wave 2 or wave 3).

Three regression models were tested: the first model was unadjusted; the second model adjusted for age, sex, educational attainment, BMI, smoking status, and excess alcohol intake; and the third model adjusted for baseline subthreshold depressive symptoms and additional clinical covariates, such as cardiac disease, cognitive impairment, and stroke. Variables were chosen a priori based on their likely probability of modifying the index relationship between gait and depression.

To exclude the effect of antidepressant use, models were rerun excluding all antidepressant users, regardless of their baseline depression status based on the CES-D-8.

$P \leq .05$ was considered statistically significant.

RESULTS

After exclusion of those meeting criteria for depression at wave 1, there were 4235 participants eligible for inclusion in the longitudinal analysis for incident depression. Of these participants, 15% (620/4235) did not complete 4-year follow-up and were therefore excluded, yielding a final study sample of 3615 participants who were included in the longitudinal analysis.

Almost 10% (344/3615) of the study sample met criteria for incident depression during follow-up (ie, they scored 9 or greater on the CES-D-8 at either wave 2 or wave 3). Those who had incident depression were more likely to be females with lower levels of educational attainment, and they had a higher prevalence of BMI of 30 kg/m^2 or greater. Table 1 provides details.

As shown in Table 2, participants who subsequently met criteria for incident depression had significantly slower gait speed and shorter step length under normal and manual task conditions. They also had a marginally shorter step width during cognitive dual task walking only. There was no difference in percentage of time spent in double support phase between groups during any of the walking conditions.

Figure 2 illustrates the significant difference in trajectory of depressive symptoms, as measured by CES-D-8 during 4-year follow-up, when stratified by tertiles of gait speed at wave 1. While there were no significant differences at baseline, those with a gait speed of less than 129.6 cm/s had a significantly higher burden of depressive symptoms at wave 2 (compared to those in the highest tertile of gait speed) and wave 3 (compared to both the middle and highest gait speed tertiles) after controlling for covariates, although mean CES-D-8 falls below the cutoff for depression diagnosis.

Logistic regression models demonstrate that those within the slowest tertile for gait speed (less than 126.9 cm/s) and shortest tertile for step length (less than 67.5 cm) have a significantly increased risk of incident depression in fully adjusted models. These findings remained consistent after removing participants taking antidepressants (n = 154) at baseline assessment from the analysis. There was no association with tertiles of step width and double support. Table 3 provides details.

The fully adjusted logistic regression output, with incident depression as the dependent variable and gait speed as the independent variable of interest, is shown in supplementary Table S1. Other variables significantly associated with incident depression include educational attainment, baseline subthreshold depressive symptoms, and benzodiazepine use.

DISCUSSION

This study demonstrates that older people with incident depression over a 4-year follow-up period have significantly

Table 1. Baseline Characteristics by Incident Depression[a]

Variable	Incident Depression (n = 344)	Not Depressed (n = 3271)	Statistics
Age, mean (95% CI), y	63.3 (61.8-64.8)	63.6 (63.1-64.1)	F = 0.15; *P* = .701
Female sex, Prop (95% CI)	0.58 (0.52-0.65)	0.50 (0.48-0.51)	Z = 2.82; *P* = .004
Educational attainment, Prop (95% CI)			
Primary	0.40 (0.34-0.47)	0.27 (0.25-0.30)	Z = 5.10; *P* < .001
Secondary	0.40 (0.34-0.46)	0.48 (0.46-0.50)	Z = -2.83; *P* = .005
Tertiary	0.20 (0.16-0.24)	0.24 (0.23-0.26)	Z = -1.66; *P* = .096
Body mass index, Prop (95% CI), kg/m^2			
<24.9	0.23 (0.18-0.28)	0.21 (0.20-0.23)	Z = 0.86; *P* = .389
25.0-29.9	0.37 (0.31-0.43)	0.47 (0.45-0.49)	Z = -3.54; *P* < .001
≥30.0	0.40 (0.34-0.47)	0.32 (0.30-0.34)	Z = 3.01; *P* = .003
Current smoker, Prop (95% CI)	0.21 (0.16-0.27)	0.15 (0.13-0.16)	Z = 2.92; *P* = .004
CAGE score ≥2, Prop (95% CI)[b]	0.14 (0.10-0.18)	0.11 (0.10-0.12)	Z = 1.68; *P* = .095
Systolic BP, mean (95% CI), mm Hg[c]	135.3 (132.6-138.0)	136.5 (135.6-137.3)	F = 0.67; *P* = .413
Cardiovascular disease, Prop (95% CI)[d]	0.15 (0.11-0.21)	0.14 (0.12-0.15)	Z = 0.51; *P* = .610
Stroke, Prop (95% CI)	0.01 (0.00-0.03)	0.01 (0.01-0.02)	Z = 0.00; *P* = 1.000
Osteoarthritis, Prop (95% CI)	0.17 (0.13-0.22)	0.13 (0.12-0.15)	Z = 2.10; *P* = .038
MOCA, mean (95% CI)	24.6 (24.1-25.0)	24.9 (24.8-25.1)	F = 1.97; *P* = .161
Antidepressant use, Prop (95% CI)	0.12 (0.08-0.16)	0.04 (0.03-0.05)	Z = 6.63; *P* < .001
Benzodiazepine use, Prop (95% CI)	0.06 (0.03-0.10)	0.02 (0.01-0.02)	Z = 4.60; *P* < .001

Abbreviations: BP, blood pressure; CI, confidence interval; MOCA, Montreal Cognitive Assessment; Prop, proportional estimation.

[a]Incident depression is eight-item Center for Epidemiological Studies Depression Scale score of 9 or greater at either wave 2 or wave 3 (ie, 2- and/or 4-year follow-up). Student's *t*-test used for continuous variables with adjusted Wald test postestimation. Prop used for categorical variables with Z score calculated postestimation.

[b]CAGE Alcohol Scale for Alcohol Problem.

[c]Systolic BP measured twice in seated position using OMRON digital cuff and average of two readings taken.

[d]Cardiovascular disease defined as self-report of angina, cardiac failure, myocardial infarction, or arrhythmia.

slower gait speed, and shorter step length, but no difference in step width or double support phase at initial assessment. On average, they walk over 4-cm/s slower than their peers who do not develop depression. Slower gait speed and shorter step length were associated with an increased risk of depression. The associations with these gait parameters remained

Table 2. Comparison of Baseline Gait Characteristics by Incident Depression[a]

Gait Variable	Incident Depression (n = 344)	Nondepressed (n = 3271)	Statistics
Gait speed, mean (95% CI), cm/s			
Normal walking	129.9 (127.2-132.6)	134.1 (133.0-135.1)	F = 8.82; *P* = .003
Manual task	126.6 (123.6-129.6)	131.5 (130.5-132.5)	F = 9.93; *P* = .002
Cognitive task	107.0 (103.8-110.1)	109.1 (107.8-110.3)	F = 1.56; *P* = .212
Step length, mean (95% CI), cm			
Normal walking	68.0 (66.9-69.2)	70.3 (69.9-70.7)	F = 13.99; *P* < .001
Manual task	66.3 (65.1-67.5)	68.9 (68.5-69.3)	F = 17.58; *P* < .001
Cognitive task	63.5 (62.1-64.9)	66.3 (65.8-66.8)	F = 14.14; *P* < .001
Step width, mean (95% CI), cm			
Normal walking	8.3 (8.1-8.5)	8.5 (8.4-8.6)	F = 3.66; *P* = .056
Manual task	8.3 (8.1-8.5)	8.6 (8.4-8.7)	F = 3.59; *P* = .059
Cognitive task	8.4 (8.1-8.6)	8.6 (8.5-8.8)	F = 4.59; *P* = .033
Double support phase, % (95% CI)			
Normal walking	25.5 (24.9-26.2)	25.4 (25.1-25.6)	F = 0.28; *P* = .590
Manual task	26.1 (25.5-26.8)	25.8 (25.6-26.1)	F = 0.72; *P* = .398
Cognitive task	27.2 (26.5-28.0)	26.9 (26.6-27.3)	F = 0.50; *P* = .478

Abbreviation: CI, confidence interval.

[a]Incident depression is eight-item Center for Epidemiological Studies Depression Scale score of 9 or greater at either wave 2 or wave 3 (ie, 2- or 4-year follow-up).

Student's *t*-test used for continuous variables with adjusted Wald test postestimation.

Gait speed, step length, step width, and double support phase measured using GAITRite system. Manual task involves carrying a glass of water. Cognitive task involves reciting alternate letters of the alphabet (ie, A-C-E).

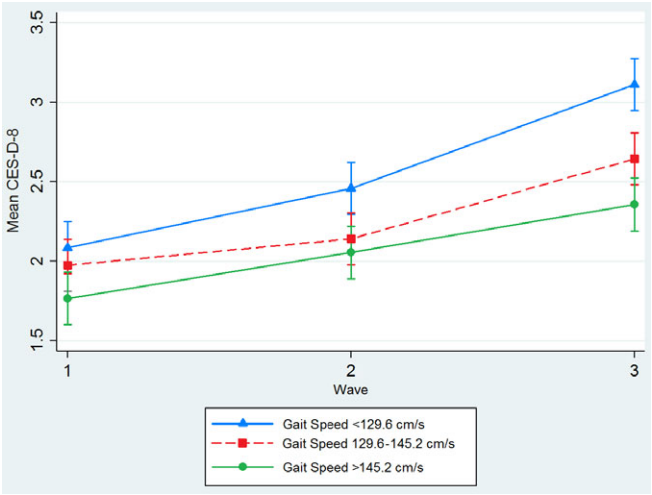

Figure 2. Mean eight-item Center for Epidemiological Studies Depression Scale (CES-D-8) at waves 1, 2, and 3 by gait speed tertiles. N = 3615. Multilevel model demonstrating trajectory of mean CES-D-8 scores at waves 1, 2, and 3 (ie, baseline and 2- and 4-year follow-up by tertiles of baseline gait speed at wave 1). Analysis controls for age, sex, educational attainment, body mass index, systolic blood pressure, alcohol excess (CAGE score of 2 or greater), cardiovascular disease (self-report of angina, cardiac failure, myocardial infarction, or arrhythmia), stroke, cognitive impairment (Mini-Mental State Examination score of 24 or less), and antidepressant use.

significant after controlling for important covariates, including sociodemographics, cardiovascular disease, systolic BP, smoking, and alcohol excess. Furthermore, findings did not change significantly when participants taking antidepressants at baseline were excluded from the analysis.

To our knowledge, this is the first longitudinal study to analyze the association between specific spatiotemporal gait measures and incident depression. We have previously shown that abnormal timed up and go (which measures the time taken to rise from a chair, walk 3 m, and return to seated position) predicted incident depression within the TILDA cohort.[21] Furthermore, longitudinal studies have demonstrated a close relationship between gait speed (analyzed during a 2.5– 3-m walk) and depressive symptoms but did not analyze specific spatiotemporal gait parameters.[22,23] This study also adds significantly to the evidence base in this field as it involves a large well-described cohort of community-dwelling older people and importantly the comprehensive TILDA data set allows us to control for a wide range of covariates, including subthreshold depressive symptoms, and cardiovascular markers.

A possible mechanism for the association we have found is cerebral white matter disease, reflected by white matter hyperintensities (WMHs) on brain magnetic resonance imaging. WMHs, particularly involving the frontal lobe, are more prevalent in older people with both depression and gait problems.[14,24] In parallel with gait disturbance, an increasing burden of white matter disease is also a marker for an increased risk of chronic depressive symptoms and lower remission rates.[25] Importantly, the characteristic higher-level gait disorder seen in this context involves problems with gait ignition, and short shuffling steps, consistent with the reduced gait speed and step length we have demonstrated in this study.[3]

Executive dysfunction, which is implicated in gait problems in later life,[26] is a common clinical feature of late-life depression, and often related to cerebral WMHs.[27] It has been suggested as a potential mediator for the link between depression and gait problems.[28] While some smaller studies have demonstrated a relationship between dual task gait and depression,[29,30] we found no association between gait speed and incident depression during the cognitive dual task walk, although the association with step length remained significant. An alternative explanation for the longitudinal relationship we have identified is that mobility restriction has an adverse effect on mood and well-being as a response to the limitations it imposes on independence and functional status in later life.

These findings are significant because, given current and future demographic shifts and increasing worldwide longevity,[31] unraveling and understanding associations between common late-life conditions that impact significantly on functional status is imperative.[32] Both depression and gait problems commonly coexist in later life,[33] and it appears that older people with a combination of both conditions are at particularly high risk of functional decline.[34]

Additionally, these findings raise the possibility that gait analysis could be used as a tool to identify those at higher risk of late-life depression. Depression in later life is difficult to diagnose, and older people are much less likely to present to a healthcare professional with mood-related symptoms.[35] Given the adverse outcomes associated with untreated depression in later life, including early mortality and functional decline,[36,37] it is important to identify older individuals at higher risk of developing depression to improve case finding and promote early intervention. However, any such tool would need to be tested against a clinical depression diagnosis rather than a tool such as the CES-D-8.

Furthermore, given recent evidence that physical exercise may be an effective adjunctive therapy in late-life depression,[38,39] this study also raises the possibility that exercise could also be used as a preventative strategy for depression, due to the beneficial effect it can have on gait and mobility in later life.[40] This hypothesis would need to be tested in carefully planned interventional studies, however.

There are some important limitations of this study that should be noted. Depression diagnosis is based on the CES-D-8, which has been validated for use in an older population but is not the gold standard for depression diagnosis, which remains a structured clinical interview. In addition, self-reported physician diagnosis was used to define cardiovascular disease and may, therefore, be subject to response bias. Furthermore, as stated previously, exclusion of participants with dementia at baseline was based on a prior physician's diagnosis only, so therefore this study may include some participants with undiagnosed dementia. Additionally, participants did not undergo clinical examination to exclude incipient dementia as part of this study. While it is difficult, therefore, to account for the fact that participants may develop dementia during follow-up, we controlled for MOCA at wave 1 in regression models, and by wave 3 only three participants included in the study had a new physician's diagnosis of dementia.

Table 3. Logistic Regression Reporting Odds Ratios With Incident Depression as Dependent Variable[a]

Gait Variable	Model 1	Model 2	Model 3	Model 4
Gait speed, cm/s				
Reference: gait speed >145.2				
Gait speed 129.6-145.2	1.26 (0.86-1.83)	1.24 (0.84-1.81)	1.17 (0.80-1.71)	1.24 (0.84-1.84)
Gait speed <129.6	1.78 (1.30-2.44)*	1.72 (1.22-2.43)**	1.54 (1.08-2.19)**	1.53 (1.05-2.25)**
Step length, cm				
Reference: step length >74.8				
Step length 67.5-74.8	1.47 (1.02-2.12)**	1.37 (0.93-2.03)	1.32 (0.89-1.95)	1.32 (0.87-2.00)
Step length <67.5	1.96 (1.42-2.70)*	1.81 (1.20-2.74)**	1.54 (1.01-2.35)*	1.70 (1.09-2.64)*
Step width, cm				
Reference: step width >9.4				
Step width 7.7-9.4	1.18 (0.83-1.68)	1.07 (0.74-1.56)	1.12 (0.76-1.65)	1.09 (0.73-1.64)
Step width <7.7	1.33 (0.95-1.86)	1.11 (0.71-1.72)	1.19 (0.76-1.85)	1.13 (0.71-1.81)
Double support, %				
Reference: double support >26.9				
Double support 23.5-26.9	0.77 (0.54-1.08)	0.83 (0.58-1.19)	0.86 (0.59-1.25)	0.80 (0.54-1.17)
Double support <23.5	0.81 (0.59-1.11)	0.89 (0.63-1.27)	0.92 (0.64-1.31)	0.95 (0.66-1.36)

[a]Data are given as odds ratio (95% confidence interval). N = 3615 (incident depression, n = 344; not depressed, n = 3271).
Logistic regression models with incident depression as dependent variable and gait parameters as independent variables. Model 1 is unadjusted; model 2 controls for age, sex, body mass index, educational attainment, smoking status, and alcohol excess; model 3 controls for model 2 covariates, as well as subthreshold depressive symptoms, cardiovascular disease (self-report of angina, cardiac failure, myocardial infarction, or arrhythmia), stroke, osteoarthritis, benzodiazepine use, Montreal Cognitive Assessment score, and systolic blood pressure; model 4 controls for model 3 covariates but excludes antidepressant users (n = 154) from analysis. Gait speed, step length, step width, and double support time measured using GAITRite system.
*$P < .05$.
**$P < .001$.

Strengths of this study include the large, well-described population of older adults who underwent advanced gait analysis, as well as robust 2- and 4-year follow-up assessment.

In conclusion, this study demonstrates that reduced step length and slower gait speed are independent predictors of incident depression in a large, nondepressed cohort of community-dwelling adults aged 50 years and older. These findings are important given the high prevalence of both gait problems and depression in later life, as well as the significant impact both conditions have on functional status, and further work examining the role of cerebral white matter disease, which is common to both conditions and may explain these findings, would be welcome.

ACKNOWLEDGMENTS

Financial Disclosure: Financial support was provided by the Irish Government, the Atlantic Philanthropies, and Irish Life plc.

Conflicts of Interest: The authors have no conflicts of interest to report.

Author Contributions: R.B. formulated the concept, designed the initial analysis, and wrote the manuscript. R.A.K. and S.P.K. assisted in formulation of the concept and supervised the study. D.C. advised and supervised statistical analysis and edited the manuscript. P.C. and T.M. provided clinical input to the manuscript. O.D. provided expertise on gait measures and assisted with analysis design and writing the manuscript.

Sponsor's Role: The funders had no involvement in the study design; collection, analysis, and interpretation of data; writing of the manuscript; or submission for publication. Any views expressed in this report are not necessarily those of the Department of Health and Children or of the Minister for Health.

REFERENCES

1. Mahlknecht P, Kiechl S, Bloem BR, et al. Prevalence and burden of gait disorders in elderly men and women aged 60-97 years: a population-based study. PLoS One. 2013;8(7):e69627.
2. Nutt JG, Marsden CD, Thompson PD. Human walking and higher-level gait disorders, particularly in the elderly. Neurology. 1993;43(2):268-279.
3. Briggs R, O'Neill D. Vascular gait dyspraxia. Clin Med (Lond). 2014;14(2):200-202.
4. White DK, Neogi T, Nevitt MC, et al. Trajectories of gait speed predict mortality in well-functioning older adults: the health, aging and body composition study. J Gerontol A Biol Sci Med Sci. 2013;68(4):456-464.
5. Studenski S, Perera S, Patel K, et al. Gait speed and survival in older adults. JAMA. 2011;305(1):50-58.
6. Heiland EG, Welmer AKK, Wang R, et al. Association of mobility limitations with incident disability among older adults: a population-based study. Age Ageing. 2016;45(6):812-819.
7. Allan LM, Ballard CG, Burn DJ, Kenny RAA. Prevalence and severity of gait disorders in Alzheimer's and non-Alzheimer's dementias. J Am Geriatr Soc. 2005;53(10):1681-1687.
8. Beauchet O, Annweiler C, Callisaya ML, et al. Poor gait performance and prediction of dementia: results from a meta-analysis. J Am Med Dir Assoc. 2016;17(6):482-490.
9. Lemke MR, Wendorff T, Mieth B, Buhl K, Linnemann M. Spatiotemporal gait patterns during over ground locomotion in major depression compared with healthy controls. J Psychiatr Res. 2000;34(4-5):277-283.
10. Brandler TC, Wang C, Oh-Park M, Holtzer R, Verghese J. Depressive symptoms and gait dysfunction in the elderly. Am J Geriatr Psychiatry. 2012;20(5):425-432.
11. Hausdorff JM, Peng C-K, Goldberger AL, Stoll AL. Gait unsteadiness and fall risk in two affective disorders: a preliminary study. BMC Psychiatry. 2004;4:39.

12. Sanders JB, Bremmer MA, Comijs HC, Deeg DJ, Beekman AT. Gait speed and the natural course of depressive symptoms in late life: an independent association with chronicity? J Am Med Dir Assoc. 2016;17(4):331-335.
13. Briggs R, Kennelly SP, Kenny RAA. Does baseline depression increase the risk of unexplained and accidental falls in a cohort of community-dwelling older people? data from The Irish Longitudinal Study on Ageing (TILDA). Int J Geriatr Psychiatry. 2018;33(2):e205-e211.
14. Wang L, Leonards CO, Sterzer P, Ebinger M. White matter lesions and depression: a systematic review and meta-analysis. J Psychiatr Res. 2014;56:56-64.
15. Whelan BJ, Savva GM. Design and methodology of The Irish Longitudinal Study on Ageing. J Am Geriatr Soc. 2013;61(suppl 2):S265-S268.
16. Vilagut G, Forero CG, Barbaglia G, Alonso J. Screening for depression in the general population with the Center for Epidemiologic Studies Depression (CES-D): a systematic review with meta-analysis. PLoS One. 2016;11(5):e0155431.
17. O' Halloran AM, Kenny RA, King-Kallimanis BL. The latent factors of depression from the short forms of the CES-D are consistent, reliable and valid in community-living older adults. Eur Geriatr Med. 2015;34(4):681-692.
18. Briggs R, Carey D, Kenny RA, Kennelly SP. Validation of the 8-item centre for epidemiological studies depression scale in a cohort of community-dwelling older people: data from The Irish Longitudinal Study on Ageing (TILDA). Eur Geriatr Med. 2018;9:121-126.
19. Webster KE, Wittwer JE, Feller JA. Validity of the GAITRite walkway system for the measurement of averaged and individual step parameters of gait. Gait Posture. 2005;22(4):317-321.
20. Bush B, Shaw S, Cleary P, Delbanco TL, Aronson MD. Screening for alcohol abuse using the CAGE questionnaire. Am J Med. 1987;82(2):231-235.
21. Briggs R, Carey D, Kenny RAA, Kennelly SP. What is the longitudinal relationship between gait abnormalities and depression in a cohort of community-dwelling older people? Data from The Irish Longitudinal Study on Ageing (TILDA). Am J Geriatr Psychiatry. 2018;26(1):75-86.
22. Sanders JB, Bremmer MA, Deeg DJ, Beekman AT. Do depressive symptoms and gait speed impairment predict each other's incidence? a 16-year prospective study in the community. J Am Geriatr Soc. 2012;60(9):1673-1680.
23. Demakakos P, Cooper R, Hamer M, de Oliveira C, Hardy R, Breeze E. The bidirectional association between depressive symptoms and gait speed: evidence from the English Longitudinal Study of Ageing (ELSA). PLos One. 2013;8(7):e68632.
24. Van der Holst HM, Tuladhar AM, Zerbi V, et al. White matter changes and gait decline in cerebral small vessel disease. Neuroimage Clin. 2018;17:731-738.
25. Taylor WD, Steffens DC, MacFall JR, et al. White matter hyperintensity progression and late-life depression outcomes. Arch Gen Psychiatry. 2003;60(11):1090-1096.
26. Yogev G, Hausdorff JM, Giladi N. The role of executive function and attention in gait. Mov Disord. 2008;23(3):329-472.
27. Smith EE, Salat DH, Jeng J, et al. Correlations between MRI white matter lesion location and executive function and episodic memory. Neurology. 2011;76(17):1492-1499.
28. Hajjar I, Yang F, Sorond F, et al. A novel aging phenotype of slow gait, impaired executive function, and depressive symptoms: relationship to blood pressure and other cardiovascular risks. J Gerontol A Biol Sci Med Sci. 2009;64A(9):994-1001.
29. Wright SL, Kay RE, Avery ET, Giordani B, Alexander NB. The impact of depression on dual tasking among patients with high fall risk. J Geriatr Psychiatry Neurol. 2011;24(3):142-150.
30. Gabel NM, Crane NA, Avery ET, et al. Dual-tasking gait variability and cognition in late-life depression. Int J Geriatr Psychiatry. 2015;30(11):1120-1128.
31. Christensen K, Doblhammer G, Rau R, Vaupel JW. Ageing populations: the challenges ahead. Lancet. 2009;374(9696):1196-1208.
32. Fabbri E, Zoli M, Gonzalez-Freire M, Salive ME, Studenski SA, Ferrucci L. Aging and multimorbidity: new tasks, priorities, and frontiers for integrated gerontological and clinical research. J Am Med Dir Assoc. 2015;16(8):640-647.
33. Hajjar I, Yang F, Sorond F, et al. A novel aging phenotype of slow gait, impaired executive function, and depressive symptoms: relationship to blood pressure and other cardiovascular risks. J Gerontol A Biol Sci Med Sci. 2009;64(9):994-1001.
34. Tsutsumimoto K, Doi T, Shimada H, et al. Combined effect of slow gait speed and depressive symptoms on incident disability in older adults. J Am Med Dir Assoc. 2016;17(2):123-127.
35. Briggs R, Tobin K, Kenny RAA, Kennelly SP. What is the prevalence of untreated depression and death ideation in older people? data from The Irish Longitudinal Study on Aging. Int Psychogeriatr. 2018;30:1-9.
36. Murphy E, Smith R, Lindesay J, Slattery J. Increased mortality rates in late-life depression. Br J Psychiatry. 1988;152:347-353.
37. Hybels CF, Pieper CF, Payne ME, Steffens DC. Late-life depression modifies the association between cerebral white matter hyperintensities and functional decline among older adults. Am J Geriatr Psychiatry. 2016;24(1):42-49.
38. Zanetidou S, Belvederi Murri M, Menchetti M, et al. Physical exercise for late-life depression: customizing an intervention for primary care. J Am Geriatr Soc. 2017;65(2):348-355.
39. Belvederi Murri M, Amore M, Menchetti M, et al. Physical exercise for late-life major depression. Br J Psychiatry. 2015;207(3):235-242.
40. VanSwearingen JM, Perera S, Brach JS, Wert D, Studenski SA. Impact of exercise to improve gait efficiency on activity and participation in older adults with mobility limitations: a randomized controlled trial. Phys Ther. 2011;91(12):1740-1751.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

Table S1. Fully Adjusted Logistic Regression Model With Incident Depression as Dependent Variable and Gait Speed as Independent Variable of Interest.