Research Article

The measurement properties of the Lean-and-Release test in people with incomplete spinal cord injury or disease

Janelle Unger[1,2], Alison R. Oates[3], Joel Lanovaz[3], Katherine Chan[2], Jae W. Lee[2,4], Pirashanth Theventhiran[2,4], Kei Masani[2,4], Kristin E. Musselman[1,2,5]

[1]Rehabilitation Sciences Institute, University of Toronto, Toronto, Canada, [2]Lyndhurst Centre, KITE - University Health Network, Toronto, Canada, [3]College of Kinesiology, University of Saskatchewan, Saskatoon, Canada, [4]Institute of Biomechanics and Biomedical Engineering, University of Toronto, Toronto, Canada, [5]Department of Physical Therapy, University of Toronto, Toronto, Canada

Objective: To evaluate test-retest reliability, agreement, and convergent validity of the Lean-and-Release test for the assessment of reactive stepping among individuals with incomplete spinal cord injury or disease (iSCI/D).
Design: Multi-center cross-sectional multiple test design.
Setting: SCI/D rehabilitation hospital and biomechanics laboratory.
Participants: Individuals with motor incomplete SCI/D (iSCI/D).
Interventions: None.
Outcome Measures: Twenty-six participants attended two sessions to complete the Lean-and-Release test and a battery of clinical tests. Behavioral (*i.e.* one-step, multi-step, loss of balance) and temporal (*i.e.* timing of foot off, foot contact, swing of reactive step) parameters were measured. Test-retest reliability was determined with intraclass correlation coefficients, and agreement was evaluated with Bland–Altman plots. Convergent validity was assessed through correlations with clinical tests.
Results: The behavioral responses were reliable for the Lean-and-Release test (ICC = 0.76), but foot contact was the only reliable temporal parameter using data from a single site (ICC = 0.79). All variables showed agreement according to the Bland–Altman plots. The behavioral responses correlated with scores of lower extremity strength (0.54, $P<0.01$) and balance confidence (0.55, $P < 0.01$). Swing time of reactive stepping correlated with step time (0.73, $P < 0.01$) and cadence (-0.73 $P < 0.01$) of over ground walking.
Conclusions: The behavioral response of the Lean-and-Release test is a reliable and valid measure for people with iSCI/D. Our findings support the use of the behavioral responses to evaluate reactive stepping for research and clinical purposes.
Trial registration: ClinicalTrials.gov identifier: NCT02960178.

Key Words: Spinal cord injuries, Postural balance, Validation study

Introduction

When balance is lost one relies on reactive strategies to prevent a fall.[1] One reactive balance strategy is reactive stepping, which involves taking a step to increase the size of the base of support to return the center of mass within it. Research in individuals who have experienced a stroke has shown that people with impaired reactive stepping are at an increased risk of falling.[2] Hence there is a need to evaluate this specific reactive strategy in clinical populations. However, reactive stepping is not often assessed in clinical settings,[3] and when it is, it is not assessed in a standardized way.[4]

The Lean-and-Release test, which simulates a forward fall, is a standardized method of assessing reactive stepping ability.[5] It has previously been used in individuals with Parkinson's disease,[6] stroke,[7] and spinal cord injury or disease (SCI/D).[8] Despite the increasing use of this test, its validity and reliability

Correspondence to: Kristin E. Musselman, The institution is Lyndhurst Centre, Toronto Rehabilitation Institute-University Health Network, 520 Sutherland Drive, Toronto ON, Canada M4G 3V9. Email: kristin.musselman@uhn.ca

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have not been evaluated in any population. The test involves using a tether at waist height to support a portion of an individual's body weight as they lean forward; unexpectedly releasing the tether causes the individual to lose their balance in a forward direction and elicit reactive step(s).[5] The number of steps used to recover balance is recorded as the behavioral response. When approximately 8–12% of body weight is borne by the tether, young, healthy individuals are able to recover balance using a single step.[9, 10] Recovering balance through a single step is ideal, compared to using multiple steps or requiring external assistance to recover.[11] If the test is performed on force plates, temporal parameters of reactive stepping, such as foot off, foot contact, and swing time, can also be measured.[5]

Despite the fact that almost 80% of individuals with motor incomplete spinal cord injury or disease (iSCI/D) will experience at least one fall per year,[12] there has been little study of reactive balance in this population.[8, 13–15] The Lean-and-Release test has been used to describe the reactive stepping ability of individuals with iSCI/D,[8] but the reliability and validity of this test have not been established. Reliability is broadly defined as the "degree to which measurement is free from measurement error"[16], with measurement error including systematic and random error not associated with an individual's true change in performance.[16] More specifically, test-retest reliability considers whether scores for individuals whose status has not changed are reproducible over time,[16] while agreement uses measurement error to evaluate the accuracy of repeated scores taken from a measure.[17] Validity is broadly defined as the degree to which a measurement "measures the construct(s) it purports to measure",[16] with convergent validity considering how closely the measurement relates to other measures of the same or similar construct.[18] The aim of this study was to determine the measurement properties (*i.e.* test-retest reliability, agreement, and convergent validity) of the Lean-and-Release test (*i.e.* behavioral response and temporal parameters) for the assessment of reactive stepping among individuals with iSCI/D. It was hypothesized that the behavioral response and temporal parameters of the Lean-and-Release test would demonstrate good test-retest reliability (*i.e.* intraclass correlation coefficients > 0.75) and agreement (*i.e.* majority of points falling within the 95% Confidence Interval as depicted by the Bland–Altman plots), as well as convergent validity, as evidenced by moderate to strong correlations between the Lean-and-Release test parameters and scores on clinical and self-report scales of balance and gait.

Methods

Study design

Ethical approval was obtained from the Research Ethics Boards of the University Health Network and the University of Saskatchewan. Study procedures took place at two sites: the Lyndhurst Centre, Toronto Rehabilitation Institute – University Health Network, and the Biomechanics of Balance and Movement Laboratory in the College of Kinesiology, University of Saskatchewan. As there is a need for multi-center trials in clinical research,[19] this work aimed to evaluate the measurement properties of the Lean-and-Release test when performed at more than a single site. Participants were recruited using databases of participants who agreed to be contacted about future research studies, word of mouth, and posters displayed at the Toronto Rehabilitation Institute. Participants recruited at the Toronto Rehabilitation Institute were also part of a larger clinical trial (ClinicalTrials.gov identifier NCT02960178).[20]

Sample size calculation

The sample size calculation was based on the behavioral response to the Lean-and-Release test, as this is the metric commonly used as a primary outcome.[9] Based on previous work, which found an ICC of 0.84 for the behavioral responses to a Postural Stress Test for people with stroke,[21] it was calculated that 16 participants would be needed to establish test-retest reliability of the behavioral response on the Lean-and-Release test.[18] This calculation was done using a standard error of 0.1, and a 95% confidence interval.

Participants

Participants were included if they were adults (≥ 18 years old) with chronic (> 1 year post iSCI/D), non-progressive, motor iSCI/D and had no other health conditions that could affect their ability to participate. To participate in the Lean-and-Release test, participants must have been able to stand unsupported for a minimum of 30 s and demonstrate a moderate level of trunk control (score ≥2 on item #8 on the Berg Balance Scale – "reaching forward with outstretched arm while standing").[22]

Study procedures

Participants attended two sessions spaced approximately two weeks apart,[18] which would allow sufficient recovery time between sessions, as fatigue was expected following the testing sessions. Being in the chronic phase of iSCI/D, participants were not expected to experience any functional changes over the two-week period. At both sessions they completed the Lean-and-Release test.[5] At the first session the Mini-Balance Evaluations Systems Test (Mini-BESTest),[23] the Community Balance and Mobility Scale (CB&M),[24] lower extremity manual muscle testing (LE MMT), and two self-report measures, the Activities-specific Balance Confidence Scale (ABC Scale)[25] and the Falls Efficacy Scale-International (FES-I),[26] were administered. Participants at site 1 also walked across a pressure sensitive mat (Zeno Walkway, Model 485, Ver. J; Prokinetics, Havertown Pennsylvania, USA) to collect the spatiotemporal characteristics of gait.

(1) The Mini-BESTest is a comprehensive balance assessment consisting of four sub-scales (anticipatory, reactive postural control, sensory orientation, and dynamic gait) with a maximum score of 28 points.[23] The scale (total score and sub-scale scores) has previously been used in people with chronic iSCI/D and is valid and reliable for this population.[27]
(2) The CB&M assesses high-level balance tasks, such as running or hopping, with a maximum score of 96 points.[24] This scale has been validated for use in people with iSCI/D and has also shown to discriminate among people with high levels of balance control.[28] The CB&M was included as an additional balance measure due to its lack of ceiling effect in the iSCI/D population.[28]
(3) LE MMT was used to assess the strength of 12 muscle groups in the lower extremities bilaterally. The assessor provides manual resistance, if necessary, as the participant contracts the muscle through full range. Strength is scored on an ordinal scale (0–5) with higher scores reflecting greater strength.[29] The total possible score was 120 points (maximum score of 5/muscle group × 12 muscles × 2 legs).
(4) The ABC Scale is a self-report measure in which individuals rate their confidence in maintaining their balance during various standing and walking activities on a scale from 0% (low confidence) to 100% (high confidence).[25] The ABC Scale has been found to be reliable and valid in the chronic iSCI/D population.[30]
(5) The FES-I measures concern about falling during daily activities, such as getting dressed or going to a store, with scores ranging from 16 (low fall concern) to 64 (high concern).[26] This scale has previously been used in research studies focusing on this population.[31]
(6) The participants were asked to walk at a self-selected pace across a pressure sensitive mat (Zeno Walkway, Model 485, Ver. J, Prokinetics, Havertown, Pennsylvania, USA). They were encouraged to walk without a gait aid, if possible, with a spotter for safety. The variables of step length (cm), step time (s), step width (cm), cadence (steps/min), and time spent in double support (%) were extracted, as these gait parameters have shown to be affected following iSCI/D[32] and are known to reflect balance during walking.[33]

To conduct the Lean-and-Release test, participants donned a safety harness that was attached overhead to the ceiling thereby preventing contact with the floor in case of a fall. They began the test by standing with the feet on separate force plates placed adjacent to one another (AccuSway-Dual, Advanced Mechanical Technology Inc., Watertown, Massachusetts, USA). At site 1 identical force plates were located in front of the force plate where the participants stood (Fig. 1), whereas at site 2 a single force plate (Bertec, Columbus, Ohio, USA) was centered in front of the force plate where the participants stood. Participants were tethered to a horizontal cable (43 cm at site 1, 307 cm at site 2) at the waist level that was instrumented with a force transducer (Sensor: MLP-100-CO-C, Transducer Techniques, Temecula, California, USA: Amplifier; Model 9243, Burster, Germany or ADInstruments Inc., Colorado Springs, Colorado, USA). The cable was attached to a release mechanism that was manually operated; at site 1 a hook system

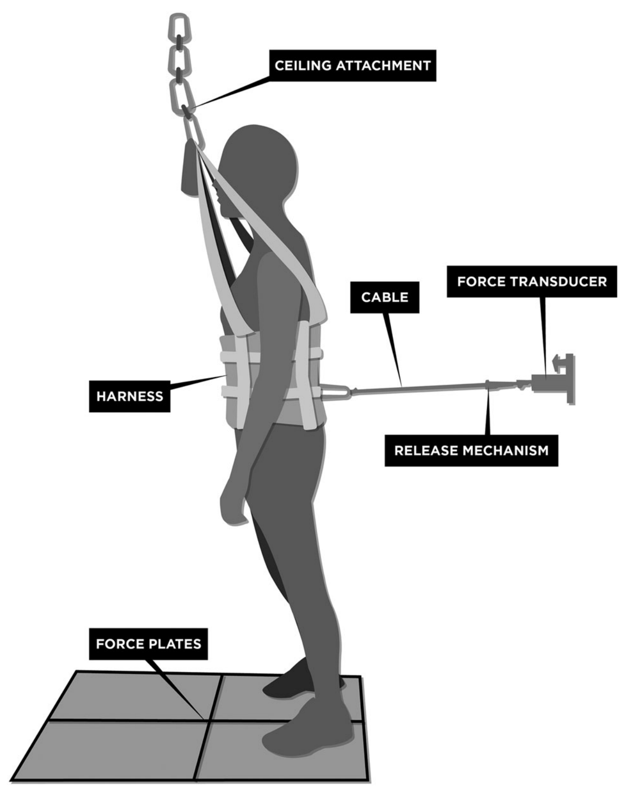

Figure 1 Lean-and-Release set up at site 1. Figure originally printed in Chan *et al*. 2019.[8] At site 2, there were only three force plates, with one wide force plate (60 cm) in front of participants during the initial standing position, and the cable behind the participants was 307 cm long.

was used, at site 2 the release mechanism was an electromagnet. The arrangement of the force plates, the length of the cable, and the release mechanism were the only differences in experimental set-up between sites. During the Lean-and-Release test, participants were asked to lean forward from the ankles while keeping the hips straight until approximately 8–12% of body weight was supported through the cable. This value range was selected due to its previous use during a similar assessment in people who had experienced a stroke.[2] At a random time within each 30-second trial, the cable was released and participants attempted to recover their balance by taking reactive step(s). Participants completed up to 13 Lean-and-Release trials, which included three false trials (*i.e.* participants were instructed to lean, but the cable was not released) randomly interspersed to mitigate the adoption of anticipatory balance strategies. Body kinematics were recorded, but not reported in this study. The ground reaction force components as well as the force transducer signal were synched and collected at 2000 Hz in the motion capture system (Cortex, Motion Analyses Corp., Rhonert Park, California, USA). The behavioral response was observed by a researcher standing close to the participant and was categorized for each trial as one of the following: (1) a single step (*i.e.* only one step required to regain balance, and a second sequential step allowed to align feet), (2) a multistep (*i.e.* more than one step necessary to regain balance), or (3) assistance required (*i.e.* assistance from a spotter or the harness was necessary for balance recovery). The proportion of trials in which participants were able to perform a single step reaction, which is the typical response,[11] was calculated so that a larger value indicated better reactive control.

Data analysis

Force plate and force transducer signals were filtered with a 4th order low-pass Butterworth filter and the cut-off frequency set at 30 Hz.[34] Temporal parameters were calculated relative to the timing of the cable release, which was defined as when the force measured by the transducer dropped to <1 Newton of force. Foot off was defined as the length of time from the release to when $<1\%$ of the participant's body weight registered on the force plate under the stepping leg. Foot contact was defined as the length of time from the release to when $>1\%$ of the participant's body weight returned to the force plate under the stepping leg after foot off. The time between these two events was referred to as swing time. The mean values of all completed trials for each participant were calculated, and for trials that resulted in more than one reactive step only the first step was used. Previous research has shown that within one multi-step response, there are no significant temporal differences between the first and subsequent reactive steps.[10]

To evaluate the test-retest reliability of the Lean-and-Release test (*i.e.* behavioral response, foot off, foot contact, and swing time), a two-way mixed effects model with absolute agreement intra-class correlation coefficient (ICC) was used, which has been recommended for assessing test-retest reliability.[35] ICC values of >0.90 are considered excellent, 0.75–0.9 are good, 0.50–0.75 are moderate, and values <0.50 are considered poor;[35] however, for clinical measures, an ICC of 0.70 or higher is recommended for reliability.[18] The standard error of measurement (SEM) was also calculated to determine the precision of the test. ICCs and SEMs were calculated for the behavioral response, foot off, foot contact, and swing time. Since this was a multi-center trial, the test-retest reliability was also evaluated only at site 1 ($n = 21$), to determine if these values were different from the sample as a whole. To evaluate agreement between the two testing sessions, Bland–Altman plots were created, with the difference between the two sessions on the y-axis and the mean score on the x-axis for each Lean-and-Release test variable. Limits of agreement were set to 95%. To evaluate convergent validity, the behavioral response and temporal parameters at the first testing session were correlated with scores on the clinical tests and self-report measures using either Pearson's R or Spearman's rho, depending on normality. The assumption of normality was assessed using a Shapiro Wilks test. Values from the second session were used if the first session was unavailable. Correlation coefficients of 0.90–1.00 are strong, 0.70–0.90 are moderately strong, 0.50–0.70 are moderate, and 0.30–0.50 are low.[36] Each Mini-BESTest subscale was also correlated with the Lean-and-Release parameters. All data were analyzed using SPSS (IBM Corporation, Version 25) with alpha set to 0.01.

Results

Participants

Twenty-six participants completed the two assessments for this study; 21 individuals participated at site 1 and five individuals participated at site 2. The participant group consisted of 16 females and 10 males, average (standard deviation) age of 57.1 (14.7) years (Table 1). All participants had chronic injuries, with the median (range) being 5.1 (1.0–38.6) years. Only 21 participants completed the ambulation tests using the pressure sensitive mat due to equipment availability at one site. Twenty-one participants were able to complete the

Table 1 Participant demographics.

Participant	Age (years)	Sex	Level of injury	Time since injury (years)	MOI
01	61	F	C3	1.0	NT
02	64	M	T6	6.8	NT
03	54	F	T10	1.0	NT
04	32	F	C4	3.5	NT
05	70	M	T1	1.8	NT
06	60	M	C5	3.2	T
07	43	F	T6	3.9	NT
08	87	F	T4	2.6	NT
09	57	F	C2	2.9	NT
10	59	F	C1	1.1	T
11	49	M	T5	21.1	NT
12	55	F	C5	9.1	T
13	38	F	T4	1.3	NT
14	54	F	C4	13.4	T
15	56	M	L1	16.3	NT
16	56	F	L5	1.2	NT
17	69	F	C5	4.8	NT
18	88	M	C6	5.3	NT
19	38	F	T11	6.8	T
20	51	M	C3	7.9	T
21	53	F	C4	38.6	T
22*	70	F	C5	9.6	T
23*	33	M	L1	10.3	T
24*	43	F	T8	4.3	NT
25*	69	M	C3	21.7	T
26*	76	M	L4	10.9	T

Participant demographics. F = female, M = male, C = cervical, T = thoracic, L = lumbar, MOI = mechanism of injury, NT = non-trauamtic, T = traumatic. *Participant tested at site 2.

CB&M as it does not allow the use of a gait aid; five participants from site 1 were not able to complete any of the items. Mean and standard deviation values for each session as well as the difference between sessions are outline in Table 2.

Reliability

The behavioral step reaction during the Lean-and-Release test proved to have good test-retest reliability (ICC = 0.76, C.I: 0.52–0.88). The SEM of the behavioral responses was 0.17.

Table 2 Values for each variable by session.

	Behavioral (proportion of single step responses) Mean (S.D)	Foot off (seconds) Mean (S.D)	Foot contact (seconds) Mean (S.D)	Swing (seconds) Mean (S.D)
Session 1	0.30 (0.36)	0.39 (0.09)	0.56 (0.11)	0.17 (0.04)
Session 2	0.31 (0.40)	0.36 (0.05)	0.55 (0.07)	0.18 (0.04)
Difference (Session 1 - 2)	0.01 (0.27)	0.03 (0.04)	0.01 (0.07)	−0.01 (0.03)

Mean and standard deviation (S.D) values for each session, as well as for the difference between sessions.

For the evaluation of temporal parameters, five participants were not included due to the lack of a step response and four participants due to equipment failures during one of the testing sessions. The temporal data for all included participants are shown in Fig. 2. ICCs indicated moderate reliability, but were not clinically useful according to the 0.70 threshold (Table 3). When considering data from site 1 only (n = 12), which is underpowered, foot contact had good reliability and foot off and swing time had moderate reliability. The SEM values for foot contact, calculated with data from site 1 only, was 0.04s.

Agreement

Visual analysis (Fig. 3) of the Bland–Altman plots demonstrated agreement between the two testing sessions for all parameters, due to low bias and narrow limits of agreement. For the parameters, the line of bias (upper limit of agreement, lower limit of agreement) were as follows: behavioral responses 0.01 (0.53, 0.51), foot off 0.05 (0.22, −0.13), foot contact 0.04 (0.23, −0.15), and swing <0.01 (0.10, −0.10).

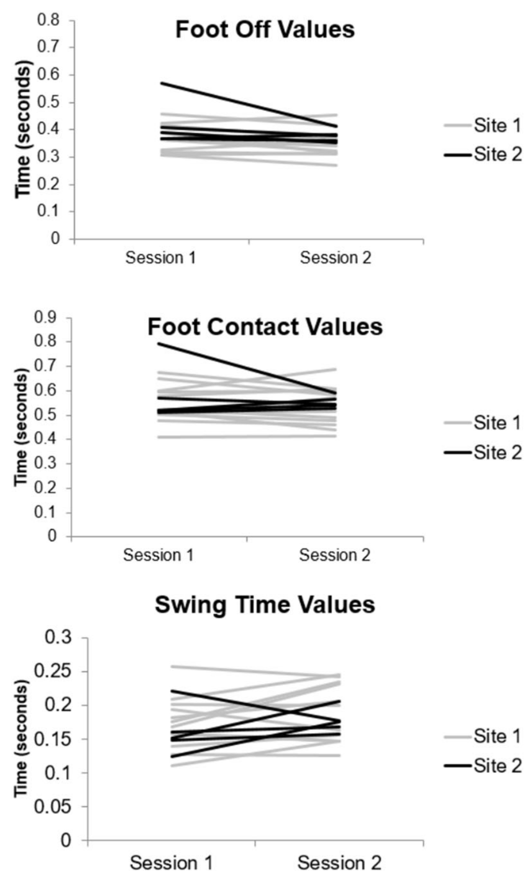

Figure 2 Comparison of foot off and foot contact values between site 1 and site 2. Foot off and foot contact values at site 1 (*n* = 12) and site 2 (*n* = 5).

Table 3 Test-retest reliability coefficients and standard error of measurement values between sites.

	Behavioral ICC (C.I.) SEM (proportion of single step responses) (C.I.)	Foot off ICC (C.I.) SEM (seconds) (C.I.)	Foot contact ICC (C.I.) SEM (seconds) (C.I)	Swing ICC (C.I.) SEM (seconds) (C.I.)
Site 1 Behavioral (n=20) Temporal (n = 12)	0.77 (0.50-0.90) 0.17 (−0.16-0.50)	0.74 (0.27-0.92) 0.05 (−0.04-0.13)	0.79 (0.40-0.93) 0.04 (−0.04-0.13)	0.71 (0.27-0.91) 0.02 (−0.02-0.07)
Total sample Behavioral (n = 25) Temporal (n = 17)	0.76 (0.52-0.88) 0.17 (−0.16-0.51)	0.61 (0.17-0.84) 0.05 (−0.04-0.15)	0.66 (0.29-0.86) 0.05 (−0.05-0.16)	0.61 (0.22-0.84) 0.03 (−0.02-0.07)

Intraclass correlation coefficients and standard error of measurement (SEM) values with 95% confidence intervals for the Lean-and-Release behavioral responses (site 1 n = 20, site 2 n = 5) and force plate variables at site 1 (n = 12) compared to the total sample (n = 17).

A positive bias was seen for foot off times from the first to second session, indicating a learning effect for this parameter.

Convergent validity

Correlation coefficients between the Lean-and-Release outcomes and the scores on the clinical measures and gait parameters are reported in Table 4. The behavioral responses showed significant, moderate correlations with scores on the LE MMT and ABC Scale only. For the temporal parameters there were only two significant correlations between swing time of the reactive steps; which showed moderately strong correlations in a positive direction with step time and a negative direction with cadence during voluntary walking.

Discussion

The behavioral response of the Lean-and-Release test, when performed at two different testing sites, was found to have clinically useful test-retest reliability in people with iSCI/D, but the temporal parameters did not. Convergent validity of the behavioral response was demonstrated as the proportion of single-step trials correlated with scores on measures of lower extremity strength and self-reported balance confidence. Surprisingly, no measure of the Lean-and-Release test (*i.e.* behavioral response or temporal parameters) correlated with scores on clinical measures of balance or gait parameters.

Since the test-retest reliability of the behavioral response is considered good, this Lean-and-release measure is acceptable for clinical use with individuals with SCI/D.[18] Obtaining the same ICC value for the behavioral responses at site 1 as well as across both sites increases confidence in using this measure in different environments. The ICC reported here for the behavioral response is slightly lower than what has been observed for another reactive balance assessment, called the Postural Stress Test, used with individuals

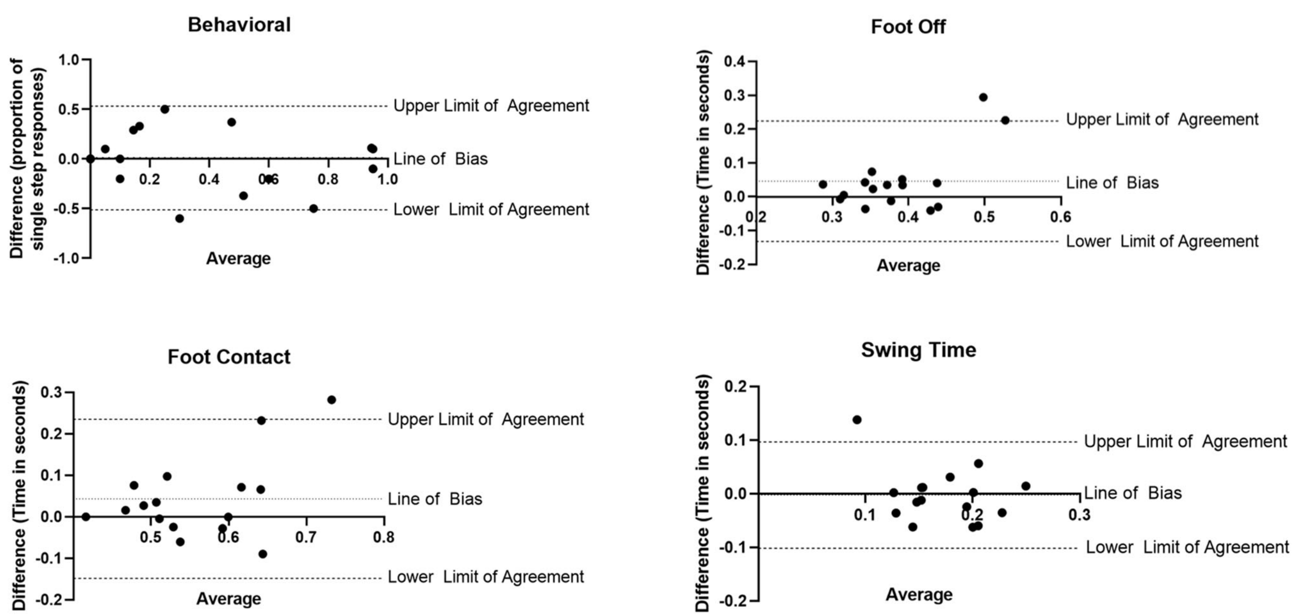

Figure 3 Bland–Altman plots of the agreement between the two testing sessions for each Lean-and-Release variable. Limits of agreement are set to the 95% confidence interval.

Table 4 Convergent validity.

		Behavioral*	*P*	Foot off*	*P*	Foot contact*	*p*	Swing	*P*
Mini-BESTest*	Total score*	0.40	0.05	−0.03	0.90	−0.26	0.22	−0.25	0.24
Behavioral (*n* = 26)	Anticipatory*	0.42	0.04	−0.09	0.68	−0.31	0.15	−0.36	0.09
Temporal (*n* = 17)	Reactive*	0.40	0.05	−0.02	0.92	−0.18	0.42	−0.06	0.79
	Sensory*	0.22	0.30	−0.10	0.65	−0.37	0.08	−0.34	0.11
	Dynamic*	0.35	0.09	0.02	0.91	−0.17	0.45	−0.22	0.32
CB&M Behavioral (*n* = 21) Temporal (*n* = 17)		0.21	0.38	−0.08	0.75	−0.23	0.32	−0.18	0.46
LE MMT Behavioral (*n* = 26) Temporal (*n* = 17)		**0.54**	0.01	−0.03	0.90	−0.15	0.51	−0.17	0.44
ABC Scale Behavioral (*n* = 26) Temporal (*n* = 17)		**0.55**	0.01	0.04	0.85	−0.01	0.98	0.03	0.91
FES-I Behavioral (*n* = 26) Temporal (*n* = 17)		−0.31	0.14	0.14	0.51	0.10	0.66	−0.14	0.54
Step Length Behavioral (*n* = 21) Temporal (*n* = 12)		0.10	0.69	−0.03	0.89	0.01	0.98	−0.09	0.71
Step Time* Behavioral (*n* = 21) Temporal (*n* = 12)		−0.25	0.30	−0.12	0.62	0.21	0.40	**0.73**	<0.01
Step Width Behavioral (*n* = 21) Temporal (*n* = 12)		−0.03	0.90	−0.38	0.12	−0.19	0.45	−0.05	0.86
Cadence* Behavioral (*n* = 21) Temporal (*n* = 12)		0.26	0.27	0.15	0.55	−0.21	0.41	**−0.73**	<0.01
Double Support* Behavioral (*n* = 21) Temporal (*n* = 12)		−0.34	0.16	−0.19	0.45	−0.17	0.51	0.07	0.80

Convergent validity correlation values, **bold font** indicates statistical significance. LE MMT = Lower extremity manual muscle testing, Mini-BESTest = Mini-Balance Evaluation Systems Test, CB&M = Community Balance and Mobility Scale, ABC Scale = Activities-specific Balance Confidence Scale, FES-I = Falls Efficacy Scale-International, *nonparametric test used.

who have experienced a stroke (ICC = 0.84).[21] In the current study, the test-retest reliability of the temporal parameters was clinically adequate only when data from a single site was evaluated. However, at site 2 one participant's performance on the Lean-and-Release test differed considerably between sessions (Fig. 2). When this participant's data were removed from the evaluation, the ICC values increased slightly: foot off ICC = 0.70 (0.25–0.89), foot contact ICC = 0.78 (0.47–0.92) and swing time ICC = 0.64 (0.21–0.86). However, in all cases the confidence intervals were quite large, particularly for foot off and swing times, possibly due to the small sample size. These large intervals reduce confidence in the reliability of these measures. The SEM values calculated specify what may be considered a true change in performance for each variable of the Lean-and-Release test, which is important when interpreting the change in scores over time. The values calculated indicate that individuals must change the proportion of successful trials by at least 0.17 and foot contact time by 0.04s to demonstrate change beyond the standard error of the measure. All variables of the Lean-and-Release test demonstrated agreement from the first session to the second; however, foot off times also demonstrated a learning effect, indicating the participants improved on this parameter with experience.

Moderate positive correlations were found between the behavioral response of the Lean-and-Release test and the clinical measures of leg strength and balance confidence only, suggesting that the Lean-and-Release test is measuring a unique aspect of balance control.[18] It is expected that those with greater leg strength would perform well on the test, as the supporting leg is needed to support the body and the stepping leg requires enough strength to perform a successful step. Participants with lower balance confidence did more poorly on the Lean-and-Release test, which is expected as those with decreased balance confidence have been shown to perform poorly on balance measures.[30]

There were no significant correlations between the behavioral responses and Mini-BESTest total score or reactive sub scale score. It is suspected that this lack of correlation is partly due to the comfort of the therapist performing the reactive sub scale testing with all participants, as there was a small subset of participants ($n = 3$) who performed well on the Lean-and-Release behavioral response (0.5 or higher) but had a score of zero on the Mini-BESTest reactive sub scale. The discrepancy could be due to the assessor choosing not to perform the reactive sub scale due to safety concerns despite the Lean-and-Release test indicating that these participants had some reactive stepping ability. The difference could also be due to the use of a safety harness during the Lean-and-Release test, which may have caused participants to feel safer than during the Mini-BESTest where no safety harness was used. As for the lack of correlations with the other sub scales of the Mini-BESTest and the CB&M Scale, it is suspected the reason is the different components of balance being assessed. Although the Lean-and-Release test and the Mini-BESTest both evaluate reactive balance specifically, they both include other components of balance as well. Reactive balance is known to be controlled by different mechanisms than other types of balance,[37] such as the dynamic and anticipatory balance tasks assessed in the clinical scales. Fall concern (*i.e.* scores on FES-I) was also not found to be correlated with the behavioral responses of the Lean-and-Release test. It is suspected that performance on the Lean-and-Release test is not affected by concern of falling since the presence of a safety harness significantly reduces the chance of a fall.

The temporal outcomes of the Lean-and-Release test did not correlate with any clinical outcomes. These findings are not altogether surprising since the temporal parameters are evaluating different constructs than strength, balance, or self-reported balance confidence and fall concern. As for gait parameters, swing time of the reactive steps evoked by the Lean-and-Release test correlated with step time and cadence during over ground walking. Swing time is likely consistent between volitional and reactive steps, so it would correlate with step time and cadence, which are both temporal parameters, during voluntary stepping. Foot-off times during the Lean-and-Release test represent reaction times, a parameter not under volitional control,[7] so it is not surprising that no correlations were seen with voluntary walking. Foot-contact times were also not correlated with any over ground walking variables, possibly due to the fact that some of the steps were successful at regaining balance and some were the first of a multi-step response, resulting in varying step lengths. The lack of convergent validity between most temporal parameters of the Lean-and-Release test and gait parameters during over ground stepping supports different control mechanisms between reactive stepping and voluntary walking.

While some Lean-and-Release variables had good measurement properties for people with iSCI/D, the feasibility of the test in clinical practice remains in question. The setup used in this study requires the use of sophisticated laboratory equipment and a safety harness system. Force plates are required to record the temporal parameters, and a force transducer is crucial to standardize the amount of body weight that is assumed by the cable. While this instrumentation is important for measuring temporal variables, the behavioral response of the Lean-and-Release test could be measured without any instrumentation, as has been demonstrated using a similar test in people with acquired brain injuries.[38] An advantage of the Lean-and-Release test compared to the reactive sub scale of the Mini-BESTest is that it is conducted up to 10 times, so the proportion of trials completed with a single step can be calculated, which may be a better indicator of reactive balance ability than a single test in each direction as is performed in the Mini-BESTest. It is possible that the Lean-and-Release test could be more responsive to change because of this, but further testing would be required to confirm.

This study was not without limitations. First, this sample was not representative of the current Canadian SCI/D population, as there was a higher number of female participants. In Canada, males are more likely than females to experience a traumatic injury;[39] for non-traumatic injuries, males and females have approximately equal risk globally.[40] Second, due to equipment limitations and failures, full data sets were not available for all participants. These missing data points further reduced the sample size for some calculations. Third, participants likely still used anticipatory balance strategies during the Lean-and-Release test despite the inclusion of three false trials. Fourth, the behavioral response of the Lean-and-Release test was evaluated as the proportion of trials with a single step reaction; hence the difference between multi-step responses and trials requiring assistance, which arguably has clinical relevance, was not considered. Lastly, a measure of state of anxiety during the testing may have been informative to describe how participants felt during the Lean-and-Release test, in order to determine correlations between anxiety states and the challenges presented by the Lean-and-Release test.

Conclusion

In conclusion, the behavioral responses outcome from the Lean-and-Release test were found to be reliable and valid for the assessment of reactive stepping among individuals with chronic iSCI/D, leading to opportunities to possibly take this test into the clinical setting. Future research evaluating the behavioral response of this test is encouraged in people with iSCI/D to determine the predictive validity and responsiveness of the measure, which will further establish its measurement properties and usefulness.

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ORCID

Kei Masani http://orcid.org/0000-0002-0207-3241
Kristin E. Musselman http://orcid.org/0000-0001-8336-8211

Bibliography

1 Maki BE, McIlroy WE. Control of rapid limb movements for balance recovery: age-related changes and implications for fall prevention. Age Ageing 2006;35(Suppl 2):ii12–ii18.
2 Mansfield A, Inness EL, Wong JS, Fraser JE, McIlroy WE. Is impaired control of reactive stepping related to falls during inpatient stroke rehabilitation? Neurorehabil Neural Repair 2013;27(6):526–33.
3 Sibley KM, Straus SE, Inness EL, Salbach NM, Jaglal SB. Balance assessment practices and use of standardized balance measures among Ontario physical therapists. Phys Ther 2011;91(11):1583–91.
4 Sibley KM, Inness EL, Straus SE, Salbach NM, Jaglal SB. Clinical assessment of reactive postural control among physiotherapists in Ontario, Canada. Gait Posture 2013;38(4):1026–31.
5 Inness EL, Mansfield A, Biasin L, Brunton K, Bayley M, McIlroy WE. Clinical implementation of a reactive balance control assessment in a sub-acute stroke patient population using a 'lean-and-release' methodology. Gait Posture 2015;41(2):529–34.
6 Jobges M, Heuschkel G, Pretzel C, Illhardt C, Renner C, Hummelsheim H. Repetitive training of compensatory steps: a therapeutic approach for postural instability in Parkinson's disease. J Neurol Neurosurg Psychiatry 2004;75(12):1682–7.
7 Mansfield A, Inness EL, Komar J, Biasin L, Brunton K, Lakhani B, *et al*. Training rapid stepping responses in an individual with stroke. Phys Ther 2011;91(6):958–69.
8 Chan K, Lee JW, Unger J, Yoo J, Masani K, Musselman KE. Reactive stepping after a forward fall in people living with incomplete spinal cord injury or disease. Spinal Cord 2020;58(2):185–93.
9 Lakhani B, Mansfield A, Inness EL, McIlroy WE. Characterizing the determinants of limb preference for compensatory stepping in healthy young adults. Gait Posture 2011;33(2):200–4.
10 K C. *Reactive stepping ability of individuals with incomplete spinal cord injury* [Dissertation]: Rehabilitation Sciences Institute, University of Toronto; 2018.
11 Wolfson LI, Whipple R, Amerman P, Kleinberg A. Stressing the postural response. A quantitative method for testing balance. J Am Geriatr Soc 1986;34(12):845–50.
12 Khan A, Pujol C, Laylor M, *et al*. Falls after spinal cord injury: a systematic review and meta-analysis of incidence proportion and contributing factors. Spinal Cord 2019;57(7):526–39.
13 Field-Fote EC, Dietz V. Single joint perturbation during gait: preserved compensatory response pattern in spinal cord injured subjects. Clin Neurophysiol 2007;118(7):1607–16.
14 Thigpen MT, Cauraugh J, Creel G, *et al*. Adaptation of postural responses during different standing perturbation conditions in individuals with incomplete spinal cord injury. Gait Posture 2009;29(1):113–8.
15 Arora T, Musselman KE, Lanovaz JL, *et al*. Walking stability during Normal walking and its association with slip intensity among individuals with incomplete spinal cord injury. PM R 2019;11(3):270–7.
16 Mokkink LB, Terwee CB, Patrick DL, *et al*. The COSMIN study reached international consensus on taxonomy, terminology, and definitions of measurement properties for health-related patient-reported outcomes. J Clin Epidemiol 2010;63(7):737–45.
17 de Vet HC, Terwee CB, Knol DL, Bouter LM. When to use agreement versus reliability measures. J Clin Epidemiol 2006;59(10):1033–9.
18 Streiner DL, Norman GR, Cairney J. Health measurement scales: a practical guide to their development and use. Oxford, UK: Oxford University Press; 2015.
19 Whyte J. Clinical trials in rehabilitation: what are the obstacles? Am J Phys Med Rehabil 2003;82(10 Suppl):S16–21.
20 Unger J, Chan K, Scovil CY, *et al*. Intensive balance training for adults with incomplete spinal cord injuries: protocol for an assessor-blinded randomized clinical trial. Phys Ther 2019;99(4):420–7.
21 Harburn KL, Hill KM, Kramer JF, Noh S, Vandervoort AA, Teasell R. Clinical applicability and test-retest reliability of an external perturbation test of balance in stroke subjects. Arch Phys Med Rehabil 1995;76(4):317–23.
22 Berg KO, Maki BE, Williams JI, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. Arch Phys Med Rehabil 1992;73(11):1073–80.
23 Franchignoni F, Horak F, Godi M, Nardone A, Giordano A. Using psychometric techniques to improve the balance evaluation systems test: the mini-BESTest. J Rehabil Med 2010;42(4):323–31.
24 Inness EL, Howe JA, Niechwiej-Szwedo E, Jaglal SB, McIlroy WE, Verrier MC. Measuring balance and mobility after traumatic brain injury: validation of the community balance and mobility scale (CB&M). Physiother Can 2011;63(2):199–208.
25 Powell LE, Myers AM. The activities-specific balance confidence (ABC) scale. J Gerontol A Biol Sci Med Sci 1995;50A(1):M28–34.
26 Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C. Development and initial validation of the falls efficacy scale-international (FES-I). Age Ageing 2005;34(6):614–9.
27 Chan K, Unger J, Lee JW, *et al*. Quantifying balance control after spinal cord injury: reliability and validity of the mini-BESTest. J Spinal Cord Med 2019;42(sup1):141–8.
28 Chan K, Guy K, Shah G, *et al*. Retrospective assessment of the validity and use of the community balance and mobility scale among individuals with subacute spinal cord injury. Spinal Cord 2017;55(3):294–9.
29 Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. *Muscles: testing and testing and function, with posture and pain*. 5th ed. Baltimore, MD: Lippincott Williams & Wilkins; 2005.
30 Shah G, Oates AR, Arora T, Lanovaz JL, Musselman KE. Measuring balance confidence after spinal cord injury: the reliability and validity of the activities-specific balance confidence scale. J Spinal Cord Med 2017;40(6):768–76.
31 Wirz M, Muller R, Bastiaenen C. Falls in persons with spinal cord injury: validity and reliability of the Berg balance scale. Neurorehabil Neural Repair 2010;24(1):70–7.

32 Perez-Sanpablo AI, Quinzanos-Fresnedo J, Loera-Cruz R, Quinones-Uriostegui I, Rodriguez-Reyes G, Perez-Zavala R. Validation of the instrumented evaluation of spatio-temporal gait parameters in patients with motor incomplete spinal cord injury. Spinal Cord 2017;55(7):712.
33 Tamburella F, Scivoletto G, Molinari M. Balance training improves static stability and gait in chronic incomplete spinal cord injury subjects: a pilot study. Eur J Phys Rehabil Med 2013;49(3):353–64.
34 King GW, Luchies CW, Stylianou AP, Schiffman JM, Thelen DG. Effects of step length on stepping responses used to arrest a forward fall. Gait Posture 2005;22(3):219–24.
35 Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15(2):155–63.
36 Mukaka MM. Statistics corner: a guide to appropriate use of correlation coefficient in medical research. Malawi Med J 2012;24(3): 69–71.
37 Misiaszek JE. Neural control of walking balance: if falling then react else continue. Exerc Sport Sci Rev 2006;34(3):128–34.
38 Borrelli JR, Junod CA, Inness EL, Jones S, Mansfield A, Maki BE. Clinical assessment of reactive balance control in acquired brain injury: a comparison of manual and cable release-from-lean assessment methods. Physiother Res Int 2019;24(4):e1787.
39 Pickett GE, Campos-Benitez M, Keller JL, Duggal N. Epidemiology of traumatic spinal cord injury in Canada. Spine (Phila Pa 1976) 2006;31(7):799–805.
40 Wyndaele M, Wyndaele JJ. Incidence, prevalence and epidemiology of spinal cord injury: what learns a worldwide literature survey? Spinal Cord 2006;44(9):523–9.