ORIGINAL ARTICLE

Dynamic Longitudinal Evaluation of the Utility of the Berg Balance Scale in Individuals With Motor Incomplete Spinal Cord Injury

Somnath Datta, PhD, Douglas J. Lorenz, PhD, Susan J. Harkema, PhD

ABSTRACT. Datta S, Lorenz DJ, Harkema SJ. Dynamic longitudinal evaluation of the utility of the Berg Balance Scale in individuals with motor incomplete spinal cord injury. Arch Phys Med Rehabil 2012;93:1565-73.

Objectives: To examine the utility of the Berg Balance Scale among patients with motor incomplete spinal cord injuries (SCIs), to determine how the utility of the Berg Balance Scale changes over time with activity-based therapy, and to identify differences in scale utility across patient groups defined by status of recovery.

Design: Prospective observational cohort.

Setting: The NeuroRecovery Network (NRN), a network of clinical centers for patients with motor incomplete SCI.

Participants: Patients with motor incomplete SCI (n=124) with American Spinal Injury Association Impairment Scale grade C or D, who were enrolled in the NRN between February 2008 and June 2009.

Intervention: Standardized locomotor training.

Main Outcome Measure: The Berg Balance Scale items were examined with longitudinal principal components analyses. Patients were categorized by phase using the Neuromuscular Recovery Scale.

Results: In the full sample, the first principal component explained a large percentage of overall scale variance (77%), items were loaded homogeneously on the first principal component, and item scores were well correlated with first principal component scores. In subgroups of low and high functioning of patients, first principal component variance accounting was reduced (49%) and only a few of the simplest and most difficult items substantially loaded onto the first principal component. Item loading coefficients evolved over time as patients recovered, with simpler items becoming less important to the full scale and difficult items more important.

Conclusions: The utility of the Berg Balance Scale in patients with motor incomplete SCI in early and advanced phases of recovery is limited. Specific item utility changes as patients recover. Thus, a more comprehensive and dynamic instrument is necessary to adequately measure balance across the spectrum of patients with motor incomplete SCI.

Key Words: Longitudinal studies; Principal components analysis; Rehabilitation; Spinal cord injuries.

RECOVERY OF THE ABILITY to walk is a key and frequently cited goal of people with spinal cord injury (SCI),[1] and is often an attainable goal, particularly for those with motor incomplete injuries.[2] To monitor the progress of locomotor recovery, several measures of walking capacity exist, including the 10-meter and 6-minute walk tests,[3] Timed Up & Go test,[4] Walking Index for Spinal Cord Injury,[5] and the Spinal Cord Injury Functional Ambulation Index.[6] While balance is a critical component of the ability to walk, few measures of balance for individuals with SCI are available.

The Berg Balance Scale is a 14-item instrument originally developed to measure the risk of falls in older adults,[7,8] and has been extended to people with stroke,[9] Parkinson's disease,[10] multiple sclerosis,[11] and brain injury.[12] Its use among patients with SCI preceded any assessments of validity and reliability.[13,14] Since then, the Berg Balance Scale has been shown to have concurrent validity with the Walking Index for Spinal Cord Injury scores, Spinal Cord Injury Functional Ambulation Index scores, 10-meter walk test speeds, and Timed Up & Go test times in a sample of patients with American Spinal Injury Association Impairment Scale (AIS) grade D injuries.[15] The Berg Balance Scale was further shown to correlate well with the Spinal Cord Independence Measure, Falls Efficacy Scale, 10-meter walk test, and the Walking Index for Spinal Cord Injury in a sample largely consisting of AIS grade C patients, and to have strong interobserver reliability.[16] The Berg Balance Scale, however, did not correlate well with number of falls and was nondiscriminatory in predicting falls in an SCI population.[16]

In our previous study,[17] people with AIS grade C and D injuries showed that the Berg Balance Scale captured a significant amount of variation in balance recovery and the first principal component scores correlated with 10-meter walk test speeds, 6-minute walk test distances, and the Spinal Cord Injury Functional Ambulation Index scores. These results suggested that the Berg Balance Scale was able to discriminate patients who were slowly recovering balance from patients with quick balance recovery. How-

List of Abbreviations

AIS	American Spinal Injury Association Impairment Scale
NRN	NeuroRecovery Network
NRS	Neuromuscular Recovery Scale
SCI	spinal cord injury

From the Department of Bioinformatics and Biostatistics, School of Public Health and Information Science (Datta, Lorenz) and Department of Neurological Surgery (Harkema), University of Louisville, Louisville, KY; and Frazier Rehab Institute, Louisville, KY (Harkema).

Supported by the Christopher and Dana Reeve Foundation (CDRF) through a grant/cooperative agreement (no. U10.CCU220379) between the CDRF and the Centers for Disease Control and Prevention.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

The contents of this article are solely the responsibility of the authors and do not necessarily represent the official views of the Christopher and Dana Reeve Foundation or the Centers for Disease Control and Prevention.

Reprint requests to Somnath Datta, PhD, School of Public Health and Information Science, University of Louisville, 485 E Gray St, Louisville, KY 40202, e-mail: *somnath.datta@louisville.edu*.

0003-9993/12/9309-00395$36.00/0
http://dx.doi.org/10.1016/j.apmr.2012.01.026

ever, the scale did not provide substantial balance-related information among those individuals that were the highest functioning and those who were most functionally impaired. In particular, simpler items on the Berg Balance Scale provided effectively no information about balance among the least impaired, and conversely more difficult items were of little utility among those more severely impaired. Hence, only small, distinct subsets of 4 or 5 items on the scale were of any utility in these 2 subgroups, and thus provided minimal information about balance function.

In this previous study,[17] the longitudinal profiles of the Berg Balance Scale and the walking measures were replaced by per-patient averages of temporal recovery prior to principal components analyses. Thus, the principal components and correlation analyses conducted were with respect to average changes in the Berg Balance Scale in response to activity-based therapy, rather than a direct examination of the utility of the Berg Balance Scale in measuring balance. In other words, the variation in balance recovery was examined, as measured by the per-patient averages of the longitudinal profiles, rather than the variation in balance itself. Further, the analyses by subgroups defined by recovery status were hindered by small sample sizes and the results were regarded as only preliminary.

The purpose of the current study was to further evaluate the utility of the Berg Balance Scale in individuals with motor incomplete SCI using longitudinal principal components analyses. We have departed from our previous study[17] by directly examining the items of the Berg Balance Scale at multiple points of follow-up during an activity-based locomotor training program. In particular, we examined how the principal components of the Berg Balance Scale and the importance of its items changed as patients progressed through an activity-based therapy program. We additionally examined the Berg Balance Scale within subgroups defined by recovery status to identify differences in full-scale utility and item importance among groups at different levels of functional recovery.

METHODS

Participants

We analyzed data from 124 patients enrolled in the NeuroRecovery Network (NRN), a network of rehabilitation centers providing standardized activity-based therapy to patients with motor incomplete SCI. Patients eligible for enrollment in the NRN had AIS grade C or D injuries with a nonprogressive spinal cord lesion at level T10 or above, and met additional previously documented inclusion criteria.[18] The patients comprising our sample were enrolled in the NRN at 7 participating treatment centers including: Frazier Rehab Institute (Louisville, KY), Magee Rehabilitation Hospital (Philadelphia, PA), Shepherd Center (Atlanta, GA), The Institute for Rehabilitation and Research (Houston, TX), Boston Medical Center (Boston, MA), Kessler Institute for Rehabilitation (West Orange, NJ), and The Ohio State University Medical Center (Columbus, OH). The institutional review board for each center approved submission of demographic, clinical, and outcomes data to the centralized NRN database, from which the data for this analysis were gathered. Each patient provided signed, written, informed consent prior to enrollment and data collection. The 124 patients considered in this analysis participated in the NRN between February 2008 and June 2009.

Procedures

All patients that were enrolled in the NRN, and those under consideration in this study, received standardized locomotor training. The procedures for the administration of locomotor training sessions in the NRN have been previously detailed[18,19]; we provide a brief summary here. Depending on therapeutic necessity and the degree of impairment, as determined at an initial evaluation by a treating therapist, NRN patients received 3 to 5 locomotor training sessions each week. A typical locomotor training session consisted of 3 components: (1) step training on a treadmill with body weight support and manual facilitation, (2) overground training, and (3) community integration training.[13,20-25] Patient evaluations, during which the Berg Balance Scale (among other outcomes) was measured, occurred at the patient's enrollment and approximately every 20 treatment sessions thereafter. Standard classification by the International Standards for the Neurological Classification of Spinal Cord Injury[26,27] occurred at the enrollment and discharge evaluations of each NRN patient. The data collected from patient evaluations at all NRN centers were compiled into a centralized database; the dataset analyzed here was taken from this database.

Data Analysis

The primary objective of this analysis was to explore the temporal evolution of the joint distribution of the 14 items of the Berg Balance Scale within and over all subgroups defined by the Neuromuscular Recovery Scale (NRS), a functional classification system for SCI, which was previously detailed.[28] Briefly, the NRS evaluates patients on a set of 11 functional tasks and assigns a 3-level classification based on performance of these tasks. Patients classified in NRS phase 1 were generally nonambulatory and unable to stand, and were highly dependent on caregivers for mobility and activities of daily living. NRS phase 2 patients were able to stand and had limited ambulatory capacity, but were generally dependent on assistive walking devices or physical assistance from a caregiver to ambulate. NRS phase 3 patients were generally ambulatory but were limited in speed and endurance or had significant gait deviations. It has been previously shown that the NRS divides patients with SCI into distinct functional groups, that is, that patients in different NRS phases exhibited significantly different performance on functional outcome measures.[28]

We pursued our goal by performing principal components analyses[29] at each evaluation in the sequence of patient evaluations, for example enrollment (first) evaluation, second evaluation, and third evaluation, for our full sample and for each NRS phase group. The first step in the analysis was a principal components analysis of the Berg Balance Scale data collected at the enrollment (first) evaluation. The results of the principal components analysis were considered empirically. Specifically, we noted the percentage variance accounted by each principal component and inspected the loading coefficients from the primary components—those explaining the most variability in the sample (typically the first principal component). Additionally, principal component scores were correlated with scores on the individual Berg Balance Scale items through a rank-based (Spearman) correlation analysis to identify Berg Balance Scale items that most substantially differentiated patient balance capability and most closely corresponded to the largest variance component of the data.[17] These at-enrollment analyses were repeated within the 3 phases of recovery defined by the NRS.[28] The loading coefficients for the first principal component were empirically compared across the 3 NRS phase groups and differences noted.

The principal components analyses of the Berg Balance Scale were repeated at each subsequent NRN evaluation (second, third, etc) with adequate data, for both the full NRN sample and each NRS phase group. As with the analysis of the enrollment Berg Balance Scale assessments, the principal components were empirically examined through consideration of variance accounting and loading coefficients. The longitudinal progression of the loading coefficients from the first principal component were plotted to identify substantial changes in the relative importance of the given Berg Balance Scale items with regard to the full scale. These plots were constructed for the first principal component from the full sample and for each of the NRS phase groups. Because the neuromuscular recovery phase was time-varying and assessed at each evaluation, the NRS phase groups were defined in terms of a patient's NRS phase at enrollment for clear interpretation of the dynamic changes in the roles of the Berg Balance Scale items as treatment progressed.

Descriptive statistics were calculated for demographic and clinical characteristics and for selected items and assessments of the Berg Balance Scale, and compared among NRS phase groups with chi-square tests for categorical variables and Kruskal-Wallis tests for ordinal and continuous variables. Nineteen (5%) of the 419 patient evaluations included in our dataset were incomplete. These evaluations were removed from the analysis, because 16 of the 19 were fully missing (all 14 Berg Balance Scale items not measured) and 3 included the measurement of only 1 of the 14 Berg Balance Scale items. All analyses were conducted using the open-source R software package.[30]

RESULTS

Demographic and Clinical Characteristics

Our sample of 124 NRN patients was mostly men and with an average age of 42 (table 1). Most patients had AIS grade D injuries and cervical injuries were most common. Patients were well distributed across all 3 phases of recovery defined by the NRS. The mechanism of SCI was diverse, with motor vehicle collisions being most common. Ambulatory patients (74% of the sample) used several types of assistive walking devices, with walkers being most common. Time from SCI to enrollment varied widely, from 0.1 to 25.8 years. The duration of NRN enrollment, number of treatment sessions received, and number of performance evaluations conducted varied widely. Average treatment intensity was in close proximity to the NRN target of 20 sessions per evaluation.

NRS phase 1 patients were more likely to have AIS grade C injuries (χ^2 test, $P<.001$) than NRS phase 2 and 3 patients, in correspondence with previous assertions about the relationship between AIS and NRS phase classification.[28] Assistive walking device use significantly differed across phases (Fisher exact test, $P<.001$), with NRS phase 1 patients more likely to be nonambulatory or requiring more support (walkers), and NRS phase 3 patients requiring little (canes/crutches) or no support.

Table 1: Demographic and Clinical Characteristics

Characteristics	Full Sample (n=124)	Phase 1 (n=46)	Phase 2 (n=55)	Phase 3 (n=23)
Sex				
Male	96 (77)	32 (70)	45 (82)	19 (83)
Female	28 (23)	14 (30)	10 (18)	4 (17)
Age (y)	42±17	42±17	44±17	38±16
AIS grade				
C	35 (28)	29 (63)	6 (11)	0 (0)
D	89 (72)	17 (37)	49 (89)	23 (100)
Injury level				
Cervical	94 (76)	31 (67)	43 (78)	20 (87)
Thoracic	30 (24)	15 (33)	12 (22)	3 (13)
Mechanism of injury				
MVC	46 (37)	13 (28)	23 (42)	11 (48)
Fall	24 (19)	12 (26)	12 (22)	4 (17)
Sporting accident	23 (19)	8 (17)	7 (13)	3 (13)
Medical/surgical	13 (10)	7 (15)	5 (9)	2 (9)
Nontrauma	11 (9)	5 (11)	4 (7)	2 (9)
Violence	7 (6)	1 (2)	4 (7)	1 (4)
Assistive walking device				
Nonambulatory	32 (26)	31 (67)	1 (2)	0 (0)
Walker	47 (38)	12 (26)	31 (56)	4 (17)
Cane(s)/crutch(es)	34 (27)	3 (7)	21 (38)	10 (43)
None	11 (9)	0 (0)	2 (4)	9 (39)
Time since SCI (y)	1 (0.1, 25.8)	1.2 (0.2, 25.8)	1 (0.1, 22)	0.3 (0.1, 5.4)
Treatment and enrollment characteristics				
Time of NRN enrollment (d)*	69 (0, 447)	72 (0, 447)	73 (0, 330)	38 (15, 146)
Cumulative treatment sessions received*	36 (0, 220)	39 (0, 220)	40 (0, 142)	20 (10, 61)
Cumulative no. of evaluations	3 (1, 12)	3 (1, 12)	3 (1, 8)	2 (2, 4)
Treatment intensity (Tx/evaluation)	19±4	19±3	19±5	18±4

NOTE. Values are mean ± SD, median (minimum, maximum), or counts (%).
Abbreviations: MVC, motor vehicle collision; Tx, treatments.
*Thirteen patients had enrolled just prior to the June 30, 2009 cutoff date for this analysis and had only received an initial evaluation and no treatment sessions.

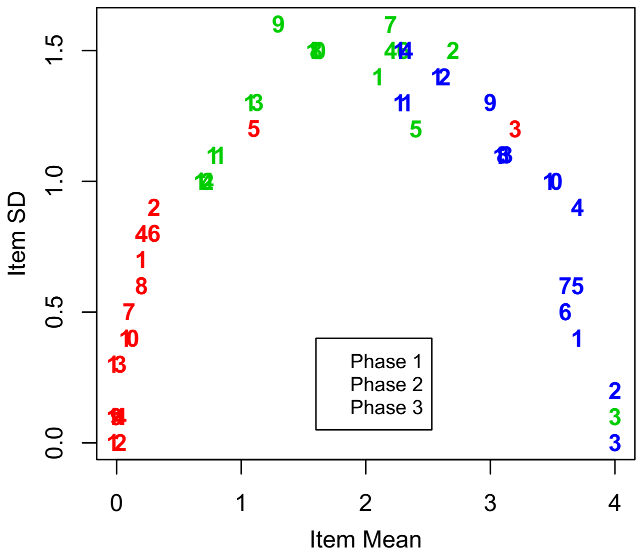

Fig 1. Plot of Berg Balance Scale item SDs against item means at the enrollment evaluation for patients in NRS phase 1 (red), NRS phase 2 (green), and NRS phase 3 (blue). Points are plotted as the number of each Berg Balance Scale item (1–14).

The significant differences among NRS phases for AIS grade and assistive walking device were suggestive of the NRS phase classification system being a marker of recovery, that is, NRS phase 1 patients generally had greater impairment with less function. Time since SCI was significantly different across the NRS phase groups (Kruskal-Wallis test, P=.03), largely because NRS phase 3 patients having been enrolled sooner after injury than NRS phase 1 and 2 patients. No other demographic or clinical parameter significantly differed across the NRS phase groups (χ^2 or Kruskal-Wallis tests, P>.09 for all).

Descriptive Statistics for Berg Balance Scale Scores at Enrollment

We first examined summary statistics of scale items from the enrollment evaluation of our sample. There were differences in item performance across the 3 NRS phases (fig 1), with patients in NRS phase 1 exhibiting the lowest scores (in red, at the left of the plot), and NRS phase 3 exhibiting the highest scores (in blue, at the right of the plot). Patients tended to perform more poorly on items higher in the numeric ordering of the Berg Balance Scale. NRS phase 1 patients were generally unable to complete items on the scale other than items 3 (sitting unsupported) and 5 (chair transfers), as item means for all other items were less than 0.5. NRS phase 3 patients scored well on the first 10 Berg Balance Scale items, with means of 3 and above, while performance on items 11 through 14 was lower. Item performance for NRS phase 2 patients was intermediate to that of NRS phase 1 and 3 patients. Patients generally were capable of sitting unsupported (item 3)—NRS phase 3 patients unilaterally scored 4 on this item, nearly all NRS phase 2 patients also scored 4, and NRS phase 1 patients performed well (mean, 3.2). The hierarchy of item difficulty, in which each Berg Balance Scale items are arranged in order of increasing difficulty, was generally although not rigidly preserved among this SCI sample; item 3 being a notable exception.

The utility of individual Berg Balance Scale items in measuring balance in the SCI population is related to their variance; items with low variability are of little importance, because performance on the given item is relatively uniform across patients. At the NRN enrollment evaluation, NRS phase 1 patients exhibited the most variability on items 1 to 6 and very little variability on items 7 to 14, as exhibited by the observed SDs (see fig 1). Variability was fairly consistent across items for NRS phase 2 patients, with slightly reduced variability for advanced Berg Balance Scale items (11–14) and almost no variability in item 3. Early Berg Balance Scale items (1–7) exhibited reduced variability relative to later items (8–14) for patients in NRS phase 3, and item 3 exhibited no variability. We noted that the mean/variance pattern for the full stratified sample was quadratic (see fig 1), and that item variability was highest for items with relatively high means among NRS phase 1 patients, item variability was relatively stable for NRS phase 2 patients, and item variability was highest for items with relatively low means among NRS phase 3 patients.

Principal Components Analysis of Enrollment Evaluations

In the full sample (ie, with phases pooled together), the first principal component of the Berg Balance Scale accounted for 77% of the variability in the scale and each subsequent component accounted for less than 6% of the overall variability. The loading coefficients for the first principal component for the Berg Balance Scale items 1 through 10 ranged from .23 to .34, with the exception of item 3 (.06), indicating that the contributions of these items were relatively uniform and thus of similar importance in measuring balance (table 2). Items 11 to 14 exhibited slightly lower coefficients and hence were of marginally lower importance, ranging from .19 to .26. Most Berg Balance Scale items were well correlated ($\rho\geq$.79) with first principal component scores (see table 2), with the exception of item 3 (ρ=.52).

When calculated by NRS phase, the first principal component was of varied importance in accounting for the scale's overall variance, being more important for NRS phase 2 patients (65%) than NRS phase 1 and 3 patients (49% each). Patterns in the loading coefficients by phase of recovery corresponded with the variance patterns described by figure 1 (see table 2, fig 2)—in general, items with low/high variability also had small/large loading coefficients. Among NRS phase 1 patients, items 1 to 6 on the Berg Balance Scale loaded highest, with coefficients ranging from .30 to .49, while items 11 to 14 were of little significance, ranging from .00 to .07. Item 3 (sitting unsupported) exhibited a large loading coefficient (.38) among NRS phase 1 patients, whereas it was of little significance in the full sample (loading coefficient=.06). Scores on items 3 (ρ=.80) and 5 (ρ=.87) were most strongly correlated with first principal component scores, and the remaining items from 1 through 8 were less strongly correlated (.42$\leq\rho\leq$.54).

Conversely, items 11 through 14 were of considerable importance in explaining full-scale variability among NRS phase 3 patients (coefficients: .31–.49, correlations: .74–.86), while items 1 through 7 were not (coefficients: .00–.15). The loading coefficient for item 3 was zero, because all NRS phase 3 patients scored a 4 on that item. The composition of the first principal component for NRS phase 2 patients at enrollment was in closest correspondence with the full sample (see table 2). The loading coefficients were of comparable magnitude; with the exception of item 3 (loading coefficient=–.01), item coefficients ranged from .18 to .34. Further, among NRS phase 2 patients, the first principal component scores were well correlated (.68$\leq\rho\leq$.89) with scores from all Berg Balance Scale items except item 3 (ρ=–.15).

Table 2: Loading Coefficients From the First Principal Component of the Berg Balance Scale and Rank Correlations Between the First Principal Component Scores and Individual Berg Balance Scale Items for the Full Sample and Each Phase Group Over Time (Evaluations)

Berg Balance Scale Item	Full Sample (n=124)	Phase 1 (n=46)	Phase 2 (n=55)	Phase 3 (n=23)
% Variance Accounted	77	49	65	49
1. Sitting to standing	0.31 (0.92)	0.30 (0.49)	0.29 (0.84)	0.10 (0.51)
2. Standing unsupported	0.34 (0.91)	0.41 (0.49)	0.31 (0.85)	0.02 (0.32)
3. Sitting unsupported	0.06 (0.52)	0.38 (0.80)	−0.01 (−0.15)	0 (0)
4. Standing to sitting	0.30 (0.89)	0.34 (0.54)	0.26 (0.70)	0.11 (0.23)
5. Chair transfers	0.23 (0.87)	0.49 (0.87)	0.20 (0.68)	0.12 (0.50)
6. Standing, eyes closed	0.31 (0.88)	0.34 (0.51)	0.31 (0.83)	0.07 (0.36)
7. Standing, feet together	0.32 (0.92)	0.17 (0.42)	0.33 (0.87)	0.15 (0.62)
8. Standing, reach forward	0.28 (0.87)	0.24 (0.48)	0.33 (0.88)	0.21 (0.54)
9. Standing, pick up object from floor	0.28 (0.83)	0.03 (0.24)	0.34 (0.84)	0.31 (0.74)
10. Standing, look over shoulder	0.31 (0.90)	0.17 (0.49)	0.34 (0.89)	0.21 (0.55)
11. Standing, turn 360°	0.19 (0.80)	0.03 (0.24)	0.18 (0.71)	0.43 (0.82)
12. Standing, place foot on stool	0.21 (0.82)	0 (0)	0.18 (0.77)	0.49 (0.86)
13. Standing, foot in front	0.26 (0.83)	0.07 (0.24)	0.26 (0.76)	0.31 (0.74)
14. Standing, 1 leg	0.20 (0.79)	0.03 (0.24)	0.19 (0.78)	0.47 (0.81)

NOTE. Values in each cell are the loading coefficient (rank correlation). Variance explained by the first principal component is given in the table headers.

Longitudinal Examination of the Berg Balance Scale

Principal components analyses for subsequent evaluations were conducted only when 20 or more patients contributed complete data. Therefore, in the full sample, we conducted analyses for evaluations 1 through 4 (n=124, 105, 67, 44). We noted that subgroups defined by the amount of follow-up were generally homogeneous with respect to clinical characteristics—sex, AIS grade, and neurologic level of injury did not significantly differ over groups defined by the number of follow-up evaluations (Fisher exact test, $P>.44$), nor did age, time since SCI, or the Berg Balance Scale total score at enrollment (Kruskal-Wallis test, $P>.54$). We conducted analyses at evaluations 1 through 3 for NRS phase 1 patients, (n=46, 38, 24), evaluations 1 through 4 for NRS phase 2 patients (n=55, 46, 33, 22), and evaluations 1 and 2 for NRS phase 3 patients (n=23, 21). NRS phase 3 patients, being more advanced in recovery at enrollment and requiring less treatment, remained enrolled in the NRN for shorter periods of time and subsequently underwent fewer evaluations than the NRS phase 1 and 2 patients (see table 1).

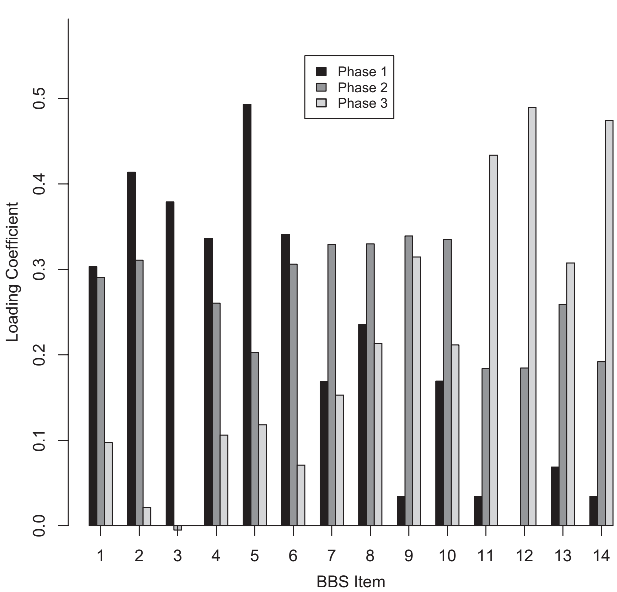

Fig 2. Loading coefficients from the first principal component of the 14 items of the Berg Balance Scale by NRS phase at enrollment. Abbreviations: BBS, Berg Balance Scale.

The proportion of full-scale variance accounted by the first principal component of the Berg Balance Scale in the full sample steadily increased from 77% at enrollment to 81%, 82%, and 83% at subsequent evaluations. The loading coefficients of the first principal component were generally stable (fig 3), with some exceptions and a few notable patterns. Item 3 (sitting unsupported) was not a major contributor to overall variability, exhibiting a low loading coefficient at enrollment (.06), which declined over time. The loading coefficients for simpler Berg Balance Scale tasks (items 1–5) decreased over time and most significantly for item 5 (chair transfers), which declined from .23 to .17. Moderately difficult Berg Balance Scale tasks (items 6–10) were most stable over time—over the 4 evaluations, no loading coefficient for these items departed farther than .01 from the enrollment evaluation. The loading coefficients for the most difficult Berg Balance Scale tasks (items 11–14) increased over time in the full sample, signaling that these items were good indicators of recovery as training progressed.

Among NRS phase 1 patients, the variance accounted by the first principal component increased from 49% at enrollment to 55% and 65% at subsequent evaluations. The loading coefficient for item 5, which had the highest coefficient at the enrollment evaluation, decreased dramatically, from .49 to .21 at the third evaluation. The same phenomenon occurred for item 3—the loading coefficient of .38 at the initial evaluation was third highest among all items, but decreased to .06 by the third evaluation. These declines signified decreasing contributions of these items to overall scale variability (fig 4), and were in correspondence with declines observed in the full sample, although these items were initially far more substantial contributors to overall scale variability for NRS phase 1 patients than for the full sample. The remaining simple Berg Balance Scale tasks—items 1 (sitting to standing), 2 (standing unsupported), and 4 (standing to sitting)—exhibited increasing load-

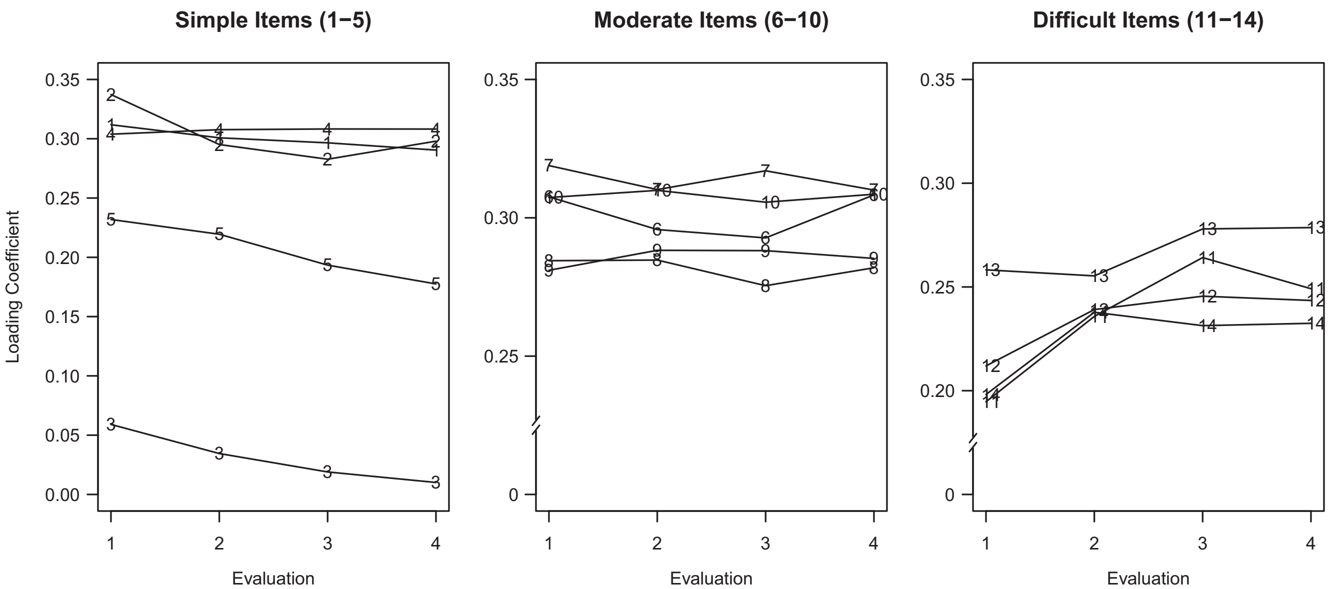

Fig 3. Loading coefficients from the first principal component of the Berg Balance Scale over time for the full sample for each item difficulty grouping (left panel = simple items, center panel = moderate items, right panel = difficult items). Center and right panels have broken y axes to better display the longitudinal pattern of loading coefficients for moderate and difficult items.

ing coefficients from the enrollment evaluation to the third evaluation. With the exception of item 8 (standing, reach forward), which slightly declined, loading coefficients for moderate Berg Balance Scale tasks (items 6–10) increased over time for NRS phase 1 patients, indicating greater importance in explaining overall variability. This was most evident for items 9 (standing, pick up object) and 10 (standing look over shoulder), which increased from .03 to .17 and .17 to .30, respectively. Difficult Berg Balance Scale tasks (items 11–14) did not significantly contribute to scale variability at any evaluation among NRS phase 1 patients.

Variance accounting of the first principal component among NRS phase 2 patients was reduced from that of the full sample but increased over time, from 65% at enrollment to 71%, 73%, and 75% at subsequent evaluations. Item 3 was a noncontributor, with loading coefficients all less than .005. Simpler (items 1–5) and moderate (items 6–10) Berg Balance Scale tasks exhibited declining loading coefficients, with the exception of item 4 (standing to sitting), indicating reduced contributions to overall variability (see fig 4). Conversely, loading coefficients for difficult Berg Balance Scale tasks (items 11–14) increased over time.

Variance accounting of the first principal component for NRS phase 3 patients increased from 49% to 62% from the first to second evaluation. Given that there were only 2 evaluations, it was not possible to discern temporal trends in loading coefficients; we simply directly compared the first and second evaluations. Loading coefficients for simpler Berg Balance Scale tasks (items 1–5) were low at enrollment relative to other coefficients ($<$.12) and remained low at the second evaluation ($<$.14). With the exception of item 9 (standing, pick up object), for which the loading coefficient increased from .31 to .45, moderately difficult Berg Balance Scale tasks (items 6–10) showed decreasing or stable loading coefficients. Loading coefficients for difficult Berg Balance Scale tasks (items 11–14), which were the most substantial contributors to overall variability at enrollment (coefficients$>$.31), were generally stable and remained the most substantial contributors at the second evaluation (coefficients$>$.28).

DISCUSSION

The Berg Balance Scale was effective at discriminating patients with poor, moderate, and strong balance function for the motor incomplete SCI population; however, its utility varied with the functional status of the patient. Our full sample analyses suggested that the variability in the Berg Balance Scale was well captured in the first principal component, because a substantially large percentage of variance was explained by the first principal component. Furthermore, item loading coefficients for the first principal component were relatively uniform, and first principal component scores were well correlated with item scores. Item 3 (sitting unsupported) was the notable exception, because most patients in our sample were fully capable of completing this task. Thus, as we have previously detailed,[17] a simple sum of the Berg Balance Scale items (less item 3) was an effective characterization of the full 14-item scale in our incomplete SCI sample, given the near perfect rank correlation between this sum and the first principal component scores (ρ=.99, $P<$.001).

The Berg Balance Scale also appeared responsive to recovery induced by an activity-based rehabilitation program, as shown by the results of our longitudinal analysis in which the composition of the first principal component changed over time to reflect patient recovery. Specifically, as patients progressed through treatment and regained balance function, simpler items on the Berg Balance Scale contributed less variability as performance on these items became uniformly better.

Our principal components analyses on the subgroups of patients defined by the NRS[28] showed that the utility of the Berg Balance Scale varied with patient functional status. Among NRS phase 1 and 3 patients, the scale seemed to provide minimal information regarding balance capability. The variability in the scale was largely confined to the simplest, first 5 items of the scale for NRS phase 1 patients and the most difficult, last 4 items for NRS phase 3 patients. The scale performed well for NRS phase 2 patients, for which the contribution of the items on the scale to overall variability was relatively uniform (excepting item 3), mirroring the perfor-

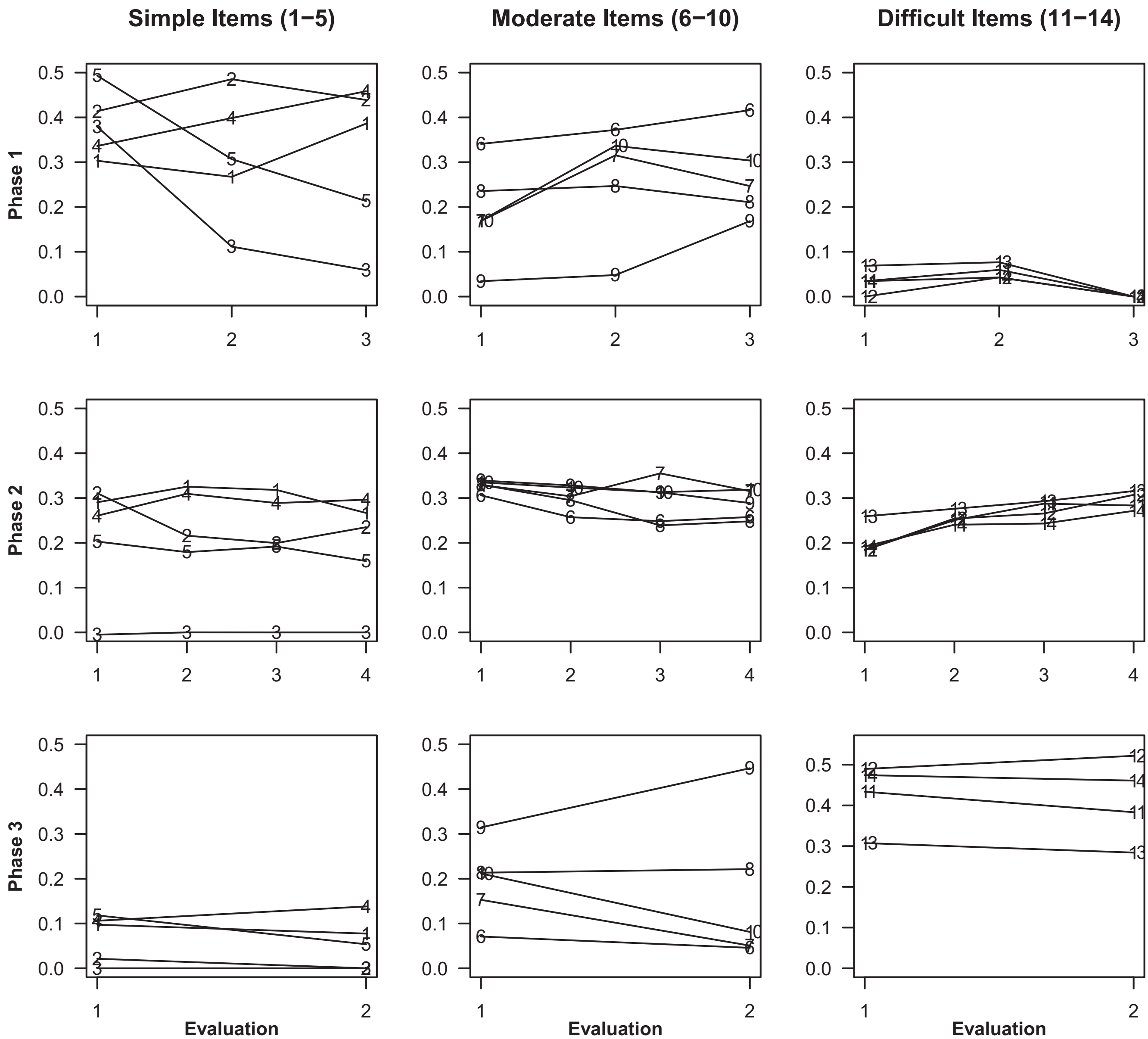

Fig 4. Loading coefficients from the first principal component of the Berg Balance Scale over time for each NRS phase group (rows) by item difficulty (columns). Abbreviation: PC, principal component.

mance of the scale in the full sample. This variability in item importance across phases also explained the scale's utility in discriminating balance function in the general population. In the full sample analysis, the early-item variability of NRS phase 1 patients and late-item variability of NRS phase 3 patients was aggregated with the all-item variability of NRS phase 2 patients, resulting in a scale with homogeneous item contributions to overall variability.

The results of our analyses by NRS phase were not altogether unexpected. The Berg Balance Scale is largely composed of items assessing balance while standing, and only a few items assessed sitting or stepping balance. In our study, patients classified as NRS phase 1 were generally nonambulatory and dependent on wheelchairs for mobility, possessing little if any capability for tasks associated with standing balance. Hence, the scale was of little utility among these patients, because they were generally incapable of completing standing balance tasks and scored uniformly low on advanced scale items. Similarly, NRS phase 3 patients were largely ambulatory, using canes, crutches, or requiring no assistance to walk and exhibited strong standing balance. These patients performed uniformly well on scale items assessing standing balance, and thus the scale was of little utility in measuring balance capability because of the absence of items assessing balance during stepping. NRS phase 2 patients ranged in ambulatory capability, from being unable to walk to walking with assistance from walkers, canes, or crutches. There existed substantial variability in their balance capability, particularly in tasks associated with standing balance. As a result, the Berg Balance Scale performed well in measuring balance in this subset of patients.

In summary, the Berg Balance Scale has useful properties for measuring balance in the general incomplete SCI population. In particular, the scale seems to adequately discriminate patients with poor and good balance function. However, the Berg Balance Scale does not appear to capture more subtle aspects of balance, particularly for patients of low and high functional capacity, and performs poorly for functionally homogeneous subgroups of patients with incomplete SCI. Specifically, most items on the scale were too difficult for patients of low function (NRS phase 1) and too simple for patients with advanced function (NRS phase 3) for the scale to be of any utility in measuring balance for these subgroups. Only subsets of Berg Balance Scale items—items 1 through 5 for NRS phase 1 patients and items 9 and 11 through 14 for NRS phase 3 patients—were substantial contributors to overall variability for low and high functioning patients. However, there was substantial diversity in performance on scale items among patients of moderate function (NRS phase 2), making it a potentially useful tool in this subset.

Based on our results, the use of the Berg Balance Scale as an outcome measure for clinical trials and intervention studies in the motor incomplete SCI population should be carefully deliberated. In particular, consideration should be given to the target population for a given study. The scale would likely be a reasonable choice for a study of patients with motor incomplete SCI with moderate functional capability. However, it would provide a poor assessment of balance for studies targeting, for example, wheelchair-bound patients or patients requiring limited or no support for ambulation. Thus, it is faulty to assume that the Berg Balance Scale adequately measures balance for all AIS grade C and D patients.

Our previous examination of the Berg Balance Scale[17] indicated that the utility of the Berg Balance Scale may have been limited in the incomplete SCI population. In the article,[17] the longitudinal component of the dataset was marginalized in that average evaluation to evaluation changes in individual scale items were analyzed. In the present study, we have directly examined the longitudinal component at each patient evaluation and shown that not only does scale item importance vary by NRS phase, but it also dynamically changes over time as patients progress through treatment. In particular, we've shown that simpler Berg Balance Scale tasks become progressively less important as treatment accumulates, patients recover more function, and begin to score uniformly well on these items. Conversely, more difficult Berg Balance Scale tasks begin to exhibit more variability, as patients recover and acquire the ability to perform these tasks. Thus, the results of this study confirm and extend the preliminary results of our previous study.

Study Limitations

The primary limitation of our analyses was the nonhomogeneity of the study sample over time because of the loss of patients from evaluation to evaluation. This introduced an aspect of variability into our analysis, in that the sample of patients considered at one of the later evaluations (second, third) may not have corresponded with the sample at the enrollment evaluation. Further, the loss of patients over time limited the available sample size for later evaluations, particularly for NRS phase 3 patients for which only the first 2 evaluations had a decent sample size for analysis. Thus, it is possible that some of the results we observed could partially be a product of loss to follow-up. However, we did note that baseline balance capability and demographic and clinical characteristics of patients with differing amounts of follow-up were not significantly different.

Because these analyses were conducted on a sample of NRN participants, it can be reasonably assumed that these results can be generalized to the NRN population, that is, patients with SCI with characteristics making them eligible for enrollment in the NRN. Extension of these results to the general motor incomplete SCI population may hinge on how representative NRN-eligible people are of the motor incomplete SCI population.

By employing principal components analysis, we have conducted an internal validation of the Berg Balance Scale by exploring the joint distributional properties of the 14 Berg Balance Scale items. This was the main goal of our investigation and, we have not considered any external validation measures, such as a correlation study with other measures of functional capacity for patients with SCI. However, correlation studies have been previously conducted in other articles,[15,17,31] which in part showed that the Berg Balance Scale correlated strongly with 6-minute walk test distances and 10-meter walk test speeds and other functional outcome measures.

Principal components analysis is an exploratory technique, and our statistical results are descriptive rather than inferential in nature. In particular, while our results suggest that the simple sum of Berg Balance Scale items (less item 3) provides an effective summary of the full 14-item scale in the incomplete SCI population, we cannot conclude that the scale is unidimensional. In fact, tests of scale unidimensionality through confirmatory factor analysis[32] strongly suggest the presence of more than 1 latent factor ($P<.001$). We briefly note that such results do not conflict; latent factors linearly combine to produce scale items, while scale items linearly combine to produce principal components, and it is entirely possible that a dominant primary principal component results from a multifactor scale. A more formal, inferential treatment of the Berg Balance Scale would likely include model-based methods, such as factor analysis, and would produce insights into the latent characteristics of the scale. An examination of the latent characteristics of the Berg Balance Scale was not the purpose of the present study, but certainly is an important topic for further investigation. We do note that our data were inherently complex—observational, nonrandomized, and longitudinal with incomplete follow-up and potentially informative length of follow-up—and that the specification of an underlying model, such as with factor analysis, which completely encapsulates these features of the data, would be a significant challenge.

CONCLUSIONS

In the motor incomplete SCI population, the Berg Balance Scale can be a useful tool for discriminating patients with poor, moderate, and advanced balance function, but its utility in measuring balance within groups of patients divided by functional status is varied. The utility of the scale varied greatly across subgroups defined by the NRS and changed markedly as patients progressed through therapy over time. While the Berg Balance Scale seemed to adequately differentiate patients with respect to balance capability, the utility of the scale in those least and most advanced in recovery was questionable. A more sensitive balance scale for the motor incomplete SCI population is needed—a scale that more adequately measures basic static, sitting balance function and advanced, dynamic balance function. A dynamic scale, with items varying with a patient's functional status, may be particularly effective for this population, because it could provide a more sensitive assessment of basic and advanced balance while reducing the testing burden for clinicians through the selection of appropriate items.

Acknowledgments: We thank Joe Canose, Susan Howley, and Michael Mangienello from the Christopher and Dana Reeve Foundation for their dedication and support. The extraordinary vision, compassion, and dedication of Christopher and Dana Reeve made the NeuroRecovery Network possible. We also thank the other current or past NeuroRecovery Network Center Directors: Steve Ahr, Linda Shelburne, PT, and Mark Sheridan, MSW (Frazier Rehab Institute); Mary Schmidt Read, PT, DPT, MS (Magee Rehabilitation); Steve Williams, MD (Boston Medical Center); Daniel Graves, PhD (Memorial Hermann/The Institute of Rehabilitation and Research); Sarah Morrison, PT, and Keith Tansey, MD, PhD (Shepherd Center); Gail F. Forrest, PhD (Kessler Medical Rehabilitation Research and Education Corporation); and D. Michele Basso, PT, EdD (The Ohio State University Medical Center) plus all other current and previous Network members. We also acknowledge the critical review and editorial support of Jessica Hillyer, PhD, and the leadership, foresight, and support of the NRN Advisory Board, V. Reggie Edgerton, PhD, Moses Chao, PhD, Michael Fehlings, MD, PhD, Andrei Krassioukov, MD, PhD, and Shelly Sorani, MA.

References

1. Ditunno PL, Patrick M, Stineman M, Ditunno JF. Who wants to walk? Preferences for recovery after SCI: a longitudinal and cross-sectional study. Spinal Cord 2008;46:500-6.
2. Barbeau H, Ladouceur M, Norman K, Pepin A, Lerous A. Walking after spinal cord injury: evaluation, treatment, and functional recovery. Arch Phys Med Rehabil 1999;80:225-35.
3. Van Hedel HJ, Wirz M, Dietz V. Assessing walking ability in subjects with spinal cord injury: validity and reliability of 3 walking tests. Arch Phys Med Rehabil 2005;86:190-6.
4. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991;39:142-8.
5. Ditunno PL, Ditunno JF Jr. Walking index for spinal cord injury (WISCI II): scale revision. Spinal Cord 2001;39:654-6.
6. Field-Fote EC, Fluet GG, Schafer SD, et al. The Spinal Cord Injury Functional Ambulation Inventory (SCI-FAI). J Rehabil Med 2001;33:177-81.
7. Berg KO, Wood-Dauphinee SL, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. Can J Public Health 1992;83(Suppl 2):S7-11.
8. 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;73:1073-80.
9. Mao HF, Hsueh IP, Tang PF, Sheu CF, Hsieh CL. Analysis and comparison of the psychometric properties of three balance measures for stroke patients. Stroke 2002;33:1022-7.
10. Qutubuddin AA, Pegg PO, Cifu DX, Brown R, McNamee S, Carne W. Validating the Berg Balance Scale for patients with Parkinson's disease: a key to rehabilitation evaluation. Arch Phys Med Rehabil 2005;86:789-92.
11. Cattaneo D, Regola A, Meotti M. Validity of six balance disorders scales in persons with multiple sclerosis. Disabil Rehabil 2006; 28:789-95.
12. Newstead AH, Hinman MR, Tomberlin JA. Reliability of the Berg Balance Scale and balance master limits of stability tests for individuals with brain injury. J Neurol Phys Ther 2005;29:18-23.
13. Behrman AL, Harkema SJ. Locomotor training after human spinal cord injury: a series of case studies. Phys Ther 2000;80:688-700.
14. Dobkin B, Apple D, Barbeau H, et al. Weight-supported treadmill vs over-ground training for walking after acute incomplete SCI. Neurology 2006;66:484-93.
15. Lemay JF, Nadeau S. Standing balance assessment in ASIA D paraplegic and tetraplegic participants: concurrent validity of the Berg Balance Scale. Spinal Cord 2010;48:245-50.
16. 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;24:70-7.
17. Datta S, Lorenz DJ, Morrison S, Ardolino E, Harkema SJ. A multivariate examination of temporal changes in Berg Balance Scale items for patients with ASIA Impairment Scale C and D spinal cord injuries. Arch Phys Med Rehabil 2009;90:1208-17.
18. Harkema SJ, Schmidt-Read M, Behrman AL, Bratta A, Sisto SA, Edgerton VR. Establishing the NeuroRecovery Network: multisite rehabilitation centers that provide activity-based therapies and assessments for neurologic disorders. Arch Phys Med Rehabil 2012;93:1498-507.
19. Harkema S, Behrman A, Barbeau H. Locomotor training: principles and practice. Oxford: Oxford Univ Pr; 2011.
20. Visintin M, Barbeau H. The effects of body weight support on the locomotor pattern of spastic paretic patients. Can J Neurol Sci 1989;16:315-25.
21. Wernig A, Nanassy A, Müller S. Maintenance of locomotor abilities following Laufband (treadmill) therapy in para- and tetraplegic persons: follow-up studies. Spinal Cord 1998;36:744-9.
22. Dietz V, Colombo G, Jensen L, Baumgartner L. Locomotor capacity of spinal cord in paraplegic patients. Ann Neurol 1995;37: 574-82.
23. Behrman AL, Harkema SJ. Physical rehabilitation as an agent for recovery after spinal cord injury. Phys Med Rehabil Clin N Am 2007;18:183-202.
24. Harkema SJ. Plasticity of interneuronal networks of the functionally isolated human spinal cord. Brain Res Rev 2008;57:255-64.
25. Behrman AK, Lawless-Dixon AR, Davis SB, et al. Locomotor training progression and outcomes after incomplete spinal cord injury. Phys Ther 2005;85:1356-71.
26. American Spinal Injury Association. Reference manual for the International Standards for the Neurological Classification of Spinal Cord Injury. Chicago: American Spinal Injury Association; 2003.
27. Marino RJ, Barros T, Biering-Sorensen F, et al. International standards for neurological classification of spinal cord injury. J Spinal Cord Med 2003;26(Suppl 1):S50-6.
28. Behrman AL, Ardolino E, VanHiel LR, et al. Assessment of functional improvement without compensation reduces variability of outcome measures after spinal cord injury. Arch Phys Med Rehabil 2012;93:1518-29.
29. Hastie T, Tibshirani R, Friedman J. The elements of statistical learning: data mining, inference, and prediction. 1st ed. New York: Springer; 2001.
30. R Development Core Team. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2009.
31. Forrest GF, Lorenz DJ, Hutchinson K, et al. Ambulation and balance outcomes measure different aspects of recovery in individuals with chronic, incomplete spinal cord injury. Arch Phys Med Rehabil 2012;93:1553-64.
32. Fox J, Byrnes J, Culbertson M, Friendly M, Kramer A, Monette G. sem: structural equation models. R package version 3.0-0. Available at: http://CRAN.R-project.org/package=sem. Accessed April 30, 2012.