Research Practice

Automatic Quantification of Tandem Walking Using a Wearable Device: New Insights Into Dynamic Balance and Mobility in Older Adults

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Abstract

Background: Wearable sensors are increasingly employed to quantify diverse aspects of mobility. We developed novel tandem walking (TW) metrics, validated these measures using data from community-dwelling older adults, and evaluated their association with mobility disability and measures of gait and postural control.

Methods: Six hundred ninety-three community-dwelling older adults (age: 78.69 ± 7.12 years) wore a 3D accelerometer on their lower back while performing 3 tasks: TW, usual-walking, and quiet standing. Six new measures of TW were extracted from the sensor data along with the clinician's conventional assessment of TW missteps (ie, trip other loss of balance in which recovery occurred to prevent a fall) and duration. Principal component analysis transformed the 6 new TW measures into 2 summary TW composite factors. Logistic regression models evaluated whether these TW factors were independently associated with mobility disability.

Results: Both TW factors were moderately related to the TW conventional measures ($r < 0.454$, $p < .001$) and were mildly correlated with usual-walking ($r < 0.195$, $p < .001$) and standing, postural control ($r < 0.119$, $p < .001$). The TW frequency composite factor ($p = .008$), but not TW complexity composite factor ($p = .246$), was independently associated with mobility disability in a model controlling for age, sex, body mass index, race, conventional measures of TW, and other measures of gait and postural control.

Conclusions: Sensor-derived TW metrics expand the characterization of gait and postural control and suggest that they reflect a relatively independent domain of mobility. Further work is needed to determine if these metrics improve risk stratification for other adverse outcomes (eg, falls and incident disability) in older adults.

Keywords: Aging, Disability, Gait, Mobility, Wearable sensors

Tandem walking (TW) is commonly employed to evaluate mobility in various clinical settings (1). For TW testing, a participant is asked to walk heel to toe on a straight-line for a fixed distance. In general, TW is more difficult to perform than usual-walking since the reduced base of support challenges the postural control system (2). Thus, TW tests may have utility in capturing meaningful aspects of

dynamic balance and mobility, potentially probing additional facets of aging and pathology beyond those gleaned from tests of standing and usual-walking.

Tandem walking is typically assessed by recording the time to complete the task and the number of missteps that occur during the test (3–5). These summary measures, however, do not

necessarily provide information about the possible underlying cause of a documented impairment and provide only a general description of performance deficits. The quantitative assessment of the 3-dimensional movements of the body may enhance the clinical utility of this test and facilitate the identification of the factors that contribute to impaired TW. Moreover, the use of a body-worn sensor has the potential to provide a more accurate reflection of dynamic balance by capturing additional measures that cannot be assessed by visual or clinical observation alone. To date, there is a paucity of work that has employed wearable sensors to characterize the TW beyond the conventional clinical measure of time to completion and missteps.

The present study develops new measures of TW based on signals recorded from a single body-fixed, wearable sensor worn during mobility testing. We extracted these measures from data collected in community-dwelling older adults and used principal component analysis (PCA) to summarize these measures into 2 composite factors. More specifically, we aimed to capture aspects of the TW that are not readily ascertained via clinical observation; in this way, the new measures have the potential to add to the value of the test. We examined the association between these new TW composite factors and other sensor-derived gait metrics based on self-paced, usual-walking, and standing posture. Then, in cross-sectional analyses, we examined if these new TW composite factors are associated with mobility disability when controlling for conventional TW measures and other gait measures. We hypothesized that the new, quantitative measures of TW would be associated with the 2 conventional TW measures and other measures of usual-walking and balance, supporting the validity of these new composites. Further, we hypothesized that the new TW composite factors would be independently related to the severity of mobility disability, supporting the utility of these new metrics.

Method

Participants

Community-dwelling older adults from 2 community-based cohort studies were included in this analysis. Rush Memory and Aging Project (MAP) (6) is a community-based, longitudinal clinical-pathologic study of chronic conditions of aging which was begun in 1997 in the Chicago area. The Minority Aging Research Study (MARS) (7) began in 2004 and involves annual clinical evaluations of older Black adults in the Chicago area recruited from the community. For both studies, older adults are eligible if they have no prior diagnosis of dementia. Instrumented gait testing (DynaPort MiniMod Hybrid Module, McRoberts B.V., The Hague, The Netherlands) was added to both studies in 2012. For the current study, we included all participants who had wearable sensor data and mobility disability data; for participants with such data in more than one testing cycle, in the present cross-sectional analyses, we evaluated data from the first time that data were available from that participant (MAP: $N = 382$; MARS: $N = 311$). All participants provided informed written consent before participating. The study was in accordance with the latest version of the Declaration of Helsinki and was approved by the Institutional Review Board of Rush University Medical Center. All participants performed the 8-ft TW, a self-paced 32-ft walk, and the quiet standing task for 20 seconds. Outliers, defined as values more than 3 times of the standard deviation away from the mean, were identified and removed (MAP: $N = 32$; MARS: $N = 23$).

Assessment of TW and Other Mobility Performances

Three performances were analyzed in this study. (i) Eight-foot TW: Participants were instructed to put one foot in front of the other foot in such a manner that the heel of the second foot touches the toe of the first foot and walk at a comfortable pace. The number of missteps and the time duration during this task were collected by the clinical assessor. A misstep was defined as a loss of balance in which the participant needed to step out to maintain balance. (ii) Thirty-two-foot walk: Participants walked at their self-selected speed on a marked 8-ft course back and forth twice without stopping. (iii) Standing posture: Participants were asked to stand for 20 seconds in a comfortable position, with their feet about shoulder-width apart, once with their eyes open and then with their eyes closed. The position of the feet was similar in both standing tasks to minimize the effect of feet position on sway.

During the performance of these 3 tasks, all participants wore a portable small, light-weight body-fixed sensor (DynaPort MiniMod Hybrid Module, McRoberts B.V.). The sensor was worn on a neoprene belt placed on the lower back at the level of the anterior iliac crest. This position roughly corresponds to the body's center-of-mass. The sensor weighs 74 g and its dimensions are $87 \times 45 \times 14$ mm. The device includes a triaxial accelerometer that measures the acceleration of the center-of-mass in 3 directions: vertical (V), medial-lateral (ML), anterior-posterior (AP). The sensor range and resolution are ± 2 g and ± 1 mg, respectively, for the acceleration signals. The sensor also includes a triaxial gyroscope that measures the angular (ie, rotational) velocity around the body's center-of-mass in 3 directions: yaw (rotation around the vertical axis), pitch (rotation around the ML axis), and roll (rotation around the AP axis). For each of the angular velocity signals, the range and resolution are ± 100 deg/s and ± 0.0069 deg/s, respectively.

Extraction of TW Measures

Six kinematic-analysis measures of TW were extracted from 100 Hz raw acceleration data in both ML and AP directions. Step detection was estimated from the acceleration signal in the AP axis by (i) band-pass filtering the acceleration signal between 0.5 and 2.5 Hz and (b) detecting the interpeak intervals by finding the local minimum peaks to estimate step duration (s) as shown in Figure 1. To capture a measure of the postural corrections used to stabilize the body during the performance of the TW, we determined the high to low frequency band ratio from the power spectral density (PSD) from the ML axis. It was calculated as the area under the curve of the PSD in the 1.25–4 Hz band to the 0.25–1.25 Hz band from ML axis (au). To assess overall movement during the TW, we calculated the signal vector magnitude (SVM) of the acceleration signal from 3 axes normalized by the test duration ($SVM = \frac{\sqrt{\text{vertical}^2 + \text{medial-lateral}^2 + \text{anterior-posterior}^2}}{\text{test duration}}$) (m/s^3). To quantify regularity and complexity in the time series of the TW, we estimated the sample entropy (8) (au) from the ML and AP directions. We also quantified the standard deviation of the acceleration signals from the ML direction (STD ML [m/s^2]).

Other Mobility Metrics

Prior work in this cohort developed gait and balance composite factors in older community-dwelling adults using PCA to summarize different aspects of gait and balance (9–11). Following this, we analyzed 6 gait and balance composite factors from 3 tests: usual-walking, quiet standing with eyes opened, and quiet standing with eyes closed.

Figure 1. Representative signals of 2 participants with good (left panel) and poor (right panel) tandem walk (TW) performance. (A, B) Raw acceleration signals and bandpassed signals from the anterior-posterior (AP) axis in the time domain. The large dots indicate consecutive steps. The shaded rectangular area in B illustrates the presence of missteps. (C, D) Raw acceleration signal from the medial-lateral axis in the frequency domain. The area to the left of 1 Hz indicates the area under the curve in the low frequency band and the area to the right of 1 Hz indicates the area under the curve in the high frequency band. PSD = power spectral density. Full color version is available within the online issue.

Assessment of Mobility Disability and Other Clinical Covariates

Mobility disability was assessed using the Rosow–Breslau scale, which assesses 3 walking tasks, scored 0–3 (12). As in prior studies, a nonzero score was considered disabled for these analyses.

Performance on this widely used test has been associated with musculoskeletal pain (13), dyspnea (14), and cognition (15). Age, sex, years of education, and race were recorded at the baseline interview. Body mass index (BMI) was calculated from measured weight in kilograms divided by height in meters squared.

Data and Statistical Analysis

Due to the non-normal distribution of the data, the TW measures were transformed. Following this, the distribution of the transformed measures was re-examined using Kolmogorov–Smirnov tests. All measures were normally distributed except for the step duration measure. To evaluate how the different TW measures were related to each other, we used Spearman's correlations. TW measures were converted to Z-scores prior to PCA. Principal component analysis was performed using the SPSS Software (v 25). Using PCA, we summarized these 6 measures into 2 TW summary factors. Further details and the loadings of the PCA of these 6 TW measures are described in the [Supplementary Material](#) and in [Supplementary Table S1](#).

To assess the association between the TW and other measures, we used Spearman's rank correlations. To investigate if the TW composite factors were independently associated with mobility disability, even after controlling for TW conventional measures and other wearable-derived metrics of walking and standing postural control, we used a series of multiple regression models in which the dependent variable was the presence or absence of mobility disability. In the first model, we examined if the 2 clinical, conventional TW measures were associated with mobility disability. In the second

model, we examined if the 2 TW composite factors were associated with mobility disability. In the third model, we examined the simultaneous contributions of the 2 TW composite factors and the 2 conventional TW measures with mobility disability. Finally, we included measures from all performances in one model: TW, usual-walking, standing postural control, and TW conventional measures. In this initial, hypothesis-generating study, a 2-tailed p -value $\leq .05$ was considered statistically significant. All of the statistical analyses used age, sex, race, and BMI as covariates. The statistical analyses were performed using SPSS Software (v 25).

Results

These analyses were based on 693 community-dwelling older adults whose clinical characteristics are summarized in [Table 1](#). On average participants, completed the TW in about 15 seconds with fewer than 2 missteps.

Representative signals of 2 participants in their TW performance are illustrated in [Figure 1](#). The participant with the poorer TW performance made 2 missteps and the test duration was longer (test duration = 20.84 seconds), while the participant with the better TW performance had no missteps and the test duration was shorter (test duration = 13.90 seconds). [Figure 1A](#) and [B](#) show the raw acceleration signals in the AP axis. Higher average step duration is shown in the participant with the poorer performance (step duration = 1.668 seconds), compared to the participant with better performance (step duration = 1.041 seconds). In addition, lower sample entropy in the AP and ML directions, STD ML, and SVM are shown in the participant with the poorer performance (sample entropy ML = 0.074 au; sample entropy AP = 0.052 au; STD ML = 0.062 m/s²; SVM = 0.206 m/s³), compared to participant with the better performance (sample entropy ML = 0.198 au; sample entropy AP = 0.096 au; STD ML = 0.089 m/s²; SVM = 0.354 m/s³). [Figure 1C](#) and [D](#) are the corresponding signals in the frequency domain, specifically, the PSD in the ML axis. The high to low frequency band ratio was lower in the participant with poor performance (frequency ratio = 0.892 au), compared to the participant with good performance (frequency ratio = 4.593 au). These results suggest that the participant with the poorer TW performance displayed less complex corrective

Table 1. Characteristics of the Community-Dwelling Older Adults

	Mean $\pm$ SD
Age (y)	78.694 $\pm$ 7.119
Height (m)	1.637 $\pm$ 0.095
Weight (kg)	75.684 $\pm$ 16.868
Body mass index (kg/m ²)	28.236 $\pm$ 5.841
Education (y)	15.360 $\pm$ 3.058
Gait speed (cm/s)	64.668 $\pm$ 7.137
Tandem walking measures	
SVM (m/s ³)	0.405 $\pm$ 0.142
STD ML (m/s ²)	0.083 $\pm$ 0.023
Sample entropy ML (au)	0.137 $\pm$ 0.054
Sample entropy AP (au)	0.127 $\pm$ 0.052
Step time (s)	1.641 $\pm$ 0.246
Frequency ratio (au)	2.623 $\pm$ 1.897
Test duration (s)	14.775 $\pm$ 5.162
Missteps (n)	1.970 $\pm$ 2.479

Notes: AP = anterior-posterior; ML = medial-lateral; STD ML = standard deviation of the acceleration signal from the ML; SVM = signal vector magnitude.

movements in the ML directions, compared to the participant with better TW performance. As we show below, these examples were representative of the general behavior across all participants.

Intercorrelations Among TW Measures and the Relationship With Conventional TW Measures

Tandem walking measures exhibited mild to moderate strength correlations with each other (eg, high to low frequency band ratio with sample entropy from the ML direction, $r = 0.276$; $p < .001$) (see [Supplementary Figure S1](#)). Evaluating the relationship between the quantitative measures of the TW with the conventional measures of missteps and test duration, the TW test duration was mildly to moderately correlated with all of the quantitative measures of the TW (eg, for SVM, $r = -0.638$; $p < .001$). The number of missteps was mildly correlated with the wearable sensor-derived TW measures (eg, STD ML, $r = 0.272$; $p < .001$) (see [Table 2](#)).

Reducing the TW Measures With PCA

To determine if there is clustering among the TW measures, the 6 TW measures were entered into the PCA yielding 2 composite factors, referred to as complexity and frequency (see [Supplementary Table S1](#)). The complexity composite factor was composed of the SVM, STD ML, and sample entropy from the ML and AP directions. This composite factor reflects the magnitude of the activity and how the TW changes over time. The frequency composite factor was composed of the frequency ratio measure and may be capturing the complex corrective movements in the ML direction. Together these factors explained 76.7% of the total variation in the data. All item loadings were > 0.6 (see [Supplementary Table S1](#)). As summarized in [Supplementary Table S2](#), these composite factors were not correlated to each other ($r = 0.015$; $p > .05$), as expected. The correlations of the 2 composite factors with age, sex, BMI, and race are depicted in [Supplementary Table S2](#). Their association with the 2 conventional measures of TW is shown in [Table 2](#).

Associations of TW Factors, Usual-Walking, and Standing Posture Sensor Metrics

As summarized in [Table 3](#), there was a low correlation between TW, gait, and balance sensor metrics when controlling for age, sex, BMI, and race (eg, gait speed composite measure with TW complexity composite measure, $r = 0.180$; $p < .001$, sway with eyes closed composite measure with TW complexity composite measure, $r = 0.119$; $p = .002$). The strongest correlation observed was between gait speed composite factor and TW frequency composite factor ($r = 0.195$; $p < .001$) (see [Table 3](#)).

Association Between TW Composite Measures and Mobility Disability

To examine if the new TW metrics are independently related to mobility disability when controlling for gait and standing sway metrics, the 693 community-dwelling older adults were classified into 2 groups based on the Rosow-Breslau scale: 448 participants with intact mobility (mean age: 78.01 ± 6.96 years; 72% women) and 242 participants with mobility disability (mean age: 79.95 ± 7.22 years; 83% women). Participants with missing mobility disability scores were excluded from these analyses ($N = 3$). With only the 2 conventional TW measures in the model, missteps were associated with mobility disability, but TW duration was not. With only the 2 new TW composites factors in the model, the frequency component was associated with mobility disability, while the complexity component was not. In the model that included both the conventional TW measures and the new composite factors, both missteps and frequency were significantly associated with mobility disability. In the final model, where usual-walking and postural control features were also included as potential predictors, the composite measures that remained associated with mobility disability were: gait speed, TW frequency, and the number of missteps (see [Table 4](#)). These results are based on using enter in the logistic regression models; similar results were obtained using backward elimination.

Discussion

By developing an automated quantitative analytical process based on metrics derived from a body-fixed wearable sensor, we were able to quantify additional aspects of the movements underlying the TW that were not captured by conventional tandem measures. These new TW measures were moderately related to conventional clinical measures of the TW. This suggests that these new metrics are quantifying novel facets of TW not assessed by conventional tandem metrics. This is supported by our findings that both conventional tandem missteps and the new TW metrics were independently associated with mobility disability when included in a single model that controlled for previously validated measures of usual-walking and quiet standing postural control. Thus, these initial cross-sectional findings support the idea that the instrumented TW may be an innovative tool that has merit for quantifying the TW and augmenting the evaluation of mobility in older adults.

A previous study that quantified the TW using wearable devices reported that sample entropy, a measure of the complexity of the movement pattern, increased significantly with maturation in children (16). Moreover, TW metrics based on an electronic walkway had strong

Table 2. The Relationships Between the Wearable-Derived TW Measures, TW Composite Factors, and the Conventional TW Measures

	Individual TW Measures						TW Composite Factors		Conventional TW Measures	
	SVM	Step Time	Sample Entropy ML	Sample Entropy AP	STD ML	Frequency Ratio	Complexity	Frequency	Test Duration	Missteps
Test duration	-0.638**	0.370**	-0.320**	-0.395**	-0.096	-0.319**	-0.315**	-0.454**	1.000	0.475**
Missteps	-0.144**	0.118**	0.057	0.012	0.272**	-0.153**	0.108**	-0.263**	0.475**	1.000

Notes: Entries shown are the Spearman's correlation coefficients (adjusted to age, sex, BMI, and race). AP = anterior-posterior; BMI = body mass index; ML = medial-lateral; STD ML = standard deviation of the acceleration signals from the ML; SVM = signal vector magnitude; TW = tandem walking.

**Correlation is significant at the .01 level (2-tailed).

Table 3. Spearman's Correlations Coefficients Summarizing the Associations Between Usual-Walking, Balance, and TW Composite Measures

		Usual-Walking				Standing Posture		TW	
		Cadence	Variability	Speed	Regularity	Sway (eyes opened)	Sway (eyes closed)	Complexity	Frequency
Usual-walking	Cadence	1	–0.152**	–0.099	0.127**	–0.077	–0.035	0.067	0.067
	Variability		1	0.328**	0.404**	–0.131**	–0.160**	0.019	0.001
	Speed			1	0.192**	–0.101*	–0.061	0.180**	0.195**
	Regularity				1	–0.105**	–0.105**	–0.008	0.019
Standing posture	Sway (eyes opened)					1	0.559**	0.087*	–0.019
	Sway (eyes closed)						1	0.119**	0.032
TW	Complexity							1	0.008
	Frequency								1

Notes: Associations are adjusted to age, sex, BMI, and race. BMI = body mass index; TW = tandem walking.

*Correlation is significant at the .05 level (2-tailed).

**Correlation is significant at the .01 level (2-tailed). Darker colors indicate stronger correlations.

Table 4. The Associations Between the Composite Measures of the Tandem Walking, Usual-Walking, and Standing Postural Control With Mobility Disability

Mobility Subtasks	Composite Measures	Model With Conventional Tandem Walking Measures Only	Model With New Tandem Walking Composites Only	Model With New Tandem Walking Composites and Conventional Measures	Model With All Composites and Conventional Measures of Tandem Walking
Conventional tandem walking	Test duration	0.023 (0.019, .222) [0.986, 1.061]		–0.018 (0.023, .438) [0.940, 1.027]	–0.036 (0.025, .145) [0.919, 1.012]
	Missteps	0.119 (0.041, .003) [1.040, 1.221]		0.139 (0.043, .001) [1.057, 1.251]	0.126 (0.046, .006) [1.037, 1.240]
Tandem walking	Complexity		–0.084 (0.088, .339) [0.774, 1.092]	–0.162 (0.100, .106) [0.699, 1.035]	–0.129 (0.111, .246) [0.707, 1.093]
	Frequency		–0.364 (0.097, <.0001) [0.574, 0.840]	–0.347 (0.112, .002) [0.567, 0.881]	–0.327 (0.124, .008) [0.566, 0.919]
Usual-walking	Speed				–0.865 (0.185, <.0001) [0.293, 0.605]
	Cadence				–0.106 (0.109, .329) [0.727, 1.113]
	Variability				0.100 (0.111, .368) [0.889, 1.373]
	Regularity				–0.081 (0.138, .556) [0.703, 1.208]
Standing eyes opened	Sway with eyes Opened				0.189 (0.142, .184) [0.914, 1.596]
Standing eyes closed	Sway with eyes closed				0.160 (0.887, .264) [0.887, 1.553]

Notes: All models are adjusted for age, sex, body mass index, and race. Table entries are β (SE, p -value) [95% confidence intervals]. Bolded values indicate those that were statistically significant in the multi-regression analyses. To further explore the added value of the tandem walking, we examined the associations with mobility disability from a different perspective using the C-statistic, a measure that reflects the goodness of fit for binary outcomes in a logistic regression model. In a model that adjusts for participant characteristics (ie, age, sex, body mass index, and race), gait speed was independently associated with mobility disability ($\beta = -0.931$; p -value < .001) and the C-statistic was 0.71. Adding the new composites of the tandem walking to the model, the C-statistic became larger. Consistent with the final model shown in Table 4, this suggests that more of the variance in the dependent variable, mobility disability, is explained by using gait speed and the new measures of the tandem walking.

associations with age and, intriguingly, also predicted mortality among older adults (17,18). These preliminary studies suggest that quantitative measures of the TW have utility in capturing meaningful aspects of dynamic balance, which might probe additional facets of development and pathology beyond those gleaned from tests of static (standing) balance and walking. The present results support the idea that quantitative measures of the TW provide additional information that can be used to enhance the characterization of mobility in older adults.

Despite its widespread use in the clinic and clinical studies, the conventional scoring of the TW test is limited. It focuses only on time and the number of missteps and ignores any other deficiency of movements. We found that several quantitative measures of TW and the 2 composite factors were significantly correlated with conventional clinical measures of time to completion and the number of missteps (recall Table 2), demonstrating content validity (also see Supplementary Material). However, the relatively low associations

suggest that there was little redundancy between the quantitative measures of TW and the 2 conventional clinical measures. Similarly, moderate to a high positive relationship between TW conventional clinical measures and commonly used laboratory measures of dynamic balance (The Biodex Balance System and gait center of pressure, temporal, and spatial parameters) were reported in a healthy population (19). Together, these findings support the relevance of these new TW measures.

To our knowledge, this is the first study that directly compared TW to usual-walking and quiet standing using an accelerometer-based, instrumented approach. The current results provide evidence that TW metrics are not strongly related to measures of usual-walking and quiet standing postural control (recall Table 3). These results suggest that TW metrics do not simply replicate conventional gait tests. Instead, these findings suggest that the TW metrics reflect distinct facets of mobility that are not captured by those other tasks. This finding echoes the results of a prospective study among older adults which reported that TW measures extracted using an instrumented gait mat were an independent domain of mobility (18). The ability to maintain postural control is critical for the successful performance of those tasks, especially for TW (2,19). Previous studies have utilized a TW test as the dynamic walking balance component of several validated test batteries for fall prediction in the older adults (20–22). Based on this, we can speculate that age-related changes in the maintenance of postural control may be reflected to a greater extent during TW than during usual-walking and quiet standing. Moreover, our results using a wearable sensor and those using an instrumented gait mat (18) suggest that to fully characterize gait and mobility it is important to include TW abilities, in addition to other domains of gait (eg, pace, variability).

Balance testing is important for identifying deficits that may suggest underlying illness and for predicting subsequent levels of functional decline and even mortality (23–25). A recent study suggested that wearable sensors can detect subtle instability and near-falls in people with Parkinson's disease during the performance of chair transfer, Timed Up and Go, and 3-m walk, but not using the conventional clinical measures of the TW (26). Tandem walking instability was rated by identifying commonly used clinical measure of the number of additional steps that were used to maintain balance. However, instrumenting the TW has the potential to provide a more accurate reflection of dynamic balance by capturing additional measures that cannot be assessed by traditional methods. Indeed, pilot studies in other cohorts have demonstrated the utility of adding instrumentation to traditional TW testing (16,27,28). Surprisingly, the complexity composite was not associated with mobility disability. We speculate that it may, perhaps, be associated with other adverse health outcomes related to mobility impairment (eg, incident falls, cognitive decline). Follow-up work should examine these questions.

The present results in almost 700 older adults are promising. We generated TW composite factors that are independent predictors of mobility disability in community-dwelling older adults (recall Table 4). Thus, this work extends prior studies by us and others which have shown that the addition of a body-fixed sensor to conventional tests of mobility like the Timed Up and Go, standing, and walking can provide new insights beyond time to completion of the test (11,29–31).

At a time in which we are dealing with COVID-19 and its implications to clinical care and research, the addition of new tools that can be utilized in the home setting to augment the assessment of older adults gives added value and timeliness to the present findings. Still, future work is needed to examine the specificity of TW

metrics for other adverse health outcomes related to mobility impairment like incident falls, cognitive decline, dementia, and death and whether these metrics can be used to improve risk stratification of older adults for adverse health outcomes. In addition, further study is needed to extend these cross-sectional findings and to determine if these metrics improve the stratification of adults at risk for impaired mobility. The present findings set the stage for such studies.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

Table S1. Loadings of the principal component analysis of the 6 TW measures after rotation.

Table S2. Correlations among the TW composite factors and with the participant characteristics.

Figure S1. Scatter plots illustrating the associations among the TW measures.

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Conflict of Interest

None declared.

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Author Contributions

Na.G., A.S.B., and J.M.H. contributed to the study concept and design, analysis, and interpretation of data, and were major contributors in writing the manuscript. E.G. assisted with the development of the new metrics. All authors contributed to the interpretation of the data and the revising and editing of the manuscript.

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