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How steady is the STEADI? Inferential analysis of the CDC fall risk toolkit

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ABSTRACT

Introduction: The CDC developed the STEADI toolkit to assist providers with incorporating fall risk screening, assessment of modifiable risk factors, and implementing evidence-based treatment strategies. The purpose of this study was two-fold: analyze the STEADI algorithm for strengths/weaknesses based upon inferential data and provide recommendations for additional research and possible limitations of the STEADI toolkit from a physical therapy perspective.

Methods: This investigation employed a quantitative, cross-sectional cohort design collating data from community-dwelling and retirement-facility seniors ($n = 77$) from two regions of the U.S. Data is reported based upon descriptive statistics, correlation, and validity of the STEADI algorithm, its subcomponent tests, and self-reported fall data. All participants completed the Stay Independent Brochure (SIB) and the algorithm's mobility, balance, and lower extremity strength tests regardless of risk categorization.

Results: Sensitivity of the STEADI with discriminating fallers and predicting future falls was better among community-dwellers (73–80%) versus the retirement facility-dwellers (56–62%). The STEADI demonstrated high false negative rates among those categorized as low risk as 57% community-dwellers and 24% facility-dwellers fell in the prior 12 months and several fell within 6 months following participation. Results suggest that it is important to conduct more than one mobility or balance screening test, and indicate that elevated STEADI risk classification was not associated with advancing age.

Conclusions: Outcomes from this study suggest that cut-off scores and the selection of functional fall screening tests, as well as the relative weights and scoring of items on the SIB/3KQ be reevaluated to maximize discriminate and predictive validity of the algorithm.

1. Introduction

Falls are the leading cause of emergency department visits, injuries, and hip fractures, resulting in morbidity and mortality among older adults. The direct medical costs for falls are over $35 billion annually and are expected to increase to over $100 billion by 2030 (Houry, Florence, Baldwin, Stevens, & McClure, 2016). This growing public health issue resulted in a robust initiative by the United States' Centers for Disease Control and Prevention (CDC) providing tools to encourage all healthcare providers to make fall prevention part of their clinical practice (Stevens & Phelan, 2013).

The American and British Geriatrics Societies and several international sources strongly recommend a multi-factorial approach to fall risk screening in older adults (Avin et al., 2015). In an effort to facilitate multifactorial fall risk screening and prevention efforts in primary care, the CDC, along with numerous healthcare experts, developed the Stopping Elderly Accidents, Deaths & Injuries (STEADI) toolkit (CDCP, 2018; Stevens & Phelan, 2013). The STEADI toolkit and algorithm was based on the 2010 American and British Geriatric Societies' Clinical Practice Guidelines. As illustrated in Fig. 1, this fall screening algorithm classifies an older adult as having a low, moderate, or high risk of falls and lists interventions including referrals to address risk factors that correspond with each level of fall risk (Stevens & Phelan, 2013). The STEADI has been successfully implemented in primary care throughout large health systems (Casey, 2017; Eckstrom et al., 2017; Smith et al., 2017). However, operationalization and validation of the STEADI have only been investigated in a retrospective survey data set from the National Health and Aging Trends Study using an adapted algorithm rather what is published by the CDC (Lohman et al., 2017).

The CDC projects that if physicians integrate fall risk screenings into clinical practice and address modifiable risk factors, future falls may decline by 25% (Houry et al., 2016). Barriers to meeting this projection include low trends in current fall prevention screenings and limited sustainability of screening frequency after implementation of STEADI.

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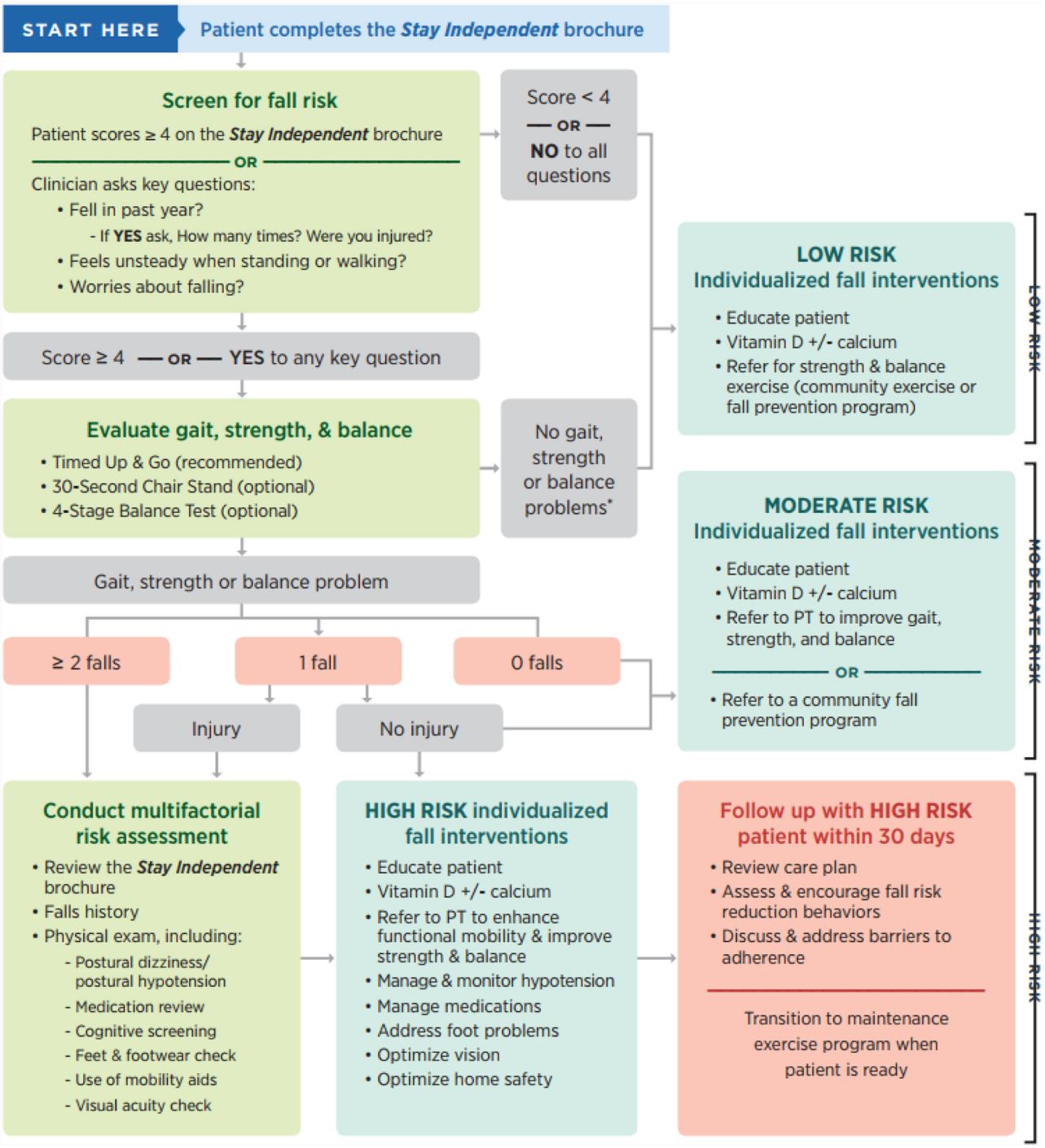

Fig. 1. The CDC's STEADI algorithm (2017).
STEADI algorithm for fall risk screening, assessment and intervention. National Center for Injury Prevention and Control, Centers for Disease Control and Prevention; 2017.

For example, prior to implementation of the STEADI, one large health system found that less than 40% of primary care providers asked patients if they had fallen in the past year (Smith et al., 2017). After implementation of the STEADI in primary care, the same health system screened 79% of older adults in the first year. However, the rate of fall risk screening regressed to only 49% in year two - a 30% decline (Stevens, Smith, Parker, Jiang, & Floyd, 2017). This information suggests that implementation in primary care does not guarantee consistent fall risk screening. Therefore, screenings performed in other places, such as the community, and by other providers such as physical therapists, may help reach a greater number of older adults and may improve the sustainability of fall risk identification initiatives (Ory & Smith, 2015).

Physical therapists, as movement system experts and direct access healthcare providers, have been using the STEADI toolkit for fall risk screening and falls prevention initiatives within their communities (Reinoso, McCaffrey, & Taylor, 2017). However, the utility and validity of the STEADI algorithm has not been investigated with community-based fall risk screenings or when conducted by physical therapists. Therefore, the purpose of this investigation was two-fold: 1) analyze the STEADI algorithm for strengths and weaknesses based upon descriptive statistics, correlation, and validity data in community screenings; 2)

provide recommendations for possible limitations and additional research of the STEADI toolkit from a physical therapy perspective.

2. Materials & methods

This investigation employed a quantitative, cross-sectional cohort and prospective design. Following approval from the appropriate institutional review boards, community-dwelling older adults age 65 and older were recruited in the Phoenix, Arizona and Fayetteville, Arkansas metropolitan areas. Volunteer participants of this convenience sample were recruited through advertising and word of mouth. The Arizona sample (n = 39) consisted of older adults who resided in private residences. The Arkansas sample (n = 41) consisted of older adults who resided at a retirement housing complex. Inclusion criteria were: participants had to be at least age 65, be able to consistently follow one-step commands, and be willing to execute an informed consent. Exclusion criteria were hemiplegia or paraplegia, use of continuous supplemental oxygen, residing in a long-term care or skilled nursing facility, hospitalized within the previous 14 days, and an inability to walk without the physical support of another person.

Demographic data such as age, gender, and fall-related information was collected face-to-face upon execution of their informed consent. A phone interview was conducted 6 months following participation in this investigation to inquire about post-participation falls and adherence to fall and fracture prevention instructions. All participants completed the 12-item Stay Independent Brochure Questionnaire (SIB) listed in Fig. 2 and the STEADI algorithm's mobility (Timed-Up and Go; TUG), balance (4-stage balance tests; 4SB), and lower extremity strength (30 s chair rise; 30STS) tests regardless of risk categorization from the SIB. Data on the three-key questions (3KQ) was extracted from the SIB (Ory & Smith, 2015). In addition to the TUG, 4SB, and 30STS, gait speed was measured with a four-meter walk test (4MWT).

2.1. Data analysis

The initial combined sample (n = 80) was reduced by three participants (n = 77) upon data analysis due to incomplete data sets. Prior to collating data from the Arizona and Arkansas samples, a paired samples T-test was used to determine if any statistical differences existed between groups. Descriptive statistics were calculated for both samples and the combined sample. Relationships between independent and dependent variables were calculated using Pearson correlation coefficients for interval and ratio data, and Spearman Rho for ordinal data (STEADI 3-tiered risk). Significance was set at $\alpha < 0.05$. Discriminate and predictive validity was determined by calculating sensitivity and specificity as well as likelihood ratios (Dawson & Trapp, 2004).

Table 1
Differences between sampled groups.

Variable	df	t	P
Age	37	5.240	< 0.001**
Gender	37	−1.356	0.183
STEADI Risk	37	−1.720	0.094
Stay Independent Brochure	37	−1.115	0.272
Retrospective Falls 12 months	37	1.944	0.060*
Prospective Falls 6 months	28	0.000	1.000
TUG	37	−1.422	0.163
30STS	37	2.751	0.676
Tandem	37	−0.365	0.717
SLS	33	−0.538	0.594
Narrow BOS	35	1.430	0.162
Narrow Stride	35	1.725	0.093
4MWT	36	−1.740	0.090

* Near significance (95% CI).
** Highly significant.

3. Results

The community-dweller and retirement facility-dweller groups were statistically congruent as per the insignificant p-value with the exception of age (Table 1). The mean age of the community dwellers was 74.6 years and the mean age for the retirement facility-dwellers was 81.9 years. The total sample consisted of 44 females (57.1%) and 33 males (42.9%). A trend towards significance was calculated (p = 0.06) with the 12-month fall history variable. The retirement-facility sample's fall history in the prior year (34%) was consistent with the CDC's one in

Circle "yes" or "no" for each statement below		Why it Matters
Yes(2) No(0)	I have fallen in the past year.	People who have fallen once are likely to fall again.
Yes(2) No(0)	I use or have been advised to use a cane or walker to get around safely.	People who have been advised to use a cane or walker may already be more likely to fall.
Yes(1) No(0)	Sometimes I feel unsteady when I am walking.	Unsteadiness or needing support while walking are signs of poor balance.
Yes(1) No(0)	I steady myself by holding onto to furniture when walking at home.	This is also a sign or poor balance.
Yes(1) No(0)	I need to push with my hands to stand up from a chair.	This is a sign of weak leg muscles, a major reason for falling.
Yes(1) No(0)	I am worried about falling.	People who are worried about falling are more likely to fall.
Yes(1) No(0)	I have some trouble stepping up onto a curb.	This is also a sign of weak leg muscles.
Yes(1) No(0)	I often have to rush to the toilet.	Rushing to the bathroom, especially at night, increases your chance of falling.
Yes(1) No(0)	I have lost some feeling in my feet.	Numbness in your feet can cause stumbles and lead to falls.
Yes(1) No(0)	I take medicine that sometimes makes me feel light-headed or more tired than usual.	Side effects from medicines can sometimes increase your chance of falling.
Yes(1) No(0)	I take medicine to help me sleep or improve my mood.	These medicines can sometimes increase your chance of falling.
Yes(1) No(0)	I often feel sad or depressed.	Symptoms of depression, such as not feeling well or feeling slowed down, are linked to falls.
TOTAL _____	Add up the number of points for each "yes" answer. If you scored 4 points or more, you may be at risk of falling. Discuss this brochure with your doctor.	

Fig. 2. Stay Independent Brochure Questions.

Table 2
Descriptive statistics and fall risk identification for the combined cohort.

	Age (yrs)	TUG (sec)	30STS (reps)	Tandem (sec)	SLS (sec)	Narrow stride (sec)	Narrow stance (sec)	4MWT (m/sec)	SIB Score	STEADI risk	Key Quest risk
Mean	78.2	10.67	10.45	7.75	5.37	9.76	9.83	1.15	4.03	1.82	1.30
Std Dev	6.8	3.98	4.91	3.30	3.92	1.16	1.01	0.28	3.15	0.77	1.07
Range	65-93	5.6-29.1	0-22	0-10	0-10	1.88-10	3.28-10	0.55-1.97	0-13	1-3	0-3
Risk (+)	*ALL*	20 (26.0%)	27 (35.1%)	37 (48.1%)	n/a	n/a	n/a	21 (27.6%)	36 (46.8%)	46 (59.7%)	56 (73.1%)

|| Tandem, SLR, Narrow Stride combination best "preferred" and separate L/R limb testing (n=116) || Risk for TUG=12sec ||
|| Risk for STEADI/4MWT 2-tiered || Risk (+) refers to number (%) above fall risk cut-off score ||

Tandem, SLR, narrow stride combination best "preferred" and separate L/R limb testing (n = 116); risk for TUG = 12 s; risk for STEADI/4MWT 2-tiered; risk (+) refers to number (%) above fall risk cut-off score.

three fall rate statistics (Centers for Disease Control and Prevention, 2013), but almost three out of four (74%) of the community-based sample reported falling in the past year. There were no differences in gender, risk classification on the SIB or STEADI, 6-month prospective fall incidence, or mobility, strength, and balance between these two populations.

Descriptive statistics outlining all the variables and STEADI risk classification for the combined cohort are in Table 2. All data in this table was based upon a sample size of 77 with the exception of tandem, semi-tandem, and single-limb stance (SLS). Because the community-based sample tested both limbs whereas the retirement facility-based sample tested only the participant's preferred limb, the sample size of these three tests increased to 119 to account for right and left limbs in the community sample. Seven of the ten screening tools included in this study had cut-off scores established for fall risk. Table 2 indicates that the majority of the sample tested positive using the 3KQ (73.1%) compared with the SIB (46.8%) and the overall STEADI (59.7%). The greatest number of participants tested positive for fall risk on the tandem stance (48.1%) followed by the 30STS (35.1%), 4MWT (27.6%), and the TUG (26%).

3.1. Relationships among variables

Table 3 illustrates the relationships between the major test variables and the age of participants. This chart reflects associations with age and poorer performance on functional assessments. A positive significant correlation with advancing age and TUG scores ($r = 0.271$, $p = 0.017$), and an inverse significant relationship with tandem stance time ($r = -0.295$, $p = 0.009$) and amount of 30STS ($r = -0.257$, $p = 0.024$) were noted. However, there was no relationship with age and overall fall risk on the STEADI ($r = 0.068$, $p = 0.557$) or SIB ($r = 0.103$, $p = 0.375$). This insignificant relationship between age and the STEADI and SIB, and the overall moderate to strong significant ($p \leq 0.001$–0.005) correlations among the TUG, 30STS, Tandem, and 4MWT are reflected in Table 3.

3.2. STEADI algorithm

The range of scores on the SIB was 0–13 points. The average score for the SIB was just above the elevated risk cut-off of 4 out of 14 possible points (4.03) (CDCP, 2018; Rubenstein, Vivrette, Harker, Stevens, & Kramer, 2011) and 46.8% of the sample tested positive for fall risk on the SIB. In comparison, 73% of participants answered "yes" to one of the 3KQ, and almost 60% of our sample demonstrated a moderate or high fall risk on the STEADI algorithm. As illustrated in Table 3, the relationship between risk classification of the SIB and 3KQ was low but significant ($r = 0.289$, $p = 0.011$) for this sample. The SIB demonstrated a moderate significant correlation with the STEADI fall risk category ($r = 0.514$, $p < 0.001$), while the 3KQ only trended towards a significant association with the STEADI fall risk category ($r = 0.213$, $p = 0.064$).

3.3. Characteristics of algorithm risk tiers

Table 4 classifies self-reported fall data according to STEADI risk classification for the community-dweller sample (n = 39), and Table 5 classifies self-reported fall data according to STEADI risk classification for the retirement facility-dweller sample (n = 38). For the 6-month follow-up call, three participants were unable to be reached in the community group and 6 were unable to be reached in the retirement group. Of the participants that were reached prospectively, equivalent fall rates were noted amongst both groups at 28%. It is notable that only 8 members of the community-sample used an assistive device (21%) despite well over half (56%) reporting multiple falls in the prior 12 months. Further, almost 28% (10 of 36) fell within 6 months of their participation (Table 4). Similarly, only 11 participants (29%) in the retirement facility population reported using an assistive device despite it being an older population (mean age 82 years) and having an equivalent 6-month prospective fall rate of 28% (9 of 32). Notably, the highest rates of assistive device use within both groups were among individuals categorized as high risk of falls.

Overall, 28% (19 of 68) of participants fell within 6 months despite receiving standardized written instructions on follow-up recommendations based upon their individual risk categorization on the STEADI algorithm. This data is outlined in Tables 4 and 5. The high-risk group had a higher incidence of prospective falls in the community sample (46%) than the retirement sample (25%). Clinically, it is anticipated that high-risk groups would demonstrate higher fall rates. In fact, 6 of the 13 community sample and 1 of the 4 retirement facility sample fell within 6 months of their participation. However, a high false negative rate with the low risk groups was identified. In the community sample, 57% experienced a fall in the past year and 7 of these 8 individuals experienced multiple falls since turning age 65 despite being categorized as low risk by the STEADI algorithm. Of this low risk group, 15% also fell within 6 months. Four of the 17 (24%) retirement facility sample categorized as low risk reported falling 12 months prior to their fall screening and again 6 months following their fall screening.

Table 3
Correlations among test variables and age.

Correlation p-value	**Age**	**TUG**	**30STS**	**Tandem**	**4MWT**	**SIB**	**STEADI**	**3KQ**
Age	1.000	0.271 *0.017	-0.257 *0.024	-0.295 *0.009	-0.432 *<0.001	0.103 0.375	0.068 0.557	0.123 0.290
TUG	0.271 *0.017	1.000	-0.657 *<0.001	-0.317 0.005	-0.720 *<0.001	0.623 *<0.001	0.653 *<0.001	0.259 *0.024
30STS	-0.257 *0.024	-0.657 *<0.001	1.000	0.454 *<0.001	0.639 *<0.001	-0.532 *<0.001	-0.623 *<0.001	-0.285 *0.012
Tandem	-0.295 *0.009	-0.317 0.005	0.454 *<0.001	1.000	0.430 *<0.001	-0.226 *0.048	-0.539 *<0.001	-0.419 *0.009
4MWT	-0.432 *<0.00 1	-0.720 *<0.001	0.639 *<0.001	0.430 *<0.001	1.000	-0.531 *<0.001	-0.567 *<0.001	-0.252 *0.029
SIB	0.103 0.375	0.623 *<0.001	-0.532 *<0.001	-0.226 *0.048	-0.531 *<0.001	1.000	0.514 *<0.001	0.289 *0.011
STEADI	0.068 0.557	0.653 *<0.001	-0.623 *<0.001	-0.539 *<0.001	-0.567 *<0.001	0.514 *<0.001	1.000	0.213 0.064
3KQ	0.123 0.290	0.259 *0.024	-0.285 *0.012	-0.419 *0.009	-0.252 *0.029	0.289 *0.011	0.213 0.064	1.000

|| Pearson Correlation for all Dependent Variables with exception STEADI (Spearman Rho) || *CI 95% ||

Pearson correlation for all dependent variables with exception STEADI (Spearman Rho).
*95% CI.

3.4. Mobility and balance assessments

Mobility and balance assessments for the combined cohort are outlined in Table 2. Of the mobility and balance tests, the widest range of performance was discovered with the TUG (5.6–29.1 s) and the 30STS (0 - 22 repetitions). Twenty-six percent of participants scored above the 12-s TUG cut-off score (lower is better), and 35% of participants performed below the age-normative cut-off score on the 30STS (higher is better) (CDCP, 2018). Regarding the 4-stage balance tests (4SB), a ceiling effect was noted with participant performance of the semi-tandem and narrow stance tests with averages well above 9 s for both screening tests. In contrast, the mean time on the tandem stance was 7.75 s. Tandem stance also had the highest percentage of positive fall risk trials at 48% of participants. Participants were able to perform a single limb stance (SLS) for an average of 5.37 s, but no cut-off scores are available for this test in accordance with the STEADI algorithm. The samples' mean gait speed (1.15 m/s) indicates that, on average, our sample were community ambulators who were independent in ADLs, less likely to be hospitalized, and less likely to have an adverse event such as a fall (Cesari et al., 2005; Fritz & Lusardi, 2009; Schoene et al., 2013; Van Kan et al., 2009). Twenty-eight percent of participants demonstrated an elevated fall risk (< 1.0 m/s) (Montero-Odasso et al., 2005) on the 4MWT (range 0.55–1.97 m/s).

3.5. Validity of mobility and balance tests

Predictive and discriminate validity including likelihood ratios for prospective 6-month falls and retrospective 12-month falls were calculated for the TUG, 30STS, tandem stance, 4MWT (Table 6), and the SIB, 3KQ, and the STEADI (Table 7). Both the CDC recommended 12-s

Table 4
Classification of fall data with STEADI risk outcomes for community-dwellers.

Community	**All Participants** (n = 39)	**Low Risk** (n = 14)	**Moderate Risk** (n = 12)	**High Risk** (n = 13)
Age, years	74.6	73.3	78.3	73.6
Prior Falls, (12mo) n (%)	29 (74%)	8 (57%)	8 (67%)	13 (100%)
Multiple Falls, (12mo) n (%)	22 (56%)	7 (50%)	4 (33%)	11 (85%)
Prior Fall Fractures, (*Age 65*) n (%)	7 (18%)	2 (14%)	2 (17%)	3 (23%)
Prospective Falls (6mo), n (%) (n = 36)	10 (28%)	2 (15%)	2 (20%)	6 (46%)
Assistive Device Use, n (%)	8 (21%)	n = 1 (7%)	n = 1 (8%)	n = 6 (46%)

Table 5
Classification of fall data with STEADI risk outcomes for retirement facility-dwellers.

Retirement	**All Participants** (n = 38)	**Low Risk** (n = 17)	**Moderate Risk** (n = 17)	**High Risk** (n = 4)
Age, years	81.9 ± 5.3	80.5 ± 3.7	81.8 ± 6.0	88.5 ± 2.6
Prior Falls, (12mo) n (%)	13 (34.2%)	4 (23.5%)	5 (29.4%)	4 (100%)
Multiple Falls, (12mo) n (%)	1 (2.6%)	0 (0%)	0 (0%)	1 (25%)
Prior Fall Fractures, (12mo) n (%)	1 (2.6%)	0 (0%)	0 (0%)	1 (25.0%)
Prospective Falls (6mo), n (%) (n = 32)	9 (28.1%)	4 (23.5%)	4 (23.5%)	1 (25.0%)
Assistive Device Use, n (%)	11 (28.9%)	1 (5.6%)	6 (35.3%)	4 (100%)

(CDCP, 2018) and the commonly cited 13-s (Shumway-Cook, Brauer, & Woollacott, 2000) cut-off points for the TUG were analyzed. Results demonstrate high specificity for discriminating past fallers and ruling out future fallers with the 13-s cut-off (83.7–85.7%, respectively) indicating greater utility than the CDC's 12-s cut-off (77.6–81%, respectively). Sensitivity was poor for both cut-off points. Overall, the 30STS demonstrated limited validity with discerning fallers from non-fallers, either retrospectively or prospectively. However, the 30STS did identify non-fallers in the older retirement-facility sample with specificity of 68% for 12-month fall history and 74% for 6-month prospective falls.

We were unable to directly collate data from our two sample groups for tandem stance due to variations in methodology with limb selection. The community-dwellers were tested on both limbs whereas the retirement facility-dwellers were tested on the participant's preferred limb. However, data from both samples separately suggest that the 10-s cut-off value for the tandem stance limits its meaning and usefulness with discriminating fallers from non-fallers. Data from the community-dwellers indicate a sensitivity of 36.4% for the left lower extremity (LE) and 27.3% for the right LE, and specificity for 58.8% for the left LE and 52.9% for the right LE in discriminating 12-month fall history. The retirement facility-dwellers also had limited sensitivity (53.8%) and specificity (56%) for identifying past fallers. Data from the community-dwellers indicated a sensitivity and specificity of 30% for the right and left LE, and specificity for 61.5% for the left LE and 65.4% for the right LE in predicting 6-month fall incidence. The retirement facility-dwellers also had limited sensitivity (44.4%) and specificity (56.5%) for predicting future fallers.

The final assessment, the 4MWT, was tested in addition to the functional assessments already included in the STEADI algorithm due to the extensive literature on the utility of gait speed (Cesari et al., 2005; Fritz & Lusardi, 2009; Schoene et al., 2013; Van Kan et al., 2009). Similar to the TUG, results demonstrated good specificity for identifying

Table 7
Sensitivity, Specificity, and Likelihood Ratios STEADI, Stay Independent Brochure, and 3 Key Questions.

	STEADI	SIB	3KQ
12-month Fall History			
Sensitivity	68.6%	71.4%	100%
Specificity	47.6%	73.4%	50.0%
(+) LR	1.31	2.73	2.00
(−) LR	0.66	0.39	0.00
6-month Prospective Falls			
Sensitivity	68.4%	52.6%	78.9%
Specificity	44.9%	61.2%	34.7%
(+) LR	1.24	1.36	1.21
(−) LR	0.70	0.77	0.61
STEADI			
Sensitivity	-	60.9%	84.8%
Specificity	-	74.2%	45.2%
(+) LR	-	2.36	1.55
(−) LR	-	0.53	0.34
Stay Independent Brochure			
Sensitivity	77.8%	-	97.2%
Specificity	56.1%	-	48.8%
(+) LR	1.77	-	1.90
(−) LR	0.40	-	0.06
3 Key Questions			
Sensitivity	69.6%	62.5%	-
Specificity	66.7%	95.2%	-
(+) LR	2.09	13.13	-
(−) LR	0.46	0.39	-

(+) LR = positive likelihood ration; (−) LR = negative likelihood ratio.

Table 6
Sensitivity, Specificity, and Likelihood Rations TUG, Chair Rise, Tandem, and 4MWT.

	TUG		30STS	Tandem community sample		Tandem retirement sample	4MWT
	12 s cut	13 s cut		L	R	Preferred LE	
12-month Fall History							
Sensitivity	34.3%	28.6%	40.0%	36.4%	27.3%	53.8%	35.3%
Specificity	81.0%	85.7%	69.0%	58.8%	52.9%	56.0%	78.6%
(+) LR	1.80	2.00	1.29	0.88	0.58	1.22	1.65
(−) LR	0.81	0.83	0.87	1.08	1.37	0.82	0.82
6-month Prospective Falls							
Sensitivity	31.6%	26.3%	31.6%	30.0%	30.0%	44.4%	31.6%
Specificity	77.6%	83.7%	65.3%	61.5%	65.4%	56.5%	75.0%
(+) LR	1.41	1.61	0.91	0.78	0.87	1.02	1.26
(−) LR	0.88	0.88	1.05	1.14	1.07	0.98	0.91

(+) LR = positive likelihood ration; (−) LR = negative likelihood ratio.

those without a prior fall (78.6%) and for predicting future non-fallers (75%). However, sensitivity was poor (31.6%). Validity comparisons of the mobility and balance tests are outlined in Table 6.

3.6. Validity of algorithm

Table 7 outlines the predictive and discriminate validity including likelihood ratios of the STEADI, SIB, and 3KQ for prospective 6-month falls and retrospective 12-month falls. Because the STEADI algorithm is a 3-tiered risk categorization, the moderate and high-risk categories were combined into one elevated risk category for statistical analysis. Unlike the sub-component tests for mobility, balance, and lower extremity strength, the STEADI demonstrated better sensitivity than specificity. The STEADI algorithm was equally effective with identifying fallers retrospectively (68.6%) and prospectively (68.4%) with the combined cohort. However, the STEADI predicted future fallers with 80% sensitivity and classified 12-month fall history with 72.7% sensitivity among the community dwellers.

The SIB demonstrated relative equivalence to the STEADI classification of fall risk with true positive (71.4%) and true negative (73.4%) rates discriminating 12-month fall history, but the SIB was not useful with predicting 6-month future fall rates with this sample. The SIB predicted a low risk categorization of the overall STEADI with 74.2% specificity, further demonstrating congruency among the algorithm's fall risk conclusions. We previously outlined a moderate, significant correlation at $r = 0.51$ between the STEADI and SIB. The SIB had excellent congruency with predicting true negative risk rates on the 3KQ at 95.2% specificity with much stronger likelihood ratios. The 3KQ demonstrated perfect 100% sensitivity with identifying participants who fell in the prior 12 months but this data is skewed as one of the key questions asks the older adult, “have you fallen in the past year?” The 3KQ performed better than the SIB with predicting falls within 6 months at an acceptable to good sensitivity of 79%. The 3KQ were also able to better discriminate an elevated fall risk categorization on the overall STEADI than the SIB with good sensitivity of 84.8%.

4. Discussion

The purpose of this study was two-fold: (1) analyze the STEADI algorithm for strengths and weaknesses based upon descriptive statistics, correlation, and validity data in community screenings; (2) provide recommendations for additional research and possible limitations of the STEADI toolkit from a physical therapy perspective. We found that the STEADI algorithm had limited utility in predicting falls 6 months after screenings within the retirement facility sample, the community sample, and the combined data. Additionally, the STEADI algorithm yielded comparative utility regardless of age and past fall history among older adults. Several findings in our study provide insight to these results as well as the strengths and weakness associated with the STEADI in an independent, community-dwelling sample of older adults.

As expected, with advancing age, there were significant and similar associations with poorer performance on all functional assessments ($r = -0.257$ to -0.295). However, these did not result in significant relationships amongst advancing age and increasing fall risk on the SIB, 3KQ, or STEADI. These results are in contrast to literature indicating fall risk increases with age (Ambrose, Paul, & Hausdorff, 2013). Our results may be different due to the sample being independent community dwellers who performed relatively well on mobility and balance assessments. For example, the mean TUG times (10.67 s), 30STS (10.45 repetitions), and gait speed (1.15 m/s) indicate that, overall, our collated sample were community ambulators who were independent in ADLs, less likely to be hospitalized, and less likely to have an adverse event such as a fall (Cesari et al., 2005; Fritz & Lusardi, 2009; Schoene et al., 2013; Van Kan et al., 2009). Additionally, interventions to reduce fall risk are recommended among people with gait speeds below 1.0 m/s or TUG above 11–13.5 s, thus most of our sample would not be at risk on these measures (Fritz & Lusardi, 2009; Schoene et al., 2013). Despite these positive attributes of our sample, 39% reported having a fall in the 12 months prior to their participation in this study.

Twenty-six percent of participants were at risk of falls based on TUG times (Schoene et al., 2013; Shumway-Cook et al., 2000), 27% were at risk based on performing below the age-norms for the 30STS, and 48% were at risk based on tandem stance times less than 10 s (7.75 s) (CDCP, 2018). Although the three functional assessment tools included with the STEADI identified people at-risk of falls, they collectively had poor sensitivity in predicting future falls (26.3–44.4%). These three functional screening tools, however, did have better specificity with the TUG exhibiting the strongest ability to predict non-fallers prospectively (78%) and identify non-fallers retrospectively (81%) than the 30STS and 4SB. The 13-s cut-off (Shumway-Cook et al., 2000) for the TUG demonstrated slightly better utility than the STEADI's 12-s cut-off (CDCP, 2018) on the TUG. Notably, gait speed measured via the 4MWT had comparable specificity to the TUG and also outperformed the 30STS and 4SB with categorizing and ruling out falls. When considering which numbers to focus on when selecting fall risk tools, a meta-analysis by Park indicates that a higher sensitivity is preferable and it achieves the goal of an assessment even if it has a lower specificity (Park, 2017).

Clinically, higher false positive rates are more acceptable than higher false negative rates among older adults who, as a population, would theoretically benefit from interventions to prevent falls and fractures. The STEADI performed better with identifying fallers and predicting falls, whereas some individual tests (TUG, 4MWT) were better than the STEADI at discerning non-fallers. That said, the 3KQ or STEADI are better predictors of falls and may have greater clinical implications compared to individual mobility and balance tests. Individual balance tests when used alone are poor predictors of falls and the SIB alone is a poor predictor of falls suggesting the STEADI, when it integrates assessment of all three balance, strength, and mobility tests, is a viable option for predicting falls and ruling out non-fallers.

Results from this investigation suggest that it is important to conduct more than one mobility or balance screening test as some people may be identified at-risk on one and not another. This is in contrast with the STEADI algorithm which lists the TUG as “recommended” and the 4SB and 30STS as “optional” (CDCP, 2018). For example, 48% of our sample were identified as at-risk of falls based on tandem stance time in the 4SB, but sensitivity was poor. For the combined group, only 26% of the sample were at-risk based on TUG times (12 s cut-off) and sensitivity was 26–32% depending on the cut-off time used. If only the TUG were used, our results indicate that participants may be erroneously ruled out of being a risk of falls, which is concerning given the elevated false negative rates identified in Tables 4 and 5. The need for screening older adults using more than one functional assessment is also supported by literature indicating that the number of people identified as at-risk of falls varies based on the measurement tool (Muir, Berg, Chesworth, Klar, & Speechley, 2010).

Similar to this investigation's inclusion of the 4MWT, future studies should consider testing other fall screening tools to supplement or substitute the algorithm's current recommendations. In addition, some recent evidence exists that suggest combinations of screening tools are more valid in predicting future fallers. For example, Lusardi et al recently suggested that five history questions, 2 self-report measures, and 5 performance-based measures (including TUG $>$ 11 s, SLS $<$ 6.5 s, 4MWT $<$ 1.0 m/s) have the best clinical usefulness in assessing fall risk (Lusardi et al., 2017). Future studies on mobility-limited older adults may yield different results. Nevertheless, because our sample's age range was a robust 65–93 with a mean of 78 years, we conclude that the STEADI is equally as effective among younger and older independent, community-dwelling seniors.

4.1. Risk category, history of falls, prospective falls

Interestingly, although 12-month fall-history trended higher in the community group (74%) compared to the retirement group (34%), prospective fall rates were equivalent at 28%. This supports the need for further screening and assessment of prospective fall risk beyond looking at 12-month fall history. Accordingly, we anticipated that individuals categorized in the STEADI algorithm as high risk of falls would have the highest incidence of falls. This was true for the community group (46%, 6/13 participants), but not the retirement group (25%, 1/4 participants). However, the small sample size in the high-risk category of the retirement group limits generalizability of these results.

Upon closer analysis of the low-risk participants, 24% (4/17) of the retirement facility group suffered a fall within 6 months following screening compared to 14% (2/14) among the community group. Interestingly, although incidence of prior falls and prospective falls were the same within the low-risk retirement group (24%), they were mutually exclusive. None of the 4 individuals in the retirement group who reported a fall within 12 months prior to screening fell 6 months after screening and the 4 low-risk individuals that reported a fall 6 months after screening did not report falling 12 months prior. This was not the case in the community sample where half the sample reported a fall in the prior 12 months, but only two participants who reported a fall within 6 months after the screenings reported falling prior to study participation. The relationship between prior and future falls is worthy of investigation given the current weight (2 points) of prior falls on the SIB (CDCP, 2018), and the paramount role the TUG, 30STS, and 4SB play in determining risk stratification within the algorithm's pathway. This study's high false negative rates suggest absolute indicators of STEADI fall-risk pathways such as 12-month fall history, for example, may be insufficient in reliably screening for fall-risk, and that additional factors should be considered to predict risk of future falls.

The CDC estimates that increasing fall risk screenings and addressing modifiable risk factors may result in a 25% decline of future falls (Houry et al., 2016). The ability to predict and prevent falls may improve the health and wellness of older adults and alleviate the burden on society. However, in order for these efforts to be effective, an evidenced-based approach to prevention initiatives should be employed. The results of our study indicate community-based fall-risk screenings using the STEADI did not predict the incidence of falls 6 months after screening, and it was equally limited with discriminating prior fallers and non-fallers. This could be costly to society. However, since the STEADI is a fall screening, assessment, and prevention tool, it is possible that the prevention aspect of the toolkit was successful, which may be why the STEADI resulted in limited ability to accurately predict future falls (68% sensitivity). This is supported by a recent study by Lohman and colleagues (Lohman et al., 2017) who conducted a retrospective analysis on the utility of an adapted STEADI using the National Health and Aging Trends Study (NHATS). They found their adapted STEADI pathways to be predictive of falls using a larger data set with longer term prospective follow-up. Individuals who had a moderate risk of falls were 2.62 times more likely to fall over a 4-year follow-up and those with high risk of falls were 4.76 times more likely to fall. Additionally, there were no recommendations or interventions to prevent falls among the subjects in the NHATS, which would avoid the confounding effect of prevention and prediction in our investigation. Ideally, thresholds for acceptable sensitivity and specificity should be 70% or higher based upon guidelines from Perell et al. (2001) and Oliver, Daly, Martin, and McMurdo (2004) (Scott, Votova, Scanlan, & Close, 2007). A positive likelihood ration (LR) indicates the clinical usefulness of a positive test result: the larger the value above 1.0, the more valuable the positive test result. In contrast, a negative LR indicates the usefulness of a negative test result: the smaller the value below 1.0, the more valuable the negative test result (Lusardi et al., 2017).

Differences in our results can be also attributed to numerous methodologic differences such as different key questions and risk stratification processes used by Lohman et al compared to the CDC's published algorithm employed by our investigation (CDCP, 2018). Supporting the accuracy of our 68% sensitivity in predicting future falls, however, was a low rate of carryover of instructions that correspond to the three-tier STEADI risk categorization. Only 33 of 68 (48.5%) participants reported following up on the STEADI wellness and prevention instructions during a 6-month phone interview. Future studies are necessary to ascertain the impact that the prevention aspect of the STEADI toolkit has on future falls and fall-related injuries.

4.2. Study limitations

Relevant limitations of this investigation include recruitment and sampling methodologies, characteristics of participants, and sample size. Although from two different regions of the U.S., the sample size is limited ($n = 77$) and provides only a snapshot of these volunteer participants over an 18-month time period with follow-up for 6 months. Longer prospective follow-up investigations are necessary to more precisely determine predictive validity. However, this 6-month post-test period is cited in a systematic review by Lusardi et al as sufficient time for fall occurrence (Lusardi et al., 2017). Qualitative data to explain the high retrospective fall rates of the community population was not collected. Elevated self-reported fall rates for this sample may have been affected by self-selection bias and/or higher impact recreational activities such as hiking and sport that predispose an older adult to fall risks not validated by the STEADI toolkit's SIB, 3KQ, TUG, 30STS, or 4-stage balance tests.

In accordance with the STEADI algorithm, participants were provided verbal and written recommendations for referrals and interventions following fall risk determination (CDCP, 2018). Theoretically, these recommendations should reduce one's fall risk if participants follow through with instructions. Thus, the STEADI algorithm may not be a good predictor of future falls if adherence to recommendations results in a decline in fall risk and outcomes of these recommendations are impactful. However, participant rate of follow through on post-participation recommendations and referrals that correspond with the STEADI's low, moderate, or high fall risk categories was relatively poor. In fact, only 33 of the 68 (48.5%) participants who participated in the 6-month follow-up reported adherence to these instructions.

Of the 33 participants who self-reported adherence, eight (24%) reported falling within 6 months compared with 11 of 35 (31%) non-adherent participants who also fell within 6 months. When analyzing non-adherence according to fall risk classification, 3 of the 7 (43%) participants categorized as high risk who fell 6 months following the study. Three of the 6 (50%) participants categorized as moderate risk fell within 6 months following the. The greatest percentage of participants who fell within 6 months and reported non-adherence were in the low risk category. Five of the 6 (83%) who self-report falls were non-adherent to the CDC's prevention instructions specific to low risk. Our outcomes on 6-month adherence rates, although low, are consistent with a systematic review by Nyman and Victor (2012) who also reported a 50% adherence rate to fall prevention interventions in a group of community-dwelling older adults. It is likely that the nine additional participants ($n = 77$) that did not respond to the 6-month follow-up also did not adhere to the post-assessment instructions.

Lastly, this investigation did not statistically adjust for age, race, sex, education, comorbidities, hearing and vision impairment, and disability. Although this investigation was able to demonstrate some diversity particularly with the community sample, the approach of the authors was that all participants were classified as community-dwelling older adults and the limited sample ($n = 77$) made controlling for certain demographic factors inefficient. Despite the limited sample size and control for demographics, this investigation's results will provide relevant inferential guidance given the limited literature base on the STEADI's psychometric properties.

5. Conclusions

Moderate to strong relationships among the 4 functional screening tools (TUG, 30STS, Tandem Stance, 4MWT) were noted. These favorable levels of agreement suggest more work needs to be done to better establish convergent and discriminant validity among mobility, balance, and lower extremity strength constructs. Of these functional tests included in the algorithm, the tandem stance and the 30STS demonstrated limited predictive and discriminate validity. Furthermore, three of the four components of the 4SB lack cut-off values in the STEADI toolkit, thus limiting their potential value to the algorithm and possibly leaving results to interpretation from non-movement specialists. For example, although a 10-s cut-off score is suggested for tandem stance time, ceiling effects were noted with this, feet together and semi-tandem stance, but not SLS. These results suggest the discriminant ability of SLS as a functional assessment in the STEADI should be researched in future investigations. Results from this investigation give the anecdotal impression that the semi-tandem and narrow stance would demonstrate limited validity among community-dwelling older adults even if the CDC did include a 10-s cut-off score, for example.

The relatively low sensitivity and specificity of the STEADI in discriminating past and future fallers highlights the opportunity to examine additional functional assessment tools and examine the item weights of the SIB and 3KQ. Additional functional assessment tools could serve as either replacement or substitute tools to appraise an older adult's performance relative to each construct. This study's inclusion of the 4MWT is one example. The vast spectrum of older adults that are participating in the STEADI across access points within the healthcare continuum and community programs indicates a potential need for this multi-factorial fall screening toolkit to be more amendable to the needs and characteristics of participants. Although the SIB is evidenced-based and represents multi-factorial fall risks (Avin et al., 2015), the results of this investigation suggest that additional research is needed to optimize its sensitivity and specificity. For example, relative weight of each item included in the SIB may need adjusted. Currently, each item on this 14-point scale is assigned one point with exception of items one and two (prior falls, use of an assistive device). Adjustments in scoring the components of the SIB, application of the 3KQ, and/or considering whether a 12-month fall history is sufficient enough information to drive the algorithm and risk categorization are additional considerations to reduce false negative rates calculated by this investigation.

The results from this investigation highlight false negative rates with the STEADI algorithm's low fall risk categorization. Thirty-nine percent of all low risk participants including 58% of community-based participants self-reported a fall in the 12 months prior to their screening assessment. Furthermore, at least 19% of low risk participants fell within 6 months following their screening assessment. Accurate screening assessments should maximize true positive rates and minimize false negative rates. The STEADI algorithm appears to be challenged with identifying fallers who test negative with the STEADI's subcomponent tests. Additional research that adopts similar methodology of integrating all functional screening tests even if outcomes from the SIB are less than 4 and a participant answers “no” to all 3KQ is needed to further quantify the validity of a low fall risk categorization.

Prior to this investigation, the relationship and agreement of fall risk and fall rates was unknown among the STEADI, the SIB, and the 3KQ. As Table 3 highlights, this investigation calculated better agreement of risk categorization among the SIB and STEADI than the 3KQ and the STEADI. Despite evidenced-based congruency among the SIB and 3KQ, a weak insignificant correlation was concluded between these two screening components ($r = 0.213$, $p = 0.064$). Convergent validity should be optimized if providers are given the option to select the SIB or 3KQ (Iinattiniemi, Jokelainen, & Luukinen, 2009).

STEADI fall risk classification in this cohort ($n = 77$) was not associated with advancing age (mean 78.2 years; Table 3). These results are in contrast with reports that indicate fall risk increases with age (Ambrose et al., 2013; Iinattiniemi et al., 2009). The take-home message is that implementation of the STEADI by health care practitioners is equally valuable among older adults regardless of age.

It is noteworthy that sensitivity of the STEADI with discriminating fallers and predicting future falls was better among community-dwellers (73–80%) versus the retirement facility-dwellers (56–62%). Taken together, this data suggests that the utility of the STEADI may be different among different sub-sets of community-dwellers regardless of age.

In conclusion, development of the STEADI toolkit and the CDC's advocacy that fall screening be consistently integrated into primary healthcare is a vital step towards improving population health of older adults and costs associated with injurious falls. Inferential conclusions from this investigation bring attention to limitations with the STEADI algorithm's validity. Additional research analyzing the sensitivity and specificity of the STEADI algorithm and its subcomponent tests among a larger sample size of community-dwelling older adults is recommended.

Conflict of interests

None declared.

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