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RESEARCH ARTICLE

Repeated Predictable Loading and Unpredictable Unloading Waist-Pull Perturbations to Elicit Protective Stepping Responses: Clinical Correlations with Fall History in Active Older Adults

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Abstract

Background: Impairments in reactive stepping responses predispose older adults to fall-risk. Prior research has determined methods to assess reactive stepping responses, however those methods lack objectivity or feasibility for use in clinical settings. Spring Scale Test (SST) is a valid, reliable, safe and a clinical tool that measures reactive stepping responses as a percent of total body weight (% TBW). However, there is a need to determine whether SST derived stepping response measures associate with falls in older adults. Thus, this study performed a retrospective analysis of the published data by DePasquale and Toscano (2009) to examine whether SST obtained reactive stepping response measures correlate with fall history in older adults.

Methods: Fifty-eight older adults (mean age = 80.80 ± 7.23) underwent SST, with loading and unloading of waist-pull forces to elicit and assess reactive stepping responses. Stepping threshold, % TBW limit, step frequency at stepping threshold and % TBW limit were noted for both anterior direction (rear stepping) and posterior direction (forward stepping) waist-pull perturbations. Previous two-year fall history was recorded. Pearson's correlation was performed to determine the association between SST stepping response measures and fall history.

Results: Individuals with fall history exhibited a lower stepping threshold and %TBW limit values compared to individuals who did not fall. Fall history significantly correlated with %TBW limit ($r = 0.786$, $p = 0.05$ for rear stepping; $r = 0.743$, $p = 0.05$ for forward stepping). Stepping threshold at rear stepping correlated more with fall history ($r = 0.557$, $p = 0.01$) compared to stepping threshold at forward stepping($r = 0.30$, $p = 0.01$). No significant associations were noted for step frequency at stepping threshold and %TBW with fall history.

Conclusion: The SST derived stepping response measures might have the potential to identify older adults at risk of falls. Future studies are required in a larger sample to determine whether SST derived stepping response measures can be utilized by healthcare professionals to predict future fall-risk in older adults.

Keywords

Reactive, Stepping, fall-risk, Older adults, Spring scale test

Abbreviations

SST: Spring Scale Test; TBW: Total Body Weight; BBS: Berg Balance Scale; TUG: Timed Up and Go; FAB: Fullerton Advanced Balance scale; ICC: Intraclass Correlation Coefficient; SD: Standard Deviation; BOS: Base of Support; COM: Center of Mass

Introduction

Falls are a leading cause of morbidity and mortality in individuals over the age of 65 [1]. Falland fall-related injuries result in physical and psychosocial consequences, thereby affecting older adults' quality of life [2,3]. Even healthy older adults are prone to falls, especially on exposure to external environmental perturbations such as slips or trips during walking [4]. Considering the risk of falls and their impact on older adults' physical, social and mental well-being, it is essential to identify those at high fall-risk and provide early fall prevention interventions to reduce risk of falls.

Falls in older adults are associated with age-

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related physiological changes in sensorimotor and neuromuscular system which are critical for maintaining postural control [5,6]. Such age-related changes include but are not limited to reduced visual acuity, impaired depth perception, reduced sensitivity to proprioception and vibratory stimuli and, reduction in muscle mass and muscle strength [7,8]. Additionally, older adults demonstrate impairments in reactive balance and stepping responses, crucial for fall prevention [9,10]. An effective reactive stepping strategy is essential to recover from a perceived postural instability and is crucial to regain stability in a loss of balance situation [11]. In response to destabilizing perturbations, it is essential that stepping responses are executed appropriately and in a timely manner to extend the base of support (BOS) and there by prevent a fall [12,13].

Stepping responses associated with falls include an increased step frequency, lower stepping threshold force and stepping limit force [13,14]. Unlike young adults, older adults demonstrate a shorter initial compensatory step and thereby resort to multiple stepping response to regain balance [15], indicative of fall-risk in older adults [16]. Such protective stepping deficits and reactive balance control issues can predispose older adults to an increased fall-risk when faced with daily challenges of community ambulation.

Despite its importance, reactive balance control is less frequently assessed in clinical settings to determine fall-risk in older adults. This can be attributed to the fact that most clinically adopted fall-risk assessment tools such as Berg Balance Scale (BBS) and Timed Up and Go (TUG) employ voluntary initiated tasks which are fundamentally unable to assess reactive stepping deficits associated with fall-risk [17]. Two clinically adopted fall-risk assessment tools, the BES Test and Fullerton Advanced Balance scale (FAB) include a reactive balance component employing therapist applied lean-release techniques [18,19]. However, these measures have certain limitations including inconsistent application of forces to elicit reactive stepping responses and subjective scoring methods. To overcome such barriers, laboratory-based perturbation devices such as mechanical treadmills, lean-release or tether-release devices have been used to evoke and objectively assess reactive stepping responses [20,21]. However, such laboratory-based perturbation devices might not be clinically feasible due to their high costs and complex design thereby limiting their use in clinical settings. Thus, there is a need for clinical translation of laboratory-based reactive stepping assessment methods. Development of a clinically safe, feasible and quantifiable reactive stepping assessment tool is essential for fall-risk assessment.

One such tool that has been developed to assess reactive stepping measures in clinical settings is the Spring Scale Test (SST). The SST is a manual tether-release, waist –pull perturbation assessment method for the purposes of quantifying reactive stepping responses as a percent of total body weight (% TBW) [22-24]. The SST employs a strap tethered at waist level to deliver manually administered predictable loading and sudden unpredictable unloading of waist pull forces. Such unpredictable release of loading forces induces reactive stepping. Even though loading can be predictable (progressive direction loading of forces), the unloading is unpredictable (timing of unloading is unknown). Such unloading of anterior direction waist pull forces evoke rear direction stepping and unloading of posterior direction waist pull forces evoke forward direction stepping. Thus, the mechanism of SST in eliciting reactive stepping responses is similar to laboratory-based mechanical waist-pull and lean release systems. However, it is portable and simple to use and can be implemented within clinical settings by healthcare professionals. Previous study done using the SST identified SST as a reliable (ICC = 0.94) and valid reactive balance assessment tool and identified 10% TBW measure as highly discriminate for explaining fall history in healthy older adults [23].

Considering the growing evidence for reactive stepping response assessment coupled with the limited feasibility of laboratory-based perturbation devices for reactive stepping response assessment devices described in the literature, the authors of this study aimed to perform a retrospective analysis of the data published by DePasquale and Toscano in 2009 [23]. This study further expounds on the SST findings reported by DePasquale and Toscano, investigating the association between the SST obtained reactive stepping response measures with self-reported fall history. We hypothesized that lower stepping threshold and limit %TBW measures and higher stepping frequencies at stepping threshold and limit %TBW stepping milestones would correlate significantly with fall history in older adults.

Method

Participants

This study performed a retrospective analysis of the same data published by DePasquale and Toscano in 2009 which was reviewed and approved by the Visiting Nurse Service of New York Center for Home Care Policy and Research Institutional Review Board (IRB) [23]. A convenience sample of 61 community dwelling older adults were recruited via flyers, formal presentations at local senior centers, one on one presentations, and through word of mouth. This study involved a one-day visit to the participant's home wherein they were screened for inclusion/exclusion. If included, interested participants provided informed written consent followed by the SST protocol.

The inclusion criteria for the participants were: 1) ability to provide informed consent, 2) community-dwelling older adults with an ability to ambulate with or without a cane for one or more blocks, 3) 65 years or older, 4) ability to complete the Timed Up and Go test (TUG) in less than 14 seconds, 5) demonstrated medically stability without the need for medical adjustments or medical intervention, 6) absence of pain in lower extremity, 7) no history of hospitalization, spinal or lower extremity fracture within 3 months of participation, 8) ability to stand unsupported without any assistive device, 9) weight of 200lbs or less and, 10) ability to understand and follow simple instructions in English.

Following screening, 58 participants were included in the study. The study cohort comprised of 19 men and 39 women with age ranging from 65 to 94 years (mean age = 80.8 years, SD = 7.23). Thirty study participants were in the age group of 80 to 89 years. A 2-year fall incident recall period was recorded and was chosen to include individuals beyond acute and sub acute stages of fall recovery. Of the 58 study participants, 29 reported at least one fall over the span of 2 years. A fall was defined as "any disturbance of balance during routine activities that resulted in a person's trunk, knee or hand unintentionally coming to rest on the ground or any other lower surface." Fall exclusions included overwhelming environmental hazards (eg. Violence) or acute medical conditions (eg. Collapse due to syncope, stroke).

Instrument

The SST uses a spring scale that has a 26-pound (12-kilogram) capacity. The pocket sized 8-inch linear spring scale is capable of quantifying manual waist-pull forces in one-pound increments with a 0-set point turn dial calibration capacity (Pelouze/Pelstar LLC, Product of Pelstar; Bridgeview, IL). Calibration accuracy of the linear spring scale-measuring instrument was achieved through suspension of a 5-pound weight prior to and at mid-point of each test day with a range of 4 to 6 participants tested per test day and was performed by the primary examiner. The spring scale is attached to the padded belt on one end and the other end is held by the examiner. A 4-foot tether strap is secured at waist level to both the examiner and the participant, with compliant surfaces like a padded table was placed within 3 feet of the participant for safety purposes while enabling unrestricted responses to the waist-pull perturbations.

Procedure

The SST is a sagittal plane, horizontal, manual waist pull tether-release perturbation tool to quantify reactive stepping responses as % TBW (Figure 1). Rounds of predictable waist-pull loading and unpredictable unloading of repeated incremental perturbation forces are manually administered. Unloading of anterior waist pull force elicits rear direction stepping responses, while unloading of posterior waist pull force elicits forward direction stepping responses.

Figure 1: Demonstrates the Spring Scale Test (SST) set-up. The examiner is performing the anterior SST rear stepping testing. The set-up demonstrates the safety precautions taken throughout the test. The examiner is holding onto the spring scale and a strap is attached to the examiner and to the participant to ensure that the examiner can provide additional support when needed.

Predictable component of the SST - Loading

The SST consists of rounds of accommodative predictable loading and quasi-random unpredictable unloading of the waist-pull forces beginning at one-pound of force. During each round, loading forces are gently administered in 1-pound increments to allow the participant to accommodate. This accommodative, 1-pound incremental waist-pull loading comprises the predictable component of the SST. Instructions to lean against loading forces while maintaining foot-flat floor contact are verbally provided during all loading trials.

Unpredictable component of the SST - Unloading

Successful foot-flat loading is followed by sudden, quasi-random unloading administered at the discretion of the examiner within a subjective 5 second window Appendix A. Successive rounds of 1-pound incremental loading and unloading forces continues to the maximal limits of loading or unloading SST performance criteria. Quasi-random unloading comprises the unpredictable SST component. Verbal instructions are repeatedly provided to step only, when necessary, with the fewest steps possible.

The reactive stepping measures derived from the SST are as follows:

1. **Stepping threshold (% total body weight):** Waist-pull force at which the participant demonstrates initial onset of stepping response or loss of foot-flat contact from the floor surface during unloading, recorded as a percentage of the person's total body weight (% TBW).

2. **Limit % total body weight:** Maximum amount of waist-pull force sustained within an effective protective stepping response limit (3 step limit criteria) beyond which the participant demonstrates failure. Thus, more than 3 steps at unloading indicated a point of failure.

3. **Step frequency at stepping threshold:** Number of steps taken by the participant to regain balance at stepping threshold.

4. **Step frequency at limit % total body weight:** Number of steps taken by the participant to regain balance at limit %TBW. The number of steps taken by the participant were based on visual observation by the examiner.

The number of trials were administered until loading or unloading SST end point criteria were determined. Study participants were verbally asked about their fatigue levels and participants did not report any fatigue during the SST protocol. To ensure safety during the testing procedure, one end of the check strap is attached to the therapist while the other end is attached to the belt around the participant's waist. The strap provides ample control to the therapist to provide additional support if need be. Further, compliant surfaces (cushioned chair, sofa or bed) are placed anteriorly (during posterior SST) and posteriorly (during anterior SST) to ensure further safety. Details of the SST protocol are described in detail in the initial study by DePasquale and Tascano [23].

Data Analysis

For the purposes of this paper, based on the previous 2-year fall history, individuals who had a fall were denoted a value of 1 and individuals who did not experience a fall were denoted a value of 0. Pearson's correlations were then performed to determine the correlation between the outcome measures, that is, stepping threshold, limit %TBW, step frequency at stepping threshold and limit %TBW derived from both anterior and posterior direction testing with fall history. Additionally, mean of stepping threshold and limit % TBW was determined by calculating the total stepping threshold and limit %TBW of individuals who fell and those who did not fall and dividing it by the number of individuals who fell and those who did not fall respectively. Percentage of individuals taking a one, two or three step response was calculated in both individuals with a fall history group as well as in individuals without a fall history group.

Results

The results obtained from the retrospective analysis of the data collected and published by DePasquale and Toscano indicated that 29 participants had a fall history (mean age 83.60 ± 5.55) and 29 participants did not have a fall history (mean age 78 ± 7.75). The study results demonstrate that reactive stepping response measures obtained in response to SST waist pull perturbations are associated with fall history in older adults. Fall history significantly correlated with limit %TBW, which is maximal amount of SST waist pull force sustained within an effective protective stepping response limit of 3 steps (r = 0.786 for rear stepping, r = 0.743 for forward stepping at p = 0.05). Rear direction stepping threshold correlated moderately with fall history r = 0.557, p = 0.01) compared to forward direction stepping threshold (r = 0.301) indicating rear direction stepping threshold measures displayed slightly higher correlations with fall history compared to forward direction stepping measures (Table 1)**.** Individuals who had a fall exhibited lower stepping threshold and limit %TBW at 4.5% and 7.5% TBW respectively compared to 6% and 12.3% TBW values at stepping threshold and limit %TBW in individuals who did not fall (Table 2). Table 2 demonstrates mean stepping threshold and mean limit % TBW in both anterior and posterior stepping directions for individuals with and without fall history including stepping frequencies (1,2 or 3 steps) at SST %TBW forces ranging from 5 %TBW to 14 %TBW. The results indicate that individuals with fall history took multiple steps compared to individuals who did not fall

Table 1: demonstrating the Pearson correlations between previous fall history and outcome measures derived from the SST. Outcome measures include stepping threshold or percentage total body weight [% TBW (T)], step frequency at threshold [steps (T)], percentage total body weight limit [% TBW (L)], step frequency at limit [steps (L)].

Stepping direction	% TBW (T)	95% CI	Steps (T)	95% CI	% TBW (L)	95% CI	Steps (L)	95% CI
Rear	0.557**	0.339-0.734	0.258*	0.105-0.482	**0.786****	0.512-0.923	0.283*	0.136-0.522
Forward	0.301	0.069-0.536	0.245	0.109-0.419	**0.743****	0.544-0.934	0.418**	0.209-0.672

T= Threshold L= Limit

****0.010 (2 tailed); *0.050 (2 tailed)**

Table 2: Demonstrates mean stepping threshold or percentage total body weight (%TBW) and mean limit % TBW for fallers and non-fallers and the percentage of fallers and non-fallers demonstrating a one, two or three step response in both anterior and posterior direction, step frequency of fallers and non-fallers at 10% TBW and the frequency of fallers and non-fallers at each %TBW (ranging from 5% TBW and 14% TBW).

		Threshold		
Fallers 4.5% TBW		**Mean % TBW Rear Direction**	**Non-fallers 6.5% TBW**	
1 Step	35%		1 Step	56%
2 Step	52%		2 Step	31%
3 Step	13%		3 Step	13%
		Mean % TBW Forward Direction		
1 Step	55%		1 Step	70%
2 Step	32%		2 Step	26%
3 Step	13%		3 Step	04%
		Limit		
Fallers 7.5% TBW		**Mean % TBW Rear Direction**	**Non-fallers 12.3% TBW**	
1 Step	10%		1 Step	31%
2 Step	42%		2 Step	45%
3 Step	48%		3 Step	24%
		Mean % TBW Forward Direction		
1 Step	17%		1 Step	62%
2 Step	59%		2 Step	31%
3 Step	24%		3 Step	07%

at all %TBW values. Multiple protective steps at stepping threshold and limit % TBW stepping milestones in both rear and forward stepping directions was noted for both groups. Rear direction stepping threshold and limit %TBW stepping milestones were associated with higher stepping frequencies for individuals who fell compared to individuals who did not fall (Table 2). Mean limit %TBW forward stepping frequency for individuals who did not fall was 1.45 compared to 2.17 for those who fell. Mean limit %TBW rear stepping frequency for those who did not fall was 1.43 compared to 2.41 for those who fell. Step frequency at rear and forward direction stepping threshold ($r = 0.258$ for rear direction; $r = 0.245$ for forward direction) and limit %TBW ($r = 0.283$ for rear direction; $r = 0.418$ for forward direction) did not correlate significantly with fall history.

Discussion

The present study examined relationships between fall history in older adults and reactive stepping response measures obtained from manual unloading waist pull perturbations. Results of this study support our hypothesis indicating that a lower stepping threshold and %TBW limit significantly correlate with fall history in community-living older adults.

Differences in stepping threshold between individuals with and without fall history

This study examined the stepping threshold (% TBW) eliciting an initial step onset in response to quasi-random unloading of accommodative waist pull loading forces. Results of this study are consistent with previous laboratory-based literature indicating that older adults, especially older adults who had a fall history demonstrate a lower stepping threshold compared to young adults or older adults who did not fall [25,26]. Mille, et al. [27] indicated that at low threshold waist-pulls, the threshold boundary is near the foremost point of the BOS.[27]An individual can balance at or near this point, however, as waist-pull perturbation increases, the body has kinetic energy which must be overcome by muscular work. A significant amount of muscle work is needed to arrest the movement. However, due to age related changes such as reduction in muscle strength and muscle mass, the muscular work needed to arrest even a low force waist-pull perturbation using in-place strategies may not be enough, resulting in a stepping response at low threshold to maintain balance following a perturbation [27]. Due to inadequate proprioception in older adults, stepping is initiated primarily to a perturbation "event" detection rather than specific movement information detection, thus triggering a step which may not be necessary, resulting in a threshold stepping response at a low % TBW [28]. Older adults with a fall history, pre-plan a step based on their prior fall experience or their individual perception of safety thereby taking a step at low perturbation intensity [29,30]. Fear of falling enables older adults to adopt a "safer" movement strategy by stepping and extending their BOS thereby resulting in a lower stepping threshold, suggesting that a low stepping threshold can be attributed to age related neurophysiological changes and fear of falling.

Differences in %TBW limit between individuals with and without fall history

In addition to threshold %TBW stepping responses, rear and forward direction limit %TBW stepping responses was examined. The SST limit %TBW stepping milestone is the maximum %TBW manual waist-pull unloading force sustained within the SST three step limit unloading criteria. Individuals who fell in our study, were unable to resist high %TBW perturbation forces, eliciting dynamic instability, thereby reaching failure point. Such failure would indicate deficits in reactive balance control and an inability to respond to increasing magnitude of waist-pull perturbation forces. The inability to execute a long compensatory step to regain balance, resorting to a multiple stepping response, is associated with high fall-risk in older adults. Thus, individuals who fell in our study might not be able to able to take one long step, perhaps reaching their failure point (3 steps) at a lower waist-pull force compared to those who did not fall [31,32].

Directional bias in stepping responses

Consistent with laboratory-based findings by Sturniekset, et al. [33] and Crenshaw, et al. [34] the SST %TBW rear stepping measures demonstrated a directional bias indicating SST acquired rear threshold stepping measures exhibit higher association with fall history compared to forward threshold stepping measures. These findings indicate that rear stepping recovery induced by SST quasi-random unloading of anterior waist-pull forces is particularly challenging as the center of mass (COM) to BOS border is relatively short and requires execution of a compensatory step to prevent a fall. The ankle plantar flexor moment that supports the body against gravity during normal standing is quickly available to resist a forward fall induced by SST quasi-random release of posterior waist-pull loading forces which could be relatively easier compared to rear stepping responses elicited by SST quasi-random release of anterior waist-pull loading forces requiring sufficient rapid knee and anterior tibial muscle response to overcome the perturbation energy [33]. This could explain the higher association of SST acquired rear stepping measures with fall history in older adults. Our results are consistent with the literature indicating that recovery from slips which leads to a backward loss of balance is more difficult than trips resulting in forward balance loss as humans are at an advantage for forward balance control given that the range of hip flexion is greater than hip extension thereby allowing greater excursion of BOS in forward direction while stepping [31].

Differences in stepping frequency between individuals with and without fall history

Previous literature has demonstrated that age related changes in older adults can affect stepping response resulting in an ineffective first compensatory step and having to resort to a second step to regain stability [35]. Changes in cognition, fear of falling and previous experience of fall might trigger multiple stepping response wherein the individuals who fell might take some unnecessary steps rather than an effective long step to maintain balance [10,29]. Our study results also support the literature that the ability to take an efficient single step response might be associated with a lower fall-risk, thereby suggesting that examining the stepping strategy could be an essential component of fall-risk assessment. Although the findings of this study are consistent with laboratory-based perturbation studies concluding multiple stepping responses are common in individuals who have experienced falls [20,36], stepping frequency at threshold and limit %TBW milestones did not correlate significantly with fall history in this study. This discrepancy could be due to the SST method described in this study. Stepping response correlations reported in this study suggest that fall-risk in older adults appears to be more associated with the ability to withstand higher threshold and limit % TBW forces and to a lesser extent stepping frequency.

Previous studies assessed stepping responses utilizing motorized waist pull perturbations or motorized

Table 3: Demonstrates a comparison of results derived from SST outcome measures with the previously published literature.

Variable	Previous literature			RIPPS/SST results
	Article	Perturbation method	Result	
Stepping threshold	Millie, et al. [27]	Motorized waist pulls perturbations	Older adults had lower stepping threshold compared to young adults	Older adults had lower step threshold compared to young adults (unpublished)
	Sturnieks, et al. [33]	Motorized waist pulls perturbations	Future falls associated with lower force threshold during rear stepping waist-pull perturbations but not forward stepping waist-pull perturbations (RR=1.68)	Stepping threshold during rear stepping better predictor than forward stepping threshold. Rear direction measures better predictors than forward direction measures
	Crenshaw, et al. [34]	Motorized treadmill	Posterior stepping direction better predicted future falls (OR: 1.5; AUC=0.62)	
Multiple stepping threshold or number of steps (%)	Sturnieks, et al. [33]	Motorized waist pulls perturbations	Non faller: Rear 37% Non faller: FWD 21% Faller: Rear 77% Faller: FWD 45%	Non faller: Rear 44 Non faller: FWD - 30% Faller: Rear 65% Faller: FWD 44%
	Schulz, et al. [36]	Motorized waist pulls perturbations	Non faller: Rear - 1.60 Non faller: FWD - 1.14 BI: Rear - 2.11 BI: FWD - 1.63	Non faller: Rear - 1.43 Non faller: FWD - 1.45 Faller: Rear - 2.41 Faller: FWD - 2.17

FWD: Forward

surface translations using treadmills [26,27]. Our results are consistent with previous literature indicating that individuals who fell, exhibited lower stepping threshold, lower step limit force values, rear step direction deficit bias and higher stepping frequency compared to those who did not fall [15,27,31]. The results of this study support the ability of the SST to quantify stepping response data comparable to reported laboratory-based methods (Table 3). The information derived from this study can be clinically translated to establishing quantifiable goals: identify those with lower stepping threshold and limit % TBW who might be at risk of falls and provide them with balance or perturbation training to reduce their risk of falls. On similar lines, the goals of balance training paradigms focusing on reducing falls could include optimizing rear direction threshold %TBW force scores, and limit % TBW force scores in both rear and forward stepping directions.

Study Limitations

This study includes several potential limitations. Firstly, this study included independent, community-living older adults who were relatively healthy and functionally independent. However, older frail adult sub-groups having multiple co-morbidities affecting balance and function may be more vulnerable to loss of balance and falls and might possess limited stepping ability. Further, these results might have limitations due to the recall bias as participants were asked to recall their two-year fall history. The findings reported in this study are based upon waist-pull perturbations which evoke both anterior and posterior stepping response may not be generalized to other forms of fall-provoking circumstances, such as slips, and trips or self-induced balance loss associated with intended movement. The present study restricted its analyses to only reactive stepping response measures. Although the SST consists of both predictable loading which might result in anticipatory postural adjustments, this study focuses only on the automatic postural reactions elicited due to unloading of waist-pull perturbations. Future studies should use techniques such as electromyography to study the interplay between the anticipatory and reactive responses and whether they have an impact on first step characteristics including floor clearance, recovery kinematics and step initiation time which could provide more insight into mechanisms influencing the SST outcomes. Further, this study did not include a power analysis and was limited to assessing associations of outcome measures derived from the SST with fall-risk. Future studies should focus on measuring clinically important differences or meaningful differences, sensitivity and specificity in a larger sample size to provide further insight on the use of SST as a clinical fall-risk assessment tool. Additionally, prospective studies are warranted to examine the ability of the SST to predict fall in older adults, the responsiveness of the SST to changes in reactive stepping measures over time and efficacy as an induced-stepping clinical intervention tool.

Conclusion

This study identified an association of reactive stepping response measures with fall history thus providing evidence of the informative value of SST stepping response measures to identify those at fall-risk and to guide clinical assessment of fall-risk in older adults. Future studies are needed to further validate these findings and determine the utilization of SST as a fall-risk assessment tool for assessing reactive stepping in the clinical settings.

Author Contributions

All authors have made substantial contributions in conception or design of the work; or the acquisition, analysis, or interpretation of data for the work and drafting the work or revising it critically for important intellectual content.

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