What Is the Relationship Between Orthostatic Blood Pressure and Spatiotemporal Gait in Later Life?

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BACKGROUND/OBJECTIVES: Little work to date has examined the relationship between gait performance and blood pressure (BP) recovery after standing in later life. The aim of this study is to clarify the association of orthostatic BP with spatiotemporal gait parameters in a large cohort of older people.

DESIGN: Cross-sectional study using multilevel linear regression to ascertain the difference in orthostatic BP patterns across tertiles of gait speed, and linear regression to analyze the association of orthostatic hypotension 30 seconds after standing (OH-30) with specific gait characteristics.

SETTING: The Irish Longitudinal Study on Ageing.

PARTICIPANTS: A total of 4311 community-dwelling adults, aged 50 years or older (mean age = 62.2 years; 54% female), one fifth (n = 791) of whom had OH-30.

MEASUREMENTS: Continuous orthostatic BP was measured during active stand. OH-30 was defined as a drop in systolic BP of 20 mm Hg or more or drop in diastolic BP of 10 mm Hg or more at 30 seconds.
Spatiotemporal gait was assessed using the GAITRite system, reporting gait speed, step length, step width, and double support time in both single and dual (cognitive task) conditions.

RESULTS: OH-30 was associated with slower gait speed (β = −3.01; 95% confidence interval [CI] = −4.46 to −1.56) and shorter step length (β = −.73; 95% CI = −1.29 to −.16) in fully adjusted models during single task walking. Similar findings were observed in dual task conditions, in addition to increased double support phase (β = .45; 95% CI = .02-.88). Multilevel models demonstrated that participants in the slowest tertile for gait speed had a significantly larger drop in systolic BP poststanding compared to those with faster gait speeds in single and dual task conditions.

CONCLUSIONS: This study demonstrates that slower recovery of BP after standing is independently associated with poorer gait performance in community-dwelling older adults. Given the adverse outcomes independently associated with OH and gait problems in later life, increasing awareness that they commonly coexist is important, particularly as both are potentially modifiable. **J Am Geriatr Soc 68:1286-1292, 2020.**

Keywords: blood pressure; gait; orthostatic hypotension

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Gait problems affect over 1 in 10 community-dwelling adults aged 60 to 69 years[1] and one-third of adults aged 70 years and older.[2] Specific gait impairments, such as slower gait speed, shorter step length, and increased gait variability, strongly predict falls,[3,4] while slow gait speed also predicts other adverse outcomes, such as fractures, disability, institutionalization, cognitive decline, and mortality.[5-8]

Orthostatic hypotension (OH), defined as a persistent fall in systolic blood pressure (BP) of at least 20 mm Hg and/or a fall in diastolic BP of at least 10 mm Hg within 3 minutes of standing,[9] occurs in 7% of community-dwelling adults aged 50 years and older[10] and is also a frequent cause of falls in older people.[11,12] It is common clinically to see gait problems and OH coexisting in older patients, particularly those who are frail or recurrent fallers.[13] OH is an important cause of cerebral hypoperfusion, often presenting with postural dizziness, which can affect gait directly by causing unsteadiness and sway.[14]

OH has also been associated with poorer global cognitive function and executive function.[15,16] The link between cognitive function, especially executive function and attention, with gait and falls has been well established.[17,18] The dual task paradigm is often used, whereby individuals are asked to walk while carrying out another task simultaneously; these competing demands generally result in reduced performance in walking, the additional task, or both, and particularly so in those with neurological conditions.[17] Changes in dual task performance have been associated with an increased risk of falls in older adults, particularly frail older adults.[19]

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It is important to unravel interrelated clinical risk factors, such as OH and gait problems, to inform strategies for prevention of falls and disability in later life. These conditions may coexist because they have shared risk factors, such as cardiovascular disease and impaired cognitive function, or because they have a direct relationship with each other. It is surprising therefore that little work to date has examined the association of gait problems with OH within an older cohort.[20] The aim of this study is to utilize the comprehensive data set of The Irish Longitudinal Study on Ageing (TILDA) to explore the cross-sectional relationship of beat-to-beat orthostatic BP with spatiotemporal gait parameters during single and dual task walking conditions in a large cohort of community-dwelling adults aged 50 years and older.

METHODS

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.

Study Design

TILDA is a large nationally representative, population-based study of 8504 community-dwelling adults aged 50 years and older. TILDA study design has been outlined previously.[21] We analyzed data from the first wave of TILDA collected between 2009 and 2011. There were three components to data collection: a computer-assisted personal interview performed by social interviewers in the participants' own home; a self-completion questionnaire completed and returned by the participant; and a comprehensive center-based health assessment or a modified home-based health assessment performed by trained research nurses.

Participants were eligible for this analysis if they were aged 50 years or older and attended a center-based health assessment at wave 1. Participants were excluded if they did not have gait or active stand data available for analysis. Supplementary Figure S1 provides a flow diagram for study recruitment.

TILDA participants who were excluded (n = 4193) were older, with a mean age of 64.1 ± 11.9 years compared to 62.2 ± 8.1 years ($P = .001$) and more likely to be female (57%; $P = .001$). There were no differences between groups in terms of heart disease (14% vs 13%; $P = .0145$), but the excluded participants were four times more likely to have cognitive impairment (12% vs 3%; $P < .001$).

Orthostatic BP

Continuous orthostatic BP was measured during active stand using a Finometer Midi (Finapres Medical Systems).[10] Briefly, participants lay in the supine position for 10 minutes in a quiet room, before standing in a timely manner aided by a

Table 1. Baseline Characteristics by OH-30

Characteristic	OH-30 (n = 791 [18%])	Not OH-30 (n = 3520 [82%])	Analysis
Age, mean (SD), y	65.8 (8.9)	61.4 (7.7)	$t = -13.92$; $P < .001$
Female, % (No.)	60 (471)	53 (1848)	$X^2 = 12.90$; $P < .001$
BMI, % (No.)			
<25 kg/m^2	27 (217)	21 (726)	$X^2 = 19.85$; $P < .001$
25-29.9 kg/m^2	43 (340)	45 (1,568)	
30-34.9 kg/m^2	21 (164)	25 (890)	
>35 kg/m^2	9 (70)	10 (336)	
Leg length, mean (SD), cm	103.2 (6.2)	103.6 (7.8)	$t = 1.21$; $P = .225$
Systolic BP, mean (SD), mm Hg[a]	138.4 (20.2)	133.9 (19.0)	$t = -5.96$; $P < .001$
Cardiovascular disease, % (No.)[b]	17 (136)	12 (426)	$X^2 = 14.77$; $P < .001$
Stroke, % (No.)	1 (10)	1 (37)	$X^2 = 0.27$; $P = .818$
Diabetes, % (No.)	9 (71)	6 (203)	$X^2 = 11.17$; $P = .001$
Depressive symptoms, % (No.)[c]	9 (75)	8 (286)	$X^2 = 1.55$; $P = .213$
CAGE alcohol score, % (No.)			
CAGE <2	81 (644)	78 (2,747)	$X^2 = 4.75$; $P = .093$
CAGE ≥2	10 (82)	13 (453)	
Did not complete	8 (65)	9 (320)	
Arthritis, % (No.)	31 (242)	26 (906)	$X^2 = 7.79$; $P = .005$
Parkinson's disease, % (No.)	1 (6)	<1 (8)	$X^2 = 5.63$; $P = .018$
Polypharmacy, % (No.)[d]	22 (176)	13 (473)	$X^2 = 39.23$; $P = .001$
MMSE score, mean (SD)	28.3 (2.0)	28.7 (1.8)	$t = 4.81$; $P < .001$
Cognitive impairment, % (No.)[e]	5 (43)	3 (96)	$X^2 = 15.19$; $P < .001$

Note. Student's *t*-test used for continuous variables; χ^2 test used for categorical variables.

Abbreviations: BMI, body mass index; BP, blood pressure; CAGE, Cut Down, Angry, Guilty, Eye Opener Alcohol Scale; OH-30, orthostatic hypotension at 30 seconds poststanding; MMSE, Mini-Mental State Examination.

[a]Measured twice in seated position using Omron digital cuff, and mean value calculated.

[b]Defined as self-report of angina, prior myocardial infarction, or cardiac failure.

[c]Defined as a score of 16 or greater on the 20-item Center for Epidemiological Studies Depression Scale.

[d]Polypharmacy defined as taking five or more medications, excluding supplements, based on examination of participant's medication lists.

[e]Defined as a score of 24 or less on the MMSE.

research nurse if necessary. Baseline BP values were an average of the readings obtained between 30 and 60 seconds before standing. After standing, BP and heart rate were monitored for a further 120 seconds.

OH 30 seconds after standing (OH-30) was defined as per consensus guidelines as a drop in systolic BP of 20 mm Hg or more or drop in diastolic BP of 10 mm Hg or more at 30 seconds compared to baseline BP.[9] The time of 30 seconds was chosen as the cutoff point in this analysis as prior work looking at normative changes in phasic BP in TILDA cohort established that an initial BP drop immediately after standing is common but nonrecovery of BP should be considered abnormal by 30 seconds.[10] Further work within TILDA cohort has shown that OH at 30 or 40 seconds is predictive of adverse outcomes, including depression[22] and unexplained falls,[12] while lower orthostatic BP within 60 seconds of standing is strongly related to dizziness and adverse outcomes, such as syncope, injury, or death.[11]

Gait Parameters

Spatiotemporal gait was assessed using the validated GAITRite system (active area = 4.88 m), a computerized mat with pressure sensors.[23] 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 two separate conditions: at usual walking pace (single task condition) and walking while carrying out a cognitive task (reciting alternate letters of the alphabet [ie, A-C-E, etc). Data from the two walks in each condition were combined and the following average gait variables were obtained: gait speed, step length, step width, and double support phase. Right leg data were utilized in this analysis.

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

Other Measures

Detailed social and biological data were also collected. BP was measured in the seated position using an OMRON digital automatic BP monitor; the average of two measures was used in the analysis. Alcohol excess was assessed using the Cut Down, Angry, Guilty, Eye Opener (CAGE) Alcohol Scale. Cardiovascular disease was defined as self-reported physician diagnoses of angina, prior myocardial infarct, or cardiac failure. Self-reported physician diagnoses were also elicited for prior stroke, diabetes, arthritis, and Parkinson's disease. Medication lists were examined for each participant, and polypharmacy was defined as being prescribed five or more medications other

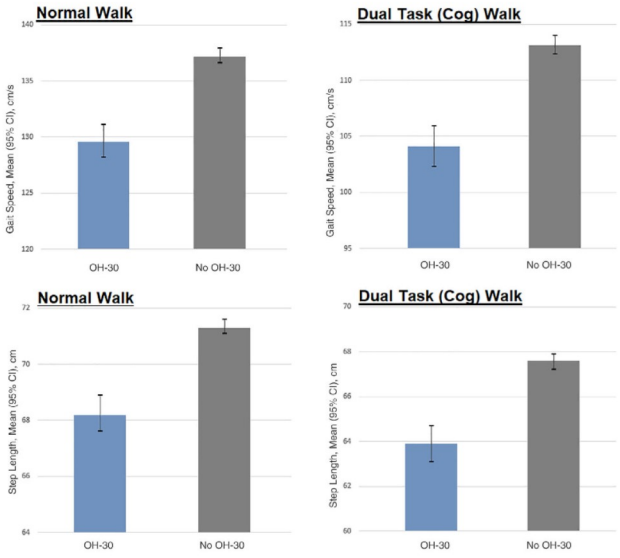

Figure 1. Differences in gait speed and step length by orthostatic hypotension at 30 seconds poststanding (OH-30). Gait speed and step length are measured using GAITRite system. CI indicates confidence interval; Cog, cognitive dual task walk. [Color figure can be viewed at wileyonlinelibrary.com]

Table 2. Comparison of Gait Characteristics by OH-30

Characteristics	OH-30 (n = 791)	Not OH-30 (n = 3520)	Analysis
Gait speed, mean (95% CI), cm/s			
Normal walking	129.6 (128.2-131.1)	137.2 (136.6-137.9)	$t = 9.72$; $P < .001$
Dual task (cognitive)	104.1 (102.3-105.9)	113.1 (112.3-114.0)	$t = 8.88$; $P < .001$
Step length, mean (95% CI), cm			
Normal walking	68.2 (67.6-68.9)	71.3 (71.1-71.6)	$t = 9.13$; $P < .001$
Dual task (cognitive)	63.9 (63.1-64.7)	67.6 (67.2-67.9)	$t = 8.78$; $P < .001$
Step width, mean (95% CI), cm			
Normal walking	8.3 (8.1-8.5)	8.5 (8.4-8.5)	$t = 2.33$; $P = .0194$
Dual task (cognitive)	8.4 (8.1-8.6)	8.5 (8.4-8.6)	$t = 1.47$; $P = .1424$
Double support phase, mean (95% CI), %			
Normal walking	25.7 (25.3-26.0)	25.0 (24.9-25.2)	$t = -3.75$; $P = .0002$
Dual task (cognitive)	27.6 (27.1-28.1)	26.4 (26.3-26.6)	$t = -5.27$; $P < .001$

Note. Gait speed, step length, step width, and double support phase measured using GAITRite system.
Abbreviations: CI, confidence interval; OH-30, orthostatic hypotension at 30 seconds poststanding.

than supplements. Depression was defined as a score of 16 or greater on the 20-item Center for Epidemiological Studies Depression Scale.[24] Cognitive impairment was defined as a Mini-Mental State Examination (MMSE) score of 24 or less.

Statistical Analysis

Data were analyzed using Stata 14 (Statacorp).

Normally distributed continuous variables were described as means and SDs and compared using Student's *t*-test. Categorical variables were compared using the χ^2 test.

Linear regression models were used to analyze the association of OH-30 with specific gait characteristics (ie, gait speed, step length, step width, and double support time). Three models were tested: the first model was unadjusted; the second model adjusted for age, sex, and body mass index; and the third model adjusted for clinical covariates, specifically seated systolic BP, cardiovascular disease (angina, prior myocardial infarct, or cardiac failure), stroke, diabetes, polypharmacy, alcohol excess, depressive symptoms, arthritis, Parkinson's disease, and cognitive impairment.

Multilevel linear regression models were used to model the difference in systolic BP from baseline as repeated measurements nested within participant across tertiles of gait speed. Average marginal effects and marginal means at each 10-second time point were derived from these models. The marginal effect is a measure of the effect that a difference in an explanatory variable (ie, second or third gait speed tertile vs first tertile) has on the mean of the outcome variable, when other covariates are kept constant. This allows us to control for covariates at the individual level and clarify what the average difference in mean outcome was across individuals.

RESULTS

Almost one-fifth (791/4311 [18%]) of the study sample had OH-30. Table 1 demonstrates the baseline characteristics of the sample by diagnosis of OH-30. Participants with OH-30 were older, were more likely to be female, had a history of cardiovascular disease, diabetes, Parkinson's disease, and

Table 3. β Coefficients With 95% Confidence Intervals From Linear Regression Models With OH-30 Regressed on Single and Dual Task Gait

Model	Gait Speed, cm/s	Step Length, cm	Step Width, cm	Double Support, %
Single Task Gait				
1	−7.60 (−9.13 to −6.07)**	−3.13 (−3.80 to −2.46)**	−.18 (−.33 to −.03)*	.63 (.30 to .96)**
2	−4.07 (−5.50 to −2.65)**	−1.22 (−1.78 to −.67)**	−.01 (−.14 to .13)	.37 (.06 to .68)*
3	−3.01 (−4.46 to −1.56)**	−.73 (−1.29 to −.16)*	.01 (−.13 to .14)	.21 (−.11 to .53)
Dual Task Gait (Cognitive)				
1	−9.03 (−11.02 to −7.04)**	−3.67 (−4.49 to −2.85)**	−.16 (−.36 to .05)	1.14 (.72 to 1.57)**
2	−5.04 (−6.97 to −3.10)**	−1.45 (−2.14 to −.76)**	−.00 (−.21 to .20)	.68 (.28 to 1.09)*
3	−4.17 (−6.17 to −2.18)**	−.94 (−1.66 to −.23)*	.02 (−.19 to .24)	.45 (.02 to .88)*

Note. Reference group is participants without OH-30. N = 4311.
Model 1 is unadjusted; model 2 controls for age, sex, and body mass index; model 3 controls for model 2 covariates, as well as systolic blood pressure, cardiovascular disease (angina, prior myocardial infarct, or cardiac failure), stroke, diabetes, polypharmacy (prescribed five or more medications other than supplements), alcohol excess (based on CAGE scale), depression (≥16 on the 20-item Center for Epidemiological Studies Depression Scale), arthritis, Parkinson's disease, and cognitive impairment (Mini-Mental State Examination score ≤24).
Abbreviation: CAGE, Cut Down, Angry, Guilty, Eye Opener Alcohol Scale; OH-30, orthostatic hypotension at 30 seconds poststanding.
*$P < .05$; **$P < .001$.

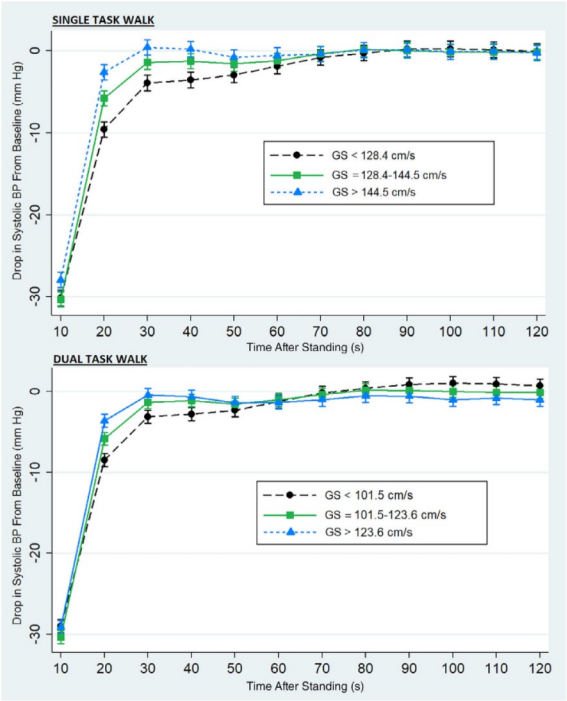

Figure 2. Adjusted marginal mean change in systolic blood pressure (BP) after standing by gait speed (GS) tertile. *Note*. N = 4311. Adjusted for age, sex, body mass index, seated systolic blood pressure, history of cardiovascular disease (angina, myocardial infarction, or congestive cardiac failure), diabetes, polypharmacy, alcohol excess, depressive symptoms, arthritis, cognitive impairment, and Parkinson's disease. Systolic BP measured continuously during active stand by Finometer and compared to baseline BP (ie, lying down before standing).

arthritis, and had higher rates of polypharmacy. Mean systolic BP was higher in the OH-30 group also.

Figure 1 and Table 2 compare gait characteristics by presence of OH-30. Participants with OH-30 walked on average 7.6 cm/s slower than their peers who did not have OH-30 during normal walking conditions and 9 cm/s slower during the cognitive dual task walk.

The OH-30 group also had a step length 3.1 cm shorter during normal walking conditions and 3.7 cm shorter step length during cognitive dual task walking. Differences in step width and double support phase between groups were less marked, with a shorter step width in the OH-30 group in normal walking conditions only.

Table 3 demonstrates results from linear regression models, with OH-30 regressed on gait parameters in both single and dual task conditions. OH-30 was associated with significantly slower gait speed and shorter step length in both conditions in fully adjusted models, while increased time spent in double support was independently associated with OH-30 in cognitive dual task walking only.

As shown in Figure 2, participants in the third (ie, the slowest) tertile for gait speed had a significantly larger drop in systolic BP poststanding compared to those with faster gait speeds after adjusting for covariates in both single and dual task conditions. Differences were significant between 20 and 50 seconds after standing.

DISCUSSION

This study demonstrates that OH and slower recovery of BP after standing are associated with poorer gait performance during single and dual task walking conditions in community-dwelling older adults. Older adults with OH-30 walk 7.8 cm/s slower than their peers without OH-30, have

shorter step length, and spend longer in double support when walking. These negative associations with gait speed and step length remained significant in all walking conditions after controlling for important covariates, including cardiovascular disease, polypharmacy, stroke, diabetes, and depression. An independent association between OH-30 and increased double support in the cognitive dual task condition was also observed.

The results of this analysis confirm a relationship that we regularly see in a clinical setting, but to the authors' knowledge, this is the first article to examine these associations in community-dwelling adults. Existing research is limited to three studies with fewer than 50 participants. Gray-Miceli et al found that older adults with OH in long-term care were less likely to walk in a steady line[25] while Nair et al demonstrated that postprandial hypotension was associated with changes in gait speed and double support time.[26] Older adults with a history of falls and OH have also been shown to spend longer in stance than nonfallers and had lower stance and swing time variability than non-OH fallers but not controls.[27] This study therefore adds significantly to existing literature in this field by including a large, well-described population-based cohort of community-dwelling adults, using continuous beat-to-beat values of orthostatic BP alongside spatiotemporal gait analysis.

Several potential mechanisms could underpin the observed associations. OH often causes dizziness, which can directly affect balance, particularly just after standing, leading to increased sway, unsteadiness, and slower gait and a need to maintain double support.[28] Furthermore, self-reported unsteadiness during walking predicts fear of falling, fear-related activity restriction, and recurrent falls,[29] which have also been associated with gait impairments,[30] possibly due to deconditioning effects.[31] Conversely, prolonged bed rest and immobility, which may occur in the setting of mobility problems or gait disturbance, have been shown to cause OH, but this is unlikely to be applicable in this cohort.[32]

While OH and gait disturbance are also more likely to occur in the context of multimorbidity and chronic disease,[33,34] we robustly controlled for a wide range of competing clinical conditions in this study, including cardiovascular and cerebrovascular disease, diabetes, arthritis, and depression, as well as polypharmacy. Both OH and gait problems are also closely linked with cognition, particularly executive function and attention.[18,35] Executive function is particularly relevant during dual task conditions,[17] and this study confirms an association between OH and gait during dual task conditions.

The most commonly cited mechanism by which OH can impact cognition and gait is via cerebral hypoperfusion.[36] Impaired brain blood flow secondary to OH may disrupt important neural networks involved in regulation of gait and balance[37] and this is supported by studies demonstrating cerebral blood flow changes measured by transcranial Doppler during executive function tasks are associated with slower walking speed,[38] narrower step width, shorter stride length, and longer double support time.[39]

Several neurodegenerative diseases have also previously been shown to be strongly linked with OH and poorer orthostatic BP recovery.[40] While there are relatively few participants in this study with Parkinson's disease (n = 14) and cognitive impairment (defined as MMSE ≤24; n = 139), we demonstrate higher rates of both conditions in those with OH. These associations are unlikely to fully explain our findings, however, as they only represent less than 4% of participants included in the study.

While consensus guidelines for diagnosis of OH generally refer to time points ranging from 0 to 120 seconds, we have used OH-30 for this analysis based on previous work within TILDA demonstrating that nonrecovery of BP to baseline after standing should be considered abnormal by 30 seconds.[10] Additionally, our multilevel models examining changes in systolic BP poststanding by gait speed tertile show that the greatest differences in BP trajectory across groups occur in this 20- to 50-second period after standing, suggesting that this time period is the most important when examining the relationship between orthostatic BP and gait.

There are limitations to this study that should be noted. Information regarding the prevalence of cardiovascular and other chronic diseases is based on self-report rather than objective measures. Importantly, analysis is cross-sectional and therefore it is not possible to confirm the direction of the association between OH and gait. TILDA sample is relatively young and healthy at baseline and composed of white Irish adults, limiting generalizability to other groups of older adults. The sample included in this analysis completed a health center–based assessment; these participants were younger and performed better in physical and cognitive tests compared to those who completed a home-based assessment.[41] The observed associations may have been stronger if they included this frailer cohort however. Key strengths of this study include the large sample size, use of continuous BP monitoring, and comprehensive, objective assessment of gait performance.

In conclusion, this study demonstrates that OH was independently associated with poorer gait performance, specifically slower gait speed and shorter step length in single and dual task walking and increased double support phase during dual task walking in a large cohort of community-dwelling older adults. Given the adverse outcomes independently associated with OH and gait problems in later life, including falls, cognitive decline, and early mortality, increasing the awareness that these age-related conditions commonly coexist is important, particularly as they are both potentially modifiable. Further longitudinal analyses identifying the direction of this relationship would therefore be welcome.

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Author Contributions: R.B. formulated the concept, designed the initial analysis, and wrote the manuscript. M.D.L.O. and O.A.D. assisted in formulation of the concept, analysis design, and writing the manuscript. D.C. advised on and supervised statistical analysis. L.N. edited the manuscript and provided expertise on gait measures. R.A.K. supervised the study, assisted in designing the analysis, and edited the manuscript.

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SUPPORTING INFORMATION

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

Supplementary Figure S1: Flow diagram of study recruitment.