



The 3-m Backwards Walk and Retrospective Falls: Diagnostic Accuracy of a Novel Clinical Measure

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ABSTRACT

Background and Purpose: Several measures of fall risk have been previously developed and include forward walking, turning, and stepping motions. However, recent research has demonstrated that backwards walking is more sensitive at identifying age-related changes in mobility and balance compared with forward walking. No clinical test of backwards walking currently exists. Therefore, this article describes a novel clinical test of backwards walking, the 3-m backwards walk (3MBW), and assessed whether it was associated with 1-year retrospective falls in a population of healthy older adults. Diagnostic accuracy of the 3MBW was calculated at different cutoff points and compared with existing clinical tests.

Methods: This study was a retrospective cohort study including residents of a retirement community without a history of neurological deficits. Demographics, medical history, and falls in the past year were collected, and clinical tests included the 3MBW and the Timed Up and Go (TUG), the 5 times sit-

to-stand, and the 4-square step test. Frequency distributions and *t* tests compared baseline characteristics of people who reported falling with people who did not. Diagnostic accuracy (sensitivity and specificity) was calculated for a series of cutoffs for the 3MBW, the TUG (≥ 8 , 10, and 13.5 seconds), 5 times sit-to-stand (≥ 12 and ≥ 15 seconds), and 4-step square test (> 15 seconds). Receiver operating curve analyses were used to define 3MBW optimal cutoffs, and the difference between the overall area under the curve (AUC) was statistically tested. SPSS 24.0 and MedCalc 17.1 were used for all analyses.

Results and Discussion: Fifty-nine adults with a mean (SD) age of 71.5 (7.6) years participated, with 25 people reporting falls in the past year. The mean (SD) time for the 3MBW was 4.0 (2.1) seconds. People who fell had a significantly slower 3MBW time (4.8 vs 3.5 seconds for people who did not fall, $P = .015$), but not a significantly slower 4-step square test (9.5 vs 8.1 seconds, $P = .056$), TUG (9.3 vs 8.0 seconds, $P = .077$), and 5 times sit-to-stand (12.5 vs 10.3 seconds, $P = .121$). The highest overall AUC for any measure was for the 3MBW at 3.5 seconds (0.707, 95% confidence interval = 0.570-0.821; sensitivity = 74%, specificity = 61%), which was significantly higher than the TUG at 8 seconds (AUC = 0.560, $P = .023$) and 13.5 seconds (AUC = 0.528, $P = .011$), the 4-step square test (AUC = 0.522, $P = .004$), but not significantly higher than the TUG at 10 seconds ($P = .098$) and the 5 times sit-to-stand at 12 ($P = .092$) or 15 seconds ($P = .276$). On the 3MBW, more than 75% of people who were faster than 3.0 seconds did not report any falls, and 94% of people who did not report falling were faster than 4.5 seconds. Of the people who were slower than 4.5 seconds, 81% reported falling.

Conclusions: In a study of healthy older adults, the 3MBW demonstrated similar or better diagnostic accuracy for falls in the past year than most commonly used measures. People walking faster than 3.0 seconds on the 3MBW were unlikely to have reported falling, whereas people slower than 4.5 seconds were very likely to have reported falling. Further validation of the 3MBW in prospective studies, larger samples, and clinical populations is recommended.

Key Words: backwards walking, fall risk, sensitivity, specificity, 3-m backwards walk

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INTRODUCTION

Approximately 1 in 3 adults fall each year,¹ and large proportions of adults report that they fear falling and experience limited balance.² Falls are the leading cause of death because of injury among older adults,³ and are costly, as the average hospital treatment of a fall-related injury is more

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than \$30000.⁴ Information that can lead to identifying who is at highest risk for falls is therefore essential. Recent research has found that strong predictors of falls include limited balance and gait, taking multiple pharmaceuticals, and having a history of falls, whereas additional risk factors include female gender, advanced age, cognitive decline, having visual impairments, and environmental factors.⁵

A range of medical history questionnaires, self-report measures, and performance-based functional measures have been developed to aid health care professionals in determining fall risk and prognoses with their patients.⁶ Common performance-based functional measures that have been associated with functional ability, balance, and fall prediction include the Timed Up and Go (TUG),⁷ 5 times sit-to-stand,⁸ the Berg Balance Scale,⁹ the 4-square step test,¹⁰ and measures of walking speed.^{7,11} A recent review indicated that most tests for fall risk prediction were only modestly effective, but that the Berg Balance Scale of 50 points or more, the TUG of 12 seconds or more, and the 5 times sit-to-stand of 12 seconds or more were the most evidence-supported predictors of future falls.⁶

These tests primarily include walking in the forwards motion and the ability to turn around. However, walking backwards is explicitly more difficult, requiring an increased reliance on neuromuscular control, proprioception, and protective reflexes.¹² Backwards walking is necessary to perform such tasks as backing up to a chair, opening up a door, or getting out of the way of a sudden obstacle. This movement can be particularly challenging for older individuals or individuals with neurological deficits. Mechanical measures of backwards walking, specifically velocity, stride length, swing length, and double limb support, have been shown to be significantly more limited in older adults compared with young, healthy persons.¹³ In addition, individuals with neurological conditions such as **Parkinson's disease** suffer from an increase in axial stiffness, and an limited sense of proprioception and verticality, resulting in **falls in the backward and lateral directions**.¹⁴⁻¹⁶

Researchers have recently reported that backwards walking measures were more sensitive at identifying age-related changes in mobility and balance compared with forward walking.^{13,17} In this context, an assessment of backwards gait may be an important clinical tool to determine fall risk, particularly an individual's propensity for backwards falls. However, to date, no clinical test that includes backwards walking has been established, nor has research assessed whether backwards walking was strongly associated with existing measures of fall risk among older adults.

Therefore, this article provides a description of a clinical test of backwards walking, the 3-m backwards walk (3MBW), and whether it was associated with 1-year retrospective fall risk in a population of healthy older adults. Specifically, we aimed to (1) report average 3MBW time (and other existing clinical tests), comparing people who fell in the past year with people who did not fall; (2) report associations of the 3MBW with existing measures of fall risk (the TUG, 5 times sit-to-stand, and the 4-step square

test); (3) report the sensitivity and specificity of a series of 3MBW cutoff points to discriminate people who fell from people who did not fall; and finally, (4) compare the diagnostic accuracy for retrospective falls of the 3MBW with the TUG, the 5 times sit-to-stand, and the 4-step square test.

METHODS

Design and Participants

This study was a retrospective cohort study, evaluating whether the 3MBW was associated with 1-year fall history. Participants were recruited from 3 retirement communities in urban areas in the Southwest in late 2013 during 4 total visits (1 community was visited twice). Study inclusion criteria included being a community-dwelling older adult resident of a retirement community, without a history of neurological deficit. Participants had to be able to walk without assistive devices and had to be able to provide consent to participate. It was not recorded how many participants were approached or ineligible, but virtually all participants who were eligible agreed to participate. All participants consented to the study and the institutional review board of the university approved all study procedures on February 10, 2012, under protocol number 12.0220.

Measures

Demographic characteristics of age and sex were collected, as was a medical history including exclusion criteria of whether people currently had medical conditions that limited their mobility (including neurological conditions). None of the participants used any assistive devices while walking. All participants completed the following clinical measures commonly measured in clinical practice (see descriptions later) in 1 setting in randomized order: the Timed Up and Go, the 5 times sit-to-stand, and the 4-square step test, and the 3MBW. Participants wore their shoes for all tests, and for the TUG and 5 times sit-to-stand used a standard armchair (height 18 inches). Cutoff criteria for determining fall risk for each of the measurements were used to classify participants as at risk for falls, dichotomized as yes or no.

Timed Up and Go

The Timed Up and Go aims to assess mobility, balance, walking ability and fall risk in older adults.¹⁸ At the start of the test, the individuals are seated with their back straight against a standard armchair. When the clinician/researcher says "go," the person stands up, walks 3 m at a comfortable pace, turns around, walks back to the chair, and sits down. The time starts at the "go" command and stops when the person is seated. For community-dwelling older adults, a cutoff of 13.5 seconds has been established as associated with fall risk.¹⁹ Other studies have suggested lower cutoff scores for older adults with osteoarthritis (>10 seconds)²⁰ and people with Parkinson's disease (ranging from 8 to 11.5 seconds).^{21,22}

Five Times Sit-to-Stand

The 5 times sit-to-stand assesses functional lower extremity strength as well as fall risk.⁸ The test starts with the individual in seated position on a standard chair and arms crossed. The individual is instructed to stand up and sit down 5 times as quickly as possible following the “go” command, while reaching full standing position between repetitions. The time starts at the “go” command and stops when the buttocks touch the chair after the final repetition. Individuals are allowed 1 practice trial before time is recorded. A cutoff score of 12 seconds has been suggested among community-dwelling older adults (74 years and older) for further assessment of fall risk,²³ whereas a cutoff of more than 15 seconds has been suggested for recurrent fall risk.²⁴

4-Square Step Test

The 4-square step test aims to assess dynamic balance and stepping over objects forwards, sideways, and backwards.¹⁰ The test is conducted by using tape to make 1 horizontal and 1 vertical line like a cross to create 4 quadrants. At the start of the test, the individual stands on the upper left square with both feet close together. They then step in clockwise direction, with both feet before moving to the next square: first to their right, then backwards, to their left and forwards to their original position. They immediately follow this by stepping in the counterclockwise direction. After 1 practice trial, the time is recorded for the next 2 trials and the best 1 counted. The 4-square step test has been found to have excellent interrater reliability and high concurrent validity with the Timed Up and Go. Among community-dwelling older adults, a time over 15 seconds has been associated with an increased risk for falls.¹⁰

3-m Backwards Walk Assessment

A distance of 3 m was measured and marked with black tape. The surface conditions of the floor were either tile or wood. Participants were asked to align their heels with the black tape. They were instructed to walk backwards as quickly, but as safely as possible when signaled to “go” and were instructed to stop when the distance of 3 m was achieved. Participants were not allowed to break into a run during the test. Participants were permitted to look behind themselves if they desired. The examiner walked backward with the participant to ensure safety. The participant completed 3 trials, with the average of all 3 recorded.

Fall History

A 1-year fall history questionnaire was completed through an interview with 1 of the members of the research team, and included questions about retrospective falls in the past year. Participants were asked: “In the past 12 months, have you fallen?” It was explained that falls that could have not been stopped by having good balance or mobility such as a trauma caused by a high-impact traffic accident should not be included. The primary dependent variable for the current study was whether a participant reported falling (dichotomized yes or no) in the past 12 months.

Analyses

Demographic characteristics of participants were summarized with descriptive statistics and frequency distributions. For aim 1, to compare people who fell in the past year with people who did not, values on the 3MBW (and other clinical tests) were compared (vs people who did not fall) using a Mann Whitney *U* test. For this and all other comparisons, a *P* value of .05 and 2-tailed tests were used. For aim 2, to assess whether the 3MBW was associated with the TUG, 5 times sit-to-stand, and 4-square step test, Spearman correlation coefficients were used.

For aim 3, diagnostic accuracy was assessed through calculation of sensitivity and specificity for a series of cutoffs for the 3MBW test. Receiver operating curve (ROC) analyses were used to define optimal cutoff points for sensitivity and specificity and overall area under the curve (AUC). Finally, for aim 4, diagnostic accuracy for the other clinical tests was calculated using previously established cutoff values for fall risk of community-dwelling older adults: for the TUG (≥ 8 , ≥ 10 , and ≥ 13.5 seconds), 5 times sit-to-stand (≥ 12 and ≥ 15 seconds), and 4-step square test (> 15 seconds). The accuracy of the 3MBW and the other clinical tests was compared by testing whether the difference between the AUC was statistically significant using the DeLong method.²⁵ All analyses were conducted using SPSS version 24.0 (SPSS Inc, Chicago, Illinois) and MedCalc version 17.1 (MedCalc Software, Ostend, Belgium).

A power analysis was conducted on the basis of a recent article comparing the difference between the AUC of 2 diagnostic tests²⁶ on the same sample using Microsoft Excel and equation 7.8, taking into account the effect size, estimated variance, an α of 0.05 and β of 20%. With a 95% confidence level and 80% power, a sample size of 50 would be sufficient to detect a difference of $\delta = 0.15$ between 2 AUCs, assuming the highest AUC was 0.80 (a sample size of 74 was needed to detect the same difference assuming the highest AUC was 0.70).

RESULTS

A total of 59 individuals (37 females 22 males) with a mean (SD) age of 71.5 (7.6) years participated in the study. The mean (SD) value for the 3MBW test was 4.0 (2.1) seconds. The mean 3MBW values for age by decade and gender are in Table 1. Across a total of 413 measurement points, the data had 13 missing values. Listwise exclusion was applied for missing data.

Aim 1: People Reporting Falling Versus People Who Did Not

People who reported falling in the past year were compared with people who did not report falling. Age and gender were not significantly different between people who fell and people who did not fall. In total, 25 of the 59 people reported falling in the past year. People who fell had a significantly slower 3MBW (mean 4.8 seconds compared with 3.5 seconds for people who did not fall (*P* = .029, see Table 2). People who did not have a significantly slower

Table 1. Time (Seconds) for Completion of 4 Clinical Tests of Fall Risk by Gender and Age

Variable	3MBW Mean ^a (SD)	TUG Mean (SD)	5xSTS Mean (SD)	4 SST Mean (SD)
Males (n = 22)	3.8 (1.8)	8.3 (2.6)	10.6 (3.1)	8.8 (2.5)
Females (n = 37)	4.2 (2.2)	8.7 (3.3)	11.5 (4.3)	8.6 (2.2)
Age, y				
60-69	3.7 (2.2)	7.7 (1.7)	10.8 (3.5)	8.7 (1.5)
70-79	3.7 (1.3)	8.2 (2.6)	11.3 (4.6)	7.7 (1.5)
80-89	5.9 (3.0)	11.0 (5.5)	12.5 (3.8)	11.1 (3.9)

Abbreviations: 5xSTS, 5 times sit-to-stand; 4 SST, 4-step square test; SD, standard deviation; 3MBW, 3-m backwards walk; TUG, Timed Up and Go.
^aAverage time on the clinical test.

TUG (9.3 vs 8.0 seconds, $P = .077$), 4-square step test (9.5 vs 8.1 seconds, $P = .056$), and five times sit-to-stand test (12.5 vs 10.3 seconds, $P = .121$).

Aim 2: Association of 3MBW With Existing Fall Risk Measures

The 3MBW was significantly associated with age ($r = 0.384$, $P = .007$), but not gender ($r = 0.009$, $P = .515$). The 3MBW was significantly associated with all other clinical tests ($P < .001$ for all correlations), with the strongest association between the 3MBW and the TUG ($r = 0.823$), followed by the 4-square step test ($r = 0.651$), and the 5 times sit-to-stand ($r = 0.608$).

Aim 3: Defining Optimal Cutoffs for Diagnostic Accuracy of the 3MBW

Using ROCs, optimal cutoffs were evaluated for the 3MBW and fall history (yes or no). Faster cutoff speeds had higher sensitivity (people who walk faster than these speeds are unlikely to report falling) and slower speeds had higher specificity (people walking at very slow speeds are likely to report falling). For example, at the faster cutoff of a 3MBW of 3.0 seconds, sensitivity was 78% but the specificity was low (45%) (see Table 3). At the slower cutoff of 4.5 seconds, specificity was high (94%) but sensitivity low (39%). The most optimal cutoffs in terms of sensitivity and specificity were 3.2 and 3.5 seconds, where overall accuracy was about two-thirds, and up to three-quarters of

people who fell were correctly captured. The highest AUC for the 3MBW was at 3.5 seconds (AUC = 0.707). The AUC for 3.5 seconds was significantly higher than at 3.0 seconds ($P = .32$), but not significantly different from the 3MBW at 3.25, 4, and 4.5 seconds.

Finally, perhaps 2 cutoffs, an upper (ie, 4.5 seconds) and lower boundary (ie, 3.0 seconds), would be a possible option. More than 75% of people who were faster than 3.0 seconds did not report any falls, and 94% of people who did not report falling were faster than 4.5 seconds. Of the people who were slower than 4.5 seconds, 81% reported falling. In other words, persons walking faster than 3.0 seconds on the 3MBW were relatively unlikely to have reported falling, whereas people walking slower than 4.5 seconds were very likely to have reported falling. People in between would require additional assessment.

Aim 4: 3MBW Diagnostic Accuracy Compared With Other Measures

Compared with the other measures, the diagnostic accuracy of the 3MBW at 3.5 seconds was similar or higher (see bottom of Table 3). The 3MBW at 3.5 seconds had a significantly higher AUC than the TUG at 8 and 13.5 seconds ($P = .023$ and $P = .011$) and the 4-step square test ($P = .004$), but not a significantly higher AUC than the TUG at 10 seconds ($P = .098$), the 5 times sit-to-stand at 12 seconds ($P = .092$), and the 5 times sit-to-stand at 15 seconds ($P = .276$). Figures 1, 2, and 3 show a

Table 2. Clinical Measures Comparing People Who Fell With People Who Did Not Fall in Past Year

Variable	People Who Fell (n = 25) Mean (SD)	People Who Did Not Fall (n = 34) Mean (SD)	P Value ^a
Age, y	72.7 (7.9)	70.8 (7.4)	.540
Females, %	60	65	.714
3-m backwards	4.8 (2.6)	3.5 (1.3)	.029 ^b
Timed Up and Go	9.3 (3.6)	8.0 (2.4)	.077
5 times sit-to-stand	12.5 (4.9)	10.3 (2.8)	.121
4-step square test	9.5 (2.8)	8.1 (1.6)	.056

^aP value assessed with Mann-Whitney U test.
^bSignificant on $P < .05$.

Table 3. Sensitivity, Specificity, and Area Under the Curve for Different Cutoffs of 4 Clinical Tests for Fall Risk

Test and Clinical Test and Cutoff Value	Sensitivity, %	Specificity, %	AUC and 95% CI for AUC	P Value for Comparison of AUC (With 3MBW at 3.5 s as Reference)
3MBW at 3.0 s	78	45	0.619 (0.479-0.745)	.032 ^a
3MBW at 3.25 s	61	70	0.653 (0.514-0.775)	.214
3MBW at 3.5 s	74	61	0.707 (0.570-0.821)	Reference
3MBW at 4.0 s	48	79	0.633 (0.494-0.758)	.227
3MBW at 4.5 s	39	94	0.665 (0.527-0.786)	.561
TUG at 8 s	64	49	0.560 (0.420-0.694)	.023 ^a
TUG at 10 s	36	79	0.586 (0.445-0.717)	.098
TUG at 13.5 s	8	97	0.528 (0.389-0.664)	.011 ^a
5xSTS at 12 s	42	76	0.592 (0.452-0.723)	.092
5xSTS at 15 s	29	97	0.637 (0.496-0.762)	.276
4 SST at 15 s	4	100	0.522 (0.383-0.658)	.004 ^b

Abbreviations: AUC, area under the curve; CI, confidence interval; 5xSTS, 5 times sit-to-stand; 4 SST, 4-step square test; 3MBW, 3-m backwards walk; TUG, Timed Up and Go.
^aSignificant on P < .05.
^bSignificant on P < .01.

graphical representation of the ROCs for the 3MBW and each of the other clinical measures.

DISCUSSION

In the context of prior research demonstrating that backwards walking measures were more sensitive at evaluating mobility and balance deficits,^{13,17} this study aimed to assess the ability of a novel clinical measure, the 3MBW, to identify people who reported falling in the previous year. Among older adult residents of a retirement community without neurological deficits or assistive devices, 3MBW cutoffs of 3.25 or 3.5 seconds were the most optimal, with the 3MBW

at 3.5 seconds having the highest overall AUC of 0.707. A cutoff at 3.25 seconds would correctly identify 74% of people who reported falling, while correctly identifying almost 60% of people who did not fall. These were much higher than the TUG at 13.5 seconds, which missed 23 of the 25 of the people who reported falling, although correctly capturing virtually all people who did not fall. Five times sit-to-stand (cutoffs of 12 and 15 seconds) was closest in overall accuracy to the 3MBW at 3.5 seconds and not significantly different in overall AUC. Possible proposed cutoffs for the 3MBW could be 3.0 seconds for low risk (less than a quarter of people who fell walked faster than 3.0 seconds) and

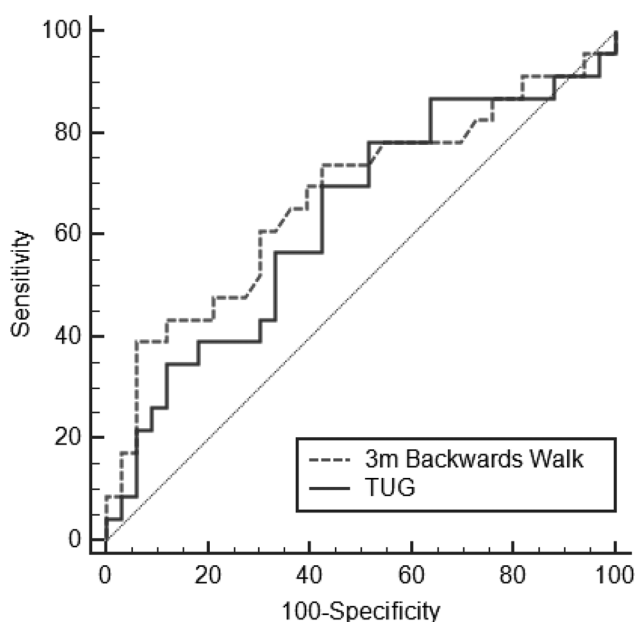


Figure 1. Receiver operating curves of the 3-m backwards walk and Timed Up and Go.

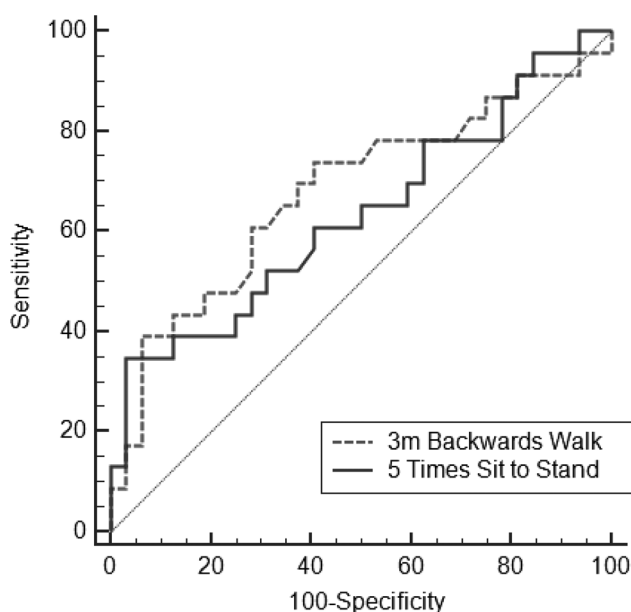


Figure 2. Receiver operating curves of the 3-m backwards walk and 5 times sit-to-stand.

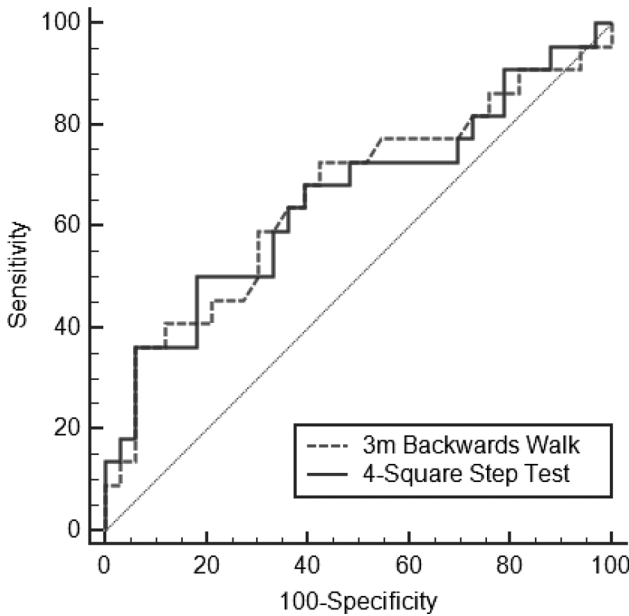


Figure 3. Receiver operating curves of the 3-m backwards walk and 4-square step test.

4.5 seconds for high risk (only 6% of people who did not fall walked slower than 4.5 seconds).

The 3MBW is the first attempt at developing a clinical measure to assess backwards walking and compare the diagnostic accuracy of the 3MBW with existing measures of fall risk. Although a wide range of clinical measures have been developed previously and have been associated with fall risk (TUG, Berg Balance Scale, the 5 times sit-to-stand, and the 4-square step test), none of these include backwards walking. More recently, another novel clinical test (the “3-m zigzag”) was developed that aimed to capture individuals’ ability to make turns and navigate an indoor environment with high fall risk.²⁷ The 3-m zigzag was shown to be associated with fall history with a sensitivity and specificity of 80% and 84%, respectively, for a cutoff time of 10.5 seconds.²⁸ However, this test also does not measure backwards walking, which is inherently more challenging and has shown to be more sensitive to age-related changes in mobility and balance.^{13,17} Our proposed cutoff of 4.5 seconds (0.67 m/s) for high fall risk is further consistent with 1 prior study that measured backward gait speed, which found that all people who reported falling walked slower than 0.6 m/s,¹³ which would translate to 5.0 seconds on the 3MBW.

In the current study, the 3MBW also had the largest proportional change of all clinical measures from participants in their 70s to participants 80 years and older (3.7-5.9 seconds on average), a 61% slower time. The other measures all showed slower times, but the effects were not as pronounced, with the TUG being 36% slower, the 5 times sit-to-stand only 8% slower, and the 4-square step test 45% slower on average. It is possible that ceiling effects of some other balance measures may be present for healthy adult populations, and a more challenging measure like backwards walking may be a valuable additional clinical tool in these situations.²⁸

Capturing deficits in backwards walking may further be particularly important for people with conditions that impair backwards walking. For example, individuals with Parkinson’s disease have difficulty with backwards ambulation, take more steps to regain balance after a backwards perturbation, and demonstrate more pronounced changes during backwards walking compared with age-matched controls.^{15,16} Backwards walking may be a particularly important predictor of falls in this population, and will be an area of future research.

Limitations

This study had several limitations. First, the sample size was fairly small with 59 community-dwelling older adults, and the study was underpowered to detect any effects smaller than a difference of $\delta = 0.15$ in AUC.²⁶ Our findings showed that 3 of the 6 AUC comparisons were significant, and that for the 3 significant AUC comparisons the 3MBW AUC ranged from 0.147 to 0.185 greater than the comparison test. Second, participants in this study were recruited from active senior living communities, were all community ambulators, able to walk backwards without assistive devices, and did not have a neurological condition. This relatively healthy population does not necessarily represent other individuals older than 60 years, particularly older adults with more complex conditions. Furthermore, the identification of falls was self-reported for the past year, and recall of falls may be inaccurate. Finally, we did not collect data on all possible factors associated with risk for falls,⁵ including measures of obesity, which some research has suggested may be associated with increased risk for falls.²⁹

CONCLUSIONS

This study was the first to aim to evaluate the diagnostic accuracy of a clinical measure of backwards walking with fall history, and compare its performance with existing measures of fall risk. In a sample of community-dwelling older adult residents, the 3MBW with a cutoff score of 3.5 seconds was similar or better in identifying people with a reported history of falls in the past year than 3 other existing clinical measures. A more challenging clinical tool including backwards walking may be a valuable addition to the currently existing measures among healthy populations. Future research on the 3MBW will focus on testing a broader range of individuals, include prospective fall assessment, and include individuals with neurological impairments that may make backwards walking particularly more challenging.

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