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Balance confidence is related to features of balance and gait in individuals with chronic stroke

Alison Schinkel-Ivy, PhD[1,*], **Jennifer S. Wong, MSc**[1], and **Avril Mansfield, PhD**[1,2,3]

[1]Toronto Rehabilitation Institute–University Health Network, 550 University Ave, Toronto, Ontario, Canada M5G 2A2

[2]Department of Physical Therapy, University of Toronto, 500 University Ave, Toronto, Ontario, Canada M5G 1V7

[3]Evaluative Clinical Sciences, Hurvitz Brain Sciences Research Program, Sunnybrook Research Institute, 2075 Bayview Ave, Toronto, Ontario, Canada M4N 3M5

Abstract

Reduced balance confidence is associated with impairments in features of balance and gait in individuals with sub-acute stroke. However, an understanding of these relationships in individuals at the chronic stage of stroke recovery is lacking. This study aimed to quantify relationships between balance confidence and specific features of balance and gait in individuals with chronic stroke. Participants completed a balance confidence questionnaire and clinical balance assessment (quiet standing, walking, and reactive stepping) at 6 months post-discharge from inpatient stroke rehabilitation. Regression analyses were performed using balance confidence as a predictor variable and quiet standing, walking, and reactive stepping outcome measures as the dependent variables. Walking velocity was positively correlated with balance confidence, while medio-lateral centre of pressure excursion (quiet standing) and double support time, step width variability, and step time variability (walking) were negatively correlated with balance confidence. This study provides insight into the relationships between balance confidence and balance and gait measures in individuals with chronic stroke, suggesting that individuals with low balance confidence exhibited impaired control of quiet standing as well as walking characteristics associated with cautious gait strategies. Future work should identify the direction of these relationships to inform community-based stroke rehabilitation programs for individuals with chronic stroke, and determine the potential utility of incorporating interventions to improve balance confidence into these programs.

Keywords

Chronic stroke; balance confidence; balance control; quiet standing; walking; reactive balance

*Corresponding author: Dr. Alison Schinkel-Ivy, Room 11-107, Toronto Rehabilitation Institute, 550 University Avenue, Toronto, Ontario, Canada M5G2A2, alison.schinkel-ivy@uhn.ca, Phone: 1-416-597-3422x7820.

Conflict of interest
None.

Introduction

Falls are among the most common complications for individuals recovering from stroke. Of community-dwelling individuals recovering from stroke, up to three-quarters may fall within 6 months after discharge from hospital [1]. Furthermore, falls risk for individuals with stroke is doubled relative to healthy older adults [2]. Balance confidence, or an individual's confidence in their ability to maintain balance and remain steady [3], has been related to falls risk in community-dwelling individuals with stroke [4], as has falls-related self-efficacy [5, 6]. Therefore, it is important to establish the nature of the relationships between balance confidence and falls risk in this population.

Balance confidence has also been associated with quiet standing and walking performance in older adults and individuals with stroke. In community-dwelling older adults, participants with greater balance confidence exhibited less centre of pressure (COP) excursion during quiet standing and faster walking scores than participants with lower balance confidence [7]. Similarly, lower falls self-efficacy (a construct related to balance confidence [8]) in community-dwelling older adults has been associated with slower gait speed, shorter stride length, increased stride width, and prolonged double support time [9]. In individuals with stroke, falls self-efficacy has been positively related to clinical balance and gait outcomes [10]. Recently, relationships between balance confidence and specific features of balance and gait were assessed in individuals with sub-acute stroke [11]. Balance confidence was positively related to walking velocity, and negatively related to antero-posterior COP excursion (antero-posterior direction) during quiet standing and double support time and step time variability during walking [11]. These results suggest that in individuals with sub-acute stroke, low balance confidence was associated with impaired control of quiet standing balance and cautious behaviour during gait [11].

Specific measures of balance and gait have also been related to falls risk in several populations, including individuals with stroke. Between-limb synchronization during quiet standing, variability during walking, and reactive stepping measures have been related to falls in individuals with stroke [6, 12]. Measures such as COP excursion during eyes-open quiet standing, walking velocity, and double support time are related to falls in older adults [13–15], as is postural sway during eyes-closed quiet standing in individuals with multiple sclerosis [16]. Given the relationships between falls risk and balance confidence [4] and between falls risk and features of balance and gait, it is warranted to explore balance confidence and these balance and gait features to better understand the strength of these relationships.

While balance confidence and features of gait and balance have been related in individuals with sub-acute stroke [11], one limitation of this study was that the assessments were administered soon after stroke (when participants were admitted to inpatient rehabilitation). The Activities-Specific Balance Confidence (ABC) Scale asks participants to assess confidence in completing activities that individuals in in-patient rehabilitation may not have attempted since their strokes (e.g., walking in a crowded environment or on icy surfaces) [11]. Therefore, it may have been challenging for participants to quantify their levels of balance confidence at that time point in their stroke recovery. The assessment of balance confidence at a later stage in the recovery process (i.e. chronic stroke) may provide a higher level of ecological validity and potentially further insight into relationships between balance confidence and features of balance and gait. To our knowledge, no study has determined whether the associations between balance confidence and specific features of balance and gait remain as individuals reach the chronic stage of stroke (6 months post-stroke). This study aimed to quantify relationships between balance confidence and specific features of balance and gait in community-dwelling individuals with chronic stroke. It was hypothesized that balance confidence would be positively associated with: between-limb synchronization of antero-posterior COP (eyes-open quiet standing) and walking velocity; and negatively associated with: COP excursion (eyes-open quiet standing), reliance on vision (quiet standing), double support time and variability measures (walking), and the number of steps taken, occurrence of reach-to-grasp reactions, and need for assistance (reactive stepping).

Materials and methods

Participants

This study involved cross-sectional, retrospective review of data from individuals with stroke who underwent in-patient stroke rehabilitation at a rehabilitation hospital between September 2010 and March 2013 [12, 17]. As part of the larger study, participants were invited to complete a clinical assessment of balance and gait at 6 months post-discharge from in-patient rehabilitation if they had completed the same assessment at discharge from in-patient rehabilitation; had been discharged home from in-patient rehabilitation; and were capable of independent ambulation at discharge [12]. Individuals were included in the current analysis if they completed the ABC Scale [3] and at least one of the following tasks in the 6-month assessment: quiet standing, self-paced walking without a walking aid across a pressure-sensitive mat, and/or an unconstrained lean-and-release reactive stepping trial (assessment details below) [11, 12]. Initially, 100 individuals were recruited, with 69 of those individuals returning for a follow-up assessment. Of those 69 individuals, 66 (95.7%) were included in the present analysis; the remaining three individuals were excluded due to missing data (2) or because they presented with bilaterally affected limbs (1). Data for just over half of these individuals (38/66; 58%), collected at admission to in-patient rehabilitation, were also included in a previous study examining the relationships between balance confidence and features of gait and balance in individuals with sub-acute stroke [11]. All procedures were approved by the institution’s Research Ethics Board with a waiver of patient consent approved for the purpose of the review.

Assessments

Demographic and stroke information—Information regarding sex, age, date of stroke, affected side of the body, and fall history (a fall prior to or during the stroke, in acute care or inpatient rehabilitation, or following discharge to the community) was collected from participants’ hospital charts and/or via questionnaire (Table 1). Scores on the National Institutes of Health Stroke Scale [18] and Chedoke-McMaster Stroke Assessment [19] were also obtained to characterize the participant sample.

Balance confidence—Balance confidence was assessed using the ABC Scale [3], which quantifies individuals' confidence in their ability to perform 16 activities of daily living by rating confidence from 0% (no confidence) to 100% (complete confidence) for each activity. The scores for each of the activities are averaged to obtain a total score. The ABC Scale has good internal consistency (Cronbach's α=0.94) and test-retest reliability (intraclass correlation coefficient=0.85) in individuals with chronic stroke [20].

Clinical balance assessment

Quiet standing: Participants performed two quiet standing trials for 30 s each (one with the eyes open, one with the eyes closed) [11]. The feet were positioned with one foot on each of two adjacent force plates (Advanced Mechanical Technology, Inc., Watertown, MA), according to a standardized template [21]. Ground reaction forces and moments were sampled at 256 Hz, and low-pass filtered using a dual-pass, fourth-order Butterworth filter (cutoff frequency: 10 Hz [22]). Net and individual-limb COP signals were calculated for both the antero-posterior and medio-lateral directions. Quiet standing outcome measures are described in Table 2.

Gait: Participants were asked to perform self-paced walking trials without a gait aid across a 4.6 m long pressure-sensitive mat (Gaitrite, CIR Systems, Clifton, NJ). Between three and five trials were completed, such that a minimum of 18 footfalls were recorded for each participant. Data were processed and outcome measures obtained using Gaitrite software (Table 2).

Reactive stepping: A lean-and-release system was used to assess reactive stepping ability in response to an external perturbation [12, 23]. Participants wore a safety harness during the trials to prevent a fall to the floor if the participant was unable to recover balance. A physiotherapist stood in close proximity to provide assistance if required. A cable was attached to the back of the safety harness and to a support beam behind the participant. Participants began with their feet in a standardized position [21], then leaned forward, using the cable to support their body weight (BW). Participants leaned forward until the cable supported approximately 10%BW. The cable was then released at an unpredictable time by an investigator. Following cable release, the participant began to fall forward, and was required to take at least one step to regain stability. Stepping responses were not constrained. Although five trials were typically performed in the assessment, only the first trial was analyzed to minimize familiarization effects. Trials in which the release cable supported less than 5%BW were removed from the analysis. All trials were videotaped and analyzed offline to determine the reactive stepping outcome measures (Table 2).

Statistical analysis

Regression analyses were conducted to quantify relationships between balance confidence and the outcome measures [11], using multiple linear regression [22] for the continuous outcome measures and binary logistic regression [12] for the binary outcome measures. Only individuals who completed each assessment were included in the analysis for that assessment. Rank transformations were applied to continuous measures with a non-normal distribution [22], while square root transformations were applied to count data [11]. Initial predictor variables for the standing and walking outcome measures consisted of ABC score, age, sex, time since stroke, affected side, and falls history. For the reactive stepping outcome measures, %BW load on the release cable was also included as a predictor variable. Backward selection with a criterion of alpha=0.10 for remaining in the model was used for both types of regression [22]. ABC scores were retained in all models. Tolerance and variance inflation factors were calculated to ensure that multicollinearity was not present in the final models. For all regression analyses, alpha was set at $p<0.05$ and adjusted using the Holm-Bonferroni method [24].

Results

The mean (standard deviation) balance confidence score was 77.5% (18.1), ranging from 31% (least confident) to 100% (most confident). COP excursion in the medio-lateral direction during quiet standing was significantly related to balance confidence, as were velocity, double support time, step width variability, and step time variability during walking ($p<0.001$) (Tables 3, 4 and 5). Walking velocity was positively related to balance confidence, while the remaining significant measures were negatively related to balance confidence. Balance confidence accounted for 20%–29% of the variance in the outcome measures. No significant relationships were identified between balance confidence and between-limb synchronization (eyes-open quiet standing), Romberg quotients in either direction (quiet standing), or step length variability (walking).

Additionally, no significant relationships were identified between balance confidence and the reactive stepping measures. A substantial number (19/66; 29%) of participants were excluded from the reactive stepping assessment, either because the assessment was not performed or the load on the release cable was insufficient (<5%BW). On average, the mean (standard deviation) ABC score was lower for participants who did not complete the reactive stepping assessment (73.3% (20.3)) compared to those who completed the assessment (79.2% (17.1)), although this difference was not statistically significant when compared with an independent T-test ($p=0.23$).

Discussion

This study aimed to determine whether balance confidence was related to specific features of balance and gait in individuals with chronic stroke. The study hypothesis was confirmed for several outcome measures; balance confidence was positively associated with walking velocity and negatively related to medio-lateral COP excursion (eyes-open quiet standing) and double support time, step width variability, and step time variability (walking). Between 20%–29% of the variance in the outcome measures was attributable to balance confidence. However, the analysis did not provide evidence of a relationship between balance confidence and between-limb synchronization (eyes-open quiet standing), Romberg quotients in either direction (quiet standing), step length variability (walking), or the reactive stepping measures.

COP excursion measures provide an indirect quantification of activity levels in the motor system [25] during quiet standing. Changes in the position of the COP contribute to the control of the position of the body's centre of mass [26]. Balance confidence has been found to be associated with impaired control of quiet standing in individuals with sub-acute stroke, with a negative relationship between balance confidence and antero-posterior COP excursion during quiet standing [11]. Similarly, the present study identified a negative relationship between balance confidence and medio-lateral COP excursion during quiet standing in individuals with chronic stroke. Taken together, these findings suggest that individuals with low balance confidence require greater movement of the COP to maintain an upright standing posture, and to keep the centre of mass within the base of support. There is potential for increased COP excursion to be a consequence of low balance confidence; however, it is also possible that individuals with increased COP excursion during quiet standing experienced a perception of unsteadiness, and this perception contributed to reduced balance confidence.

The findings that reduced walking velocity and increased double support time were associated with low balance confidence also agreed with those for individuals with sub-acute stroke [11]. These trends reflect cautious behaviour during walking, which may either be a contributor to low balance confidence (i.e., these changes in gait may lead to changes in balance confidence) or a consequence (i.e., individuals' walking patterns change in an attempt to increase postural stability and reduce the risk of falling [27–29]). Reduced body momentum resulting from a slower walking velocity may increase the likelihood that should a loss of balance occur, the individual will successfully be able to recover their balance [28]. This would reduce the risk of a fall following balance loss. Furthermore, an increased proportion of time spent in double support during the gait cycle may also contribute to improved postural stability, as the double support phase involves a larger base of support than the single support phase [28, 29].

Variability measures for step width and step time during walking were also negatively related to balance confidence. It has been suggested that greater variability in walking may represent a reduced ability of the control system to maintain a consistent gait pattern [30]. Increased variability in gait may be characterized by less controlled, less stable movement of the COP over and beyond the base of support, thereby predisposing the individual to postural instability and increasing the risk of a fall [30], potentially reducing balance confidence. Alternatively, if low balance confidence interferes with individuals' ability to compensate for the internal perturbations that occur during walking [31], increased variability of spatiotemporal walking measures may arise as a consequence of a lack of balance confidence.

None of the reactive stepping outcome measures were significantly associated with balance confidence, potentially due to the nature of the measures. For example, the majority of participants (31/47; 66%) took only one or two steps following cable release, and only five participants (5/47; 11%) exhibited a reach-to-grasp reaction or required assistance. Furthermore, the reactive stepping assessment was performed on fewer individuals (47/66; 71%) than the quiet standing (65/66; 98%) or walking (61/66; 92%) assessments. Of the 19 participants who were not included in the reactive stepping analysis, nine participants attempted at least one trial but were excluded from the analysis due to an insufficient load on the release cable. Alternative reasons for the lower participation rate in the reactive stepping assessment may have included insufficient tolerance for exercise or physical activity, current pain or musculoskeletal disorder, participants' preference or refusal of the assessment, and participants' anxiety [23]. Therefore, it is possible that the participants who did not complete the reactive stepping component of the assessment had poor balance control. In addition, the individuals who did not complete the reactive stepping component had lower balance confidence than those who did complete that component, although this difference was not statistically significant. Had these individuals been willing and able to perform this test and subsequently been included for this component of the analysis, there may have been greater variation in the number of steps, increased frequency of reach-to-grasp reactions, and/or increased frequency of reactions in which assistance was required. Future work may investigate a means by which the lean-and-release test may be made more tolerable for individuals post-stroke, thereby potentially incorporating a sample of individuals with a greater range of balance confidence and balance/gait capabilities.

The body of literature surrounding falls risk in individuals with stroke has generally established that impairments in clinical measures of balance and gait [17, 32], as well as specific features of balance and gait [12], constitute risk factors for falls in this population. From retrospective analysis, community-dwelling individuals with stroke and low balance confidence were more likely to have experienced multiple falls than those with higher balance confidence [4]. These relationships, along with those identified in the present study, may suggest a potential interaction between balance confidence and specific features of balance and gait in terms of contribution to falls risk in individuals with stroke. Tang et al. [33] conducted a systematic review and meta-analysis of the effects of interventions on balance confidence and balance self-efficacy in individuals with stroke. While there was evidence of a positive effect of interventions on balance confidence in the short term, there were no differences between control and intervention groups for follow-up assessments [33]. Therefore, it is currently unclear whether training interventions would result in long-term improvements in balance confidence. Incorporating a focus on balance confidence into balance control interventions may provide a potential avenue for greater or more permanent improvements in balance confidence, although this has not yet been tested as none of the studies included by Tang et al. [33] used balance confidence as a primary outcome measure. Taken together, these findings provide support for the need to assess balance confidence in individuals with stroke, and potentially to develop and evaluate means to improve balance confidence that can be incorporated into balance control interventions for individuals returning to community living.

Study limitations

Methodologically, there were several limitations to the study. Balance confidence was quantified using the ABC Scale [3], which exhibits good internal consistency and test-retest reliability in individuals with chronic stroke [20]. However, individuals are often hesitant to report a fear of falling [9]. As fear of falling and balance confidence are related [34], it is possible that individuals were also hesitant to report low balance confidence, and/or to convey the perception that they did not feel confident in performing the tasks. In addition, there was some overlap in the participants from the present study and from a previous study examining balance confidence in individuals with sub-acute stroke [11], potentially contributing to the strong agreement in the findings. The present analysis was also limited to those individuals who returned to the laboratory for a follow-up assessment at 6 months post-discharge. Individuals who did not feel confident completing the assessment during their time in inpatient rehabilitation, or whose confidence decreased following discharge from inpatient rehabilitation, may have been more likely to decline the 6-month follow-up assessment. However, while the overall sample was relatively high-functioning, the ranges for the National Institutes of Health Stroke Scale, the Chedoke-McMaster Stroke Assessment, and walking velocity demonstrated that there were also mobile but lower-functioning individuals present within the sample. Finally, due to the cross-sectional nature of the analysis, it was only possible to determine the presence of relationships between balance confidence and the balance and gait outcome measures. It may be warranted in future work to consider a longitudinal approach to determine the directionality of these relationships (i.e. whether low balance confidence leads to altered balance and gait, or if altered balance and gait results in low balance confidence).

Conclusions

This study identified relationships between balance confidence and features of balance and gait in individuals with chronic stroke. Specifically, balance confidence was positively associated with walking velocity, and negatively associated with medio-lateral COP excursion during quiet standing and double support time, step width variability, and step time variability during walking. These findings indicate that individuals with chronic stroke and low balance confidence tend to exhibit impaired quiet standing control and characteristics during walking that suggest cautious gait strategies, similar to individuals with sub-acute stroke. Future work should seek to identify the direction of these relationships to better inform community-based stroke rehabilitation programs for individuals with chronic stroke, and the potential utility of incorporating balance confidence into these programs. This may aid in improving balance confidence in individuals with stroke, thereby minimizing reductions in activity levels due to low balance confidence and reducing falls risk and furthering stroke recovery.

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Table 1

Demographic and stroke-related information of study participants.

Characteristic	Mean (SD) or number (% of group)	Range (minimum, maximum)
Used as predictors in regression analyses		
Age (years)	64.7 (12.3)	33, 91
Sex (number)		
Men	41 (62.1%)	
Women	25 (37.9%)	
Time since stroke (months)	8.2 (1.1)	6.8, 12.1
Affected side (number)		
Right	31 (47.0%)	
Left	35 (53.0%)	
Balance confidence (score on Activities-Specific Balance Confidence Scale; %)	77.5 (18.1)	31, 100
History of falling (number)	49 (74.2%)	
% body weight supported by release cable	8.6 (2.9)	5, 21.4
Descriptive only		
National Institutes of Health Stroke Scale score	1.98 (2.18)	0, 12
Chedoke-McMaster Stroke Assessment leg score	5.5 (1.0)	3, 7
Chedoke-McMaster Stroke Assessment foot score	5.1 (1.1)	3, 7
Walking velocity (m/s)	0.97 (0.33)	0.28, 1.60

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Table 2

Outcome measures determined from the quiet standing, walking, and reactive stepping assessments [11].

Outcome measure	Description
Quiet standing, eyes open (N=65)	
COP excursion (AP) (mm)	RMS of total AP COP [35]
COP excursion (ML) (mm)	RMS of total ML COP [35]
ρ_0 of COP (AP)	Between-limb synchronization (cross-correlation coefficient at zero time lag (ρ_0) of individual-limb AP COP time series) [36]
Quiet standing, eyes closed (N=65)	
Romberg quotient (AP)	RMS of AP COP (eyes closed) / RMS of AP COP (eyes open) [35]
Romberg quotient (ML)	RMS of ML COP (eyes closed) / RMS of ML COP (eyes open) [35]
Walking (N=61)	
Velocity (m/s)	Mean velocity of all trials
Double support time (% gait cycle)	Mean double support time of all trials
Step length variability (cm)	Average of standard deviation of step length for the left and right legs [12]
Step width variability (cm)	Standard deviation of step width [12]
Step time variability (ms)	Average of standard deviation of step time for the left and right legs [12]
Reactive stepping (N=47)	
Number of steps	Average number of steps taken post-perturbation to regain stability [6]
Grasp reactions (number)	Percentage of participants who reached for and grasped the physiotherapist
Assists (number)	Percentage of participants who required external support (from the harness or physiotherapist) [6, 37]

AP: antero-posterior; ML: medio-lateral; RMS: root mean square.

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Table 3

Results of the regression analyses between balance confidence and the quiet standing, walking, and reactive stepping outcome measures. The measures in the left-hand column represent the dependent variables in the regression equation.

Measures	Predictor variable	Mean (SD)	Parameter estimate	Partial R^2	*p*-value
Quiet standing, eyes open (N=65)					
COP excursion (AP)*(mm)	ABC score	5.8 (2.4)	−0.33	0.10	0.010
COP excursion (ML)*(mm)	ABC score	3.3 (2.3)	−0.46	0.20	<0.001‡
ρ_0 of COP (AP)*	ABC score	0.82 (0.15)	−0.024	0.001	0.86
Quiet standing, eyes closed (N=65)					
Romberg quotient (AP)	ABC score	1.35 (0.49)	−0.003	0.010	0.44
Romberg quotient (ML)*	ABC score	1.18 (0.58)	−0.002	<0.001	0.99
	Affected side of the body		−8.11	0.046	0.087

ABC: Activities-Specific Balance Confidence Scale; AP: antero-posterior; ML: medio-lateral; SD: standard deviation.

*Rank transformations for continuous measures that violated the assumption of normality.

‡Significant model following Holm-Bonferroni adjustment (α=0.004).

Table 4

Results of the regression analyses between balance confidence and the quiet standing, walking, and reactive stepping outcome measures. The measures in the left-hand column represent the dependent variables in the regression equation.

Measures	Predictor variable	Mean (SD)	Parameter estimate	Partial R^2	*p*-value
Walking (N=61)					
Velocity (m/s)	ABC score	0.97 (0.33)	0.010	0.29	<0.001‡
	Age		0.006	0.095	0.020
	Sex		−0.22	0.17	0.0015‡
	Time since stroke		−0.10	0.14	0.0045
	Affected side of the body		−0.12	0.065	0.055
Double support time*(% gait cycle)	ABC score	33.1 (7.2)	−0.49	0.25	<0.001‡
	Time since stroke		6.60	0.15	0.0028‡
	History of falling		−10.16	0.094	0.018
Step length variability* (cm)	ABC score	3.0 (1.1)	−0.18	0.028	0.20
Step width variability (cm)	ABC score	11.9 (4.3)	−0.13	0.23	<0.001‡
	Age		−0.11	0.10	0.013
	Affected side of the body		−1.63	0.047	0.099
Step time variability* (ms)	ABC score	32 (22)	−0.53	0.24	<0.001‡
	Age		−0.44	0.12	0.0081
	Sex		8.65	0.076	0.037
	Time since stroke		3.79	0.056	0.074

ABC: Activities-Specific Balance Confidence Scale; SD: standard deviation.

*Rank transformations for continuous measures that violated the assumption of normality.

‡Significant model following Holm-Bonferroni adjustment (α=0.004).

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Table 5

Results of the regression analyses between balance confidence and the quiet standing, walking, and reactive stepping outcome measures. The measures in the left-hand column represent the dependent variables in the regression equation. The Holm-Bonferroni corrected alpha was 0.004.

Continuous measures	**Predictor variable**	**Mean (SD)**	**Parameter estimate**	**Partial R^2**	***p*-value**
Reactive stepping (N=47)					
Number of steps†	ABC score	2.1 (1.2)	−0.0045	0.036	0.21
	Cable load (% body weight)	8.57 (2.91)	−0.040	0.078	0.061
Binary measures	**Predictor variable**	**Number of participants (%)**	**Increment**	**Odds ratio [95% CI]**	***p*-value**
Reactive stepping (N=47)					
Grasp reactions	ABC score	Grasp: 5 (10.6)	10.0	0.66 [0.39, 1.13]	0.13
Assists	ABC score	Assist: 5 (10.6)	10.0	0.63 [0.37, 1.10]	0.10

ABC: Activities-Specific Balance Confidence Scale; AP: antero-posterior; CI: confidence interval; ML: medio-lateral; SD: standard deviation.

†Square root transformations performed for count data that violated the assumption of normality.