Relationships between fear of falling, balance confidence, and control of balance, gait, and reactive stepping in individuals with sub-acute stroke

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Abstract

Fear of falling is common in individuals with stroke; however, the associations between fear of falling, balance confidence, and the control of balance and gait are not well understood for this population. This study aimed to determine whether, at the time of admission to in-patient rehabilitation, specific features of balance and gait differed between individuals with stroke who did and did not report fear of falling, and whether these features were related to balance confidence. Individuals with stroke entering inpatient rehabilitation were asked if they were afraid of falling, and completed the Activities-Specific Balance Confidence Scale. Participants performed quiet standing, gait, and reactive stepping tasks, and specific measures were extracted for each (quiet standing: centre of pressure amplitude, between-limb synchronization, and Romberg quotients; gait: walking velocity, double support time, and variability measures; reactive stepping: number of steps, frequency of grasp reactions, and frequency of assists). No significant differences were identified between individuals with and without fear of falling. Balance confidence was negatively related to centre of pressure amplitude, double support time, and step time variability, and positively related to walking velocity. Low balance confidence was related to poor quiet standing balance control and cautious behavior when walking in individuals with sub-acute stroke. While the causal relationship between balance confidence and the control of balance and gait is unclear from the current work, these findings suggest there may be a role for interventions to increase balance confidence among individuals with stroke, in order to improve functional mobility.

INTRODUCTION

Fall risk for individuals with stroke is over twice that of healthy older adults [1]. Falling is a common medical complication post-stroke [2,3], with an especially high risk of occurrence

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CONFLICT OF INTEREST STATEMENT

None.

during hospital stay [4] and after discharge home from in-patient rehabilitation [5]. Falls often contribute to fear of falling (FOF); alternatively, or FOF can develop in absence of a fall [6]. FOF is prevalent post-stroke, with up to 88% of individuals with stroke who experience a fall developing FOF [7]. Resulting activity avoidance may lead to restricted mobility and deconditioning, contributing to reduced functional capabilities, loss of functional independence, and further increases in fall risk and FOF [8–10]. FOF [11] and balance confidence [12] are both associated with falls in individuals with stroke, suggesting that these factors are influential in fall occurrence post-stroke.

FOF has been shown to influence balance and gait control in older adults. Compared to older adults with no FOF, those with FOF demonstrate greater centre of pressure (COP) amplitude during eyes-closed quiet standing [13]. Gait in older adults with FOF is characterized by decreased velocity and step length, and increased step width, double support time, and spatio-temporal variability [14–19]. Similarly, quiet standing and walking measures have been linked to balance confidence in older adults [16,20]. Rosen et al. [21] identified significant, positive correlations between falls self-efficacy and clinical measures of balance and gait capability in individuals with stroke. However, no previous study has examined relationships between balance and gait features, FOF, and balance confidence in individuals with stroke.

A better understanding of the relationships between FOF, balance confidence, and features of balance and gait may provide insight into the mechanism(s) by which FOF and balance confidence relate to fall risk in individuals with stroke, and inform rehabilitation strategies to minimize these changes and their impact on fall risk. This study determined whether features of quiet standing balance, gait, and reactive stepping (a) differed between individuals with stroke with and without FOF, and (b) were related to balance confidence. It was hypothesized that, compared to individuals without FOF, those with FOF would exhibit: increased COP amplitude and greater reliance on vision (quiet standing); reduced velocity, increased double support time, and increased variability (gait); and increased frequency of failed responses (reactive stepping). Furthermore, balance confidence was expected to be negatively related to these measures, with the exception of walking velocity (positive relationship).

METHODS

Participants

Data from individuals with stroke who underwent in-patient stroke rehabilitation at a rehabilitation hospital between October 2009 and September 2012 were analyzed retrospectively. To be included in the analysis, participants must have undergone a clinical assessment with a physiotherapist (part of routine care) at admission to in-patient rehabilitation, and answered a self-report FOF question. They must have completed at least one of: quiet standing, self-paced walking across a pressure-sensitive mat without a walking aid, or lean-and-release reactive stepping (assessment details below). These criteria were met by 208 of 512 individuals (41%). 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 information—Sex, age, date of stroke, lesion location, side of the body affected, and National Institutes of Health Stroke Scale (NIHSS) [22] score were extracted from participants' hospital charts (Table 1). Participants were also categorized as 'fallers' (having fallen prior to or during their stroke, or in acute care) or 'non-fallers'.

Fear of falling and balance confidence—While related, FOF and balance confidence are distinct constructs [23], with FOF defined as persisting concern regarding falling [24], and balance confidence defined as an individual's confidence in their ability to maintain their balance and remain steady [25]. As such, the outcome measures were analyzed with respect to both FOF and balance confidence [26].

FOF was determined by asking participants 'Are you afraid of falling?'. Responses were classified as 'yes' (Fear; N = 84) or 'no' (No Fear; N = 124). This single-item question has been utilized to categorize participants into dichotomous groups [6,13,15,19], and demonstrates good test–retest reliability ($k = 0.66$) [27]. Balance confidence was assessed using the Activities-Specific Balance Confidence (ABC) Scale [25], which quantifies individuals' confidence in performing 16 everyday tasks from 0 to 100% with higher scores representing greater confidence. The ABC Scale has good internal consistency (Cronbach's $\alpha = 0.94$) and test–retest reliability in individuals with chronic stroke (intra-class correlation coefficient = 0.85 [28]). The ABC Scale was conducted for participants who were independently ambulatory at the time of initial assessment and had the cognitive-communicative ability to respond to the questionnaire (N = 134).

Quiet standing—Participants performed one 30 s trial of eyes-open (N = 195) and eyes-closed (N = 194) quiet standing, with one foot on each of two force plates positioned side-by-side and the feet in a standardized position [29]. Force data were sampled at 256 Hz and low-pass filtered with a dual-pass, fourth-order Butterworth filter (cutoff frequency: 10 Hz) [30]. The total and individual-limb antero-posterior (AP) and medio-lateral (ML) COP signals were calculated. COP amplitude was quantified by the root mean square (RMS) of the total AP and ML COP. Romberg quotients were calculated for AP and ML COP as the eyes-closed value divided by the eyes-open value, to assess the contribution of visual information to postural control [31]. The individual-limb AP COP time series' were cross-correlated to quantify between-limb synchronization (coefficient at zero lag, ρ_0) [32]. Only AP synchronization was calculated as individual-limb AP COP is more important than individual-limb ML COP for overall balance control [33].

Gait—Walking measures were obtained using a 4.6 m long pressure mat (Gaitrite, CIR Systems, Clifton, NJ). Participants (N = 141) completed 3–5 passes across the mat at their usual pace such that at least 18 footfalls were recorded. Outcome measures included mean walking velocity and double support time (expressed as percentage of the gait cycle), as well as variability of step length, step width, and step time (average of the standard deviations for the left and right legs) [34].

Reactive stepping—Reactive stepping capacity was assessed for 115 participants using a lean-and-release system [34]. A safety harness attached to an overhead track was worn to prevent a fall to the floor if the participant was unable to recover balance, and a physiotherapist provided assistance if required. A cable connected a harness around the trunk to a support beam behind the participant. Participants stood with the feet in a standardized position [29] and leaned forward until the cable supported 5–10% of body weight. The cable was released at an unpredictable time, causing the participant to fall forward. The perturbation magnitude was such that participants needed to take at least one step to regain stability. Trials in which the cable supported less than 5% of body weight were removed from the analysis. No constraints were placed on reactive stepping responses. Typically, five trials were performed; however, only the first trial was analyzed to minimize familiarization effects. Trials were videotaped and the following outcome measures determined post-collection: number of steps; occurrence of a reach-to-grasp reaction, in which the participant reached for and grasped the physiotherapist; and occurrence of ‘assists’, in which the participant required external support (safety harness or physiotherapist).

Statistical analysis

Differences between fear of falling groups—Continuous outcome measures were tested for normality using the Shapiro–Wilk test. Measures with a non-normal distribution were rank-transformed [31,32], with the exception of the number of steps, for which a square root transform was applied to minimize the floor effect associated with count data. Demographic and stroke-related variables (sex, age, NIHSS score, time since stroke, affected side of the body, fall history) were tested as potential covariates. The amount of body weight supported by the release cable was also tested as a covariate for the reactive stepping outcome measure (number of steps). To be included as a covariate, the continuous variables (age, NIHSS score, time since stroke, cable weight) had to correlate to the outcome measure (Pearson product moment correlation, $r > 0.4$), and differ between FOF groups (independent t-test, $p < 0.15$). Nominal variables (sex, affected side, fall history) had to show differences in the outcome measure between levels (independent t-test, $p < 0.15$), and differ between FOF groups (Chi-square, $p < 0.15$). Differences in continuous outcome measures between FOF groups were assessed using one-way analyses of (co-)variance (ANOVA/ANCOVA). Nominal outcome measures were compared between groups using Chi-square analyses [35].

Relationships between balance confidence and outcome measures—ABC scores were compared between FOF groups to determine whether the FOF groups differed in balance confidence. The same procedures as described in the previous section for covariate identification and analysis of (co-)variance for continuous outcome measures were employed.

To investigate relationships between balance confidence and the outcome measures, multiple linear regression [30] and binary logistic regression [34] were used for the continuous and binary outcome measures, respectively. Continuous measures with a non-normal distribution were rank-transformed [30], with the exception of count data (number of steps), for which a

square root transform was applied. Backward selection was used for both types of regression, with the criterion for remaining in the model set at $\alpha = 0.10$ [30]. Initial predictor variables were ABC score, sex, age, NIHSS score, time since stroke, affected side of the body, and fall history, along with cable weight for the reactive stepping measures. ABC scores were retained in all models. The balance, gait, and reactive stepping measures constituted the dependent variables in the regressions. Tolerance and variance inflation factors were calculated to ensure that multicollinearity was not present in the final models. For all analyses, alpha was initially set at $p < 0.05$ and adjusted using the Holm–Bonferroni method [36].

RESULTS

Differences between fear of falling groups

FOF was reported by 40% of participants (84/208). Sex was a covariate for walking velocity, double support time, and step time variability; these measures differed between men and women ($t = 2.96$, $p < 0.06$) and sex differed between FOF groups ($\chi_{(1)}^2 = 14.96$, $p < 0.001$). Fall history was different between FOF groups ($\chi_{(1)}^2 = 2.90$, $p = 0.089$), and total AP COP amplitude and r0 of AP COP during eyes-open standing, AP Romberg quotient, double support time, and number of reactive steps also differed between fallers and non-fallers ($t = 1.54$, $p = 0.13$). Therefore, fall history was included as a covariate for these outcome measures. Following adjustment for multiple comparisons, no significant differences were identified between FOF groups for any outcome measures (Table 2).

Relationships between balance confidence and outcome measures

Sex was a covariate when comparing ABC scores between FOF groups ($t = 3.02$, $p = 0.003$; $\chi_{(1)}^2 = 14.96$, $p < 0.001$). ABC scores were significantly lower for the Fear group than the No Fear group ($F_{1,131} = 25.86$, $p < 0.001$). With respect to relationships between balance confidence and the balance, gait, and reactive stepping outcome measures, ABC scores were significantly related to the total AP COP amplitude during eyes-open quiet standing ($p = 0.002$), walking velocity ($p < 0.001$), double support time ($p < 0.001$), and step time variability ($p = 0.005$; Tables 3 and 4). Balance confidence explained 11–29% of the variance in outcome measures. Balance confidence was positively correlated with walking velocity and negatively correlated with AP COP amplitude, double support time, and step time variability.

DISCUSSION

This study identified relationships between balance confidence and specific features of balance, gait, and reactive stepping. No differences in any of the outcome measures were identified between FOF groups. The results supported the hypotheses for balance confidence, with negative relationships between balance confidence and AP COP amplitude during eyes-open quiet standing, double support time, and step time variability, and a positive relationship between balance confidence and walking velocity. However, it is important to note that only ambulatory individuals were tested for balance confidence and therefore these results only apply to ambulatory individuals.

FOF and balance confidence represent distinct constructs [23], with FOF influenced to a greater extent by anxiety and depression characteristics [37] and balance confidence related to self-efficacy [38]. Therefore, both FOF and balance confidence were analyzed in the present study [26]. While balance confidence was related to several outcome measures, no differences were identified between the FOF groups. The lack of findings between FOF groups may have been due in part to the FOF and balance confidence measurement tools. A simple FOF question may be more representative of general anxiety state, as opposed to fear or anxiety specifically related to falling or balance [20]. Furthermore, some people may not want to admit to FOF [16] for fear of stigmatization [13,20]. Men typically report FOF less often than women [13,16,20], which occurred in the present study. This effect may not be as prevalent with the ABC Scale, as the questions do not directly address fear. The ABC Scale may also have greater utility due to its continuous nature and inclusion of multiple items [20], potentially contributing to the significant findings for balance confidence but not for FOF.

Associations between balance confidence and COP amplitude during quiet standing have been identified in older adults [20]. Similarly, COP amplitude is increased in older adults with FOF, compared to those without FOF [13]. Maki et al. [13] discussed various factors that may have contributed to these findings in older adults, including physiological (e.g., anxiety-related changes in muscle tone), behavioral (e.g., increased volitional movement), and cognitive (e.g., changes in attentional focus) changes. These changes may also apply to explain the association between COP amplitude and balance confidence in individuals with stroke.

The relationships between balance confidence and walking velocity, as well as balance confidence and double support time, reflected previous findings in older adults [16,20]. Decreased velocity and double support time may represent an attempt at increasing postural stability to reduce fall risk [17,18,39]. Specifically, decreased velocity may reduce the body's momentum, increasing the likelihood of recovering from a loss of balance should one occur [18]. Increased double support time may preserve stability by increasing the proportion of the gait cycle spent with a larger (double support) versus a smaller (single support) base of support [18,39]. With respect to gait variability, previous work has observed increased variability in older adults with higher-level gait disorders and FOF compared to age-matched controls, concluding that greater stride time variability was an indicator of inefficient gait control [40].

No differences were identified between groups for reactive stepping measures, nor were the reactive stepping measures significantly related to balance confidence. While the amount of body weight supported by the release cable was not sufficiently correlated to the number of steps to be considered a covariate, there was a tendency for individuals with FOF to lean to a lesser extent. Potentially, this resulted in smaller perturbations within this group, requiring fewer steps to regain balance and thereby acting to equalize the responses of the two groups. Therefore, ensuring a consistent amount of body weight on the cable may be an important consideration for the clinical administration of lean-and-release perturbations in the future.

Previous research has established an association between falls and balance confidence [12] in individuals with stroke. Falls have also previously been associated with increased AP COP amplitude during eyes-open standing [41], decreased walking velocity [42], and increased double support time [43] in older adults. The present study found significant relationships between the aforementioned outcome measures and balance confidence post-stroke. Taken together with previous work identifying balance and gait control measures that relate to increased fall risk, the altered control of gait and balance observed among individuals with stroke who have low balance confidence may provide an explanation for the previously identified link between increased fall risk and low balance confidence.

There were several methodological limitations to the study. The study design did not allow identification of causation, which would require longitudinal data. For example, it is possible that participants with greater post-stroke impairment and slower walking velocity may have also had lower balance confidence (as opposed to balance confidence directly influencing walking velocity). Future work should determine the directions of the relationships between balance confidence and balance and gait measures. Data were collected during clinical assessments, and therefore full datasets were not available for all participants. Additionally, due to the retrospective nature of the analysis, the sizes of the FOF groups were not balanced; this may have diminished the ability to identify significant differences between the FOF groups. As only individuals who were able and willing to perform each task were included in the analysis, the study sample was likely representative of highly-functioning in-patients. However, because the study was a retrospective review of data obtained as part of routine care, individuals may have been included who otherwise would not have participated in a research study. As such, a broader participant sample may have been included than other studies requiring consent and separate data collection.

Regarding FOF and balance confidence quantification, the scores were generally collected following the three assessment tasks. Participants may have experienced a decrease in fear or an increase in confidence if they successfully completed the assessment tasks [44], thereby influencing FOF and/or ABC scores. Further, a one-dimensional, one-question measure was selected for FOF due to its simple and rapid nature [19], to avoid language and communication barriers. Additionally, previous definitions of FOF have included the avoidance of activities that the participant would otherwise be capable of [24], which was not incorporated in the present study. In conjunction with the limitations of self-reported fear [16], this may have limited the quantification of FOF, thereby contributing to the lack of differences between groups. The balance confidence analyses may have been limiting in that the ABC scale was only administered to ambulatory individuals, representing a smaller sample size than the FOF analyses. An additional issue with the ABC Scale was that the scale was administered, on average, 18 days post-stroke. However, the scale includes activities that participants may not have engaged in since their stroke, which may have hindered the ability to provide an accurate estimation of confidence.

In conclusion, balance confidence and specific features of balance and gait were related in individuals with stroke. These results provide insight into the link between balance confidence and fall risk in individuals with stroke. Furthermore, these findings may aid in developing more effective rehabilitation strategies for individuals with low balance

confidence, thereby minimizing the impact of low balance confidence and reducing the risk of falling or fear-related immobility for individuals with stroke during rehabilitation and following return to the community.

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Table 1

Demographic and stroke-related characteristics of the study participants. Continuous variables are presented as mean (*SD*), while nominal variables are presented as *N*(% of group). Variables for which data were missing for some participants are specified.

Characteristic	Fear Group (n=84)	No Fear Group (n=124)	<i>p</i> -value
Sex (number)			
Men	32 (38.1%)	81 (65.3%)	<0.001
Women	52 (61.9%)	43 (34.7%)	
Age (years)	68.6 (11.6)	65.3 (13.6)	0.065
NIHSS score *	3.3 (2.7)	3.3 (2.5)	0.98
Time since stroke (days)	18.5 (19.7)	16.8 (15.9)	0.50
Affected side of the body (number)			
Right	42 (50.0%)	66 (53.2%)	0.29
Left	34 (40.5%)	49 (39.5%)	
Both	8 (9.5%)	6 (4.8%)	
No paresis	0 (0.0%)	3 (2.4%)	
Fall history (number)			
Fallers	46 (54.8%)	53 (42.7%)	0.089
Non-fallers	38 (45.2%)	71 (57.3%)	
% body weight supported by release cable **	8.26 (2.39)	9.36 (3.19)	0.074

* Data only available for 142 participants (Fear group: n=62; No Fear Group: n=80)

** Data only available for 115 participants (Fear group: n=34; No Fear Group: n=115)

Table 2

Mean values for the Fear and No Fear groups for each outcome measure, and *p*-values for each between-group comparison. Only ABC scores differed significantly between groups, while there were no differences in specific features of quiet standing, gait, or reactive stepping. The Holm-Bonferroni corrected alpha was 0.004.

Measure	Mean [95% confidence interval]		<i>p</i> -value
	Fear Group	No Fear Group	
Balance Confidence (N=134)	N=59	N=75	
ABC score (%) *	50.3 [44.4, 56.2]	71.9 [66.7, 77.1]	<0.001
Quiet Standing, eyes-open (N=195)	N=79	N=116	
RMS of total AP COP (mm) ♦	7.0 [6.3, 7.7]	6.5 [5.9, 7.0]	0.22
RMS of total ML COP (mm)	5.1 [4.2, 6.0]	4.4 [3.6, 5.1]	0.12
ρ ₀ of AP COP *♦	0.75 [0.70, 0.80]	0.75 [0.71, 0.80]	0.77
Quiet Standing, eyes-closed (N=194)	N=78	N=116	
AP Romberg quotient ♦	1.5 [1.3, 1.6]	1.3 [1.2, 1.4]	0.039
ML Romberg quotient	1.5 [1.4, 1.6]	1.2 [1.1, 1.3]	0.007
Gait (N=141)	N=49	N=92	
Walking velocity (m/s) *	0.63 [0.55, 0.71]	0.70 [0.64, 0.76]	0.19
Double support time (% gait cycle) *♦	40.7 [37.6, 43.9]	38.0 [35.8, 40.3]	0.15
Step length variability (cm)	3.6 [3.1, 4.1]	2.8 [2.5, 3.1]	0.022
Step width variability (cm)	12.8 [11.7, 14.0]	11.3 [10.4, 12.1]	0.042
Step time variability (ms) *	60 [38, 81]	54 [39, 69]	0.030
Reactive Stepping (N=115)	N=34	N=81	
Number of steps ♦ #	2.3 [1.9, 2.8]	2.9 [2.6, 3.2]	0.023
Grasp reactions (% of trials)	32.4	11.2	0.007
Assists (% of trials)	35.3	37.0	0.86

* Sex and ♦ falls history included as a covariate in the ANCOVA model;

Rank transformations performed for measures that violated the assumption of normality;

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

Table 3

Parameter estimates, partial R^2 , and p-values for balance confidence, from multiple regression.

Measure	Parameter estimate	Partial R^2	P-value
<u>Quiet Standing, eyes-open ($N=90$)</u>			
RMS of total AP COP	-0.32	0.11	0.002 *
RMS of total ML COP	-0.26	0.072	0.010
ρ_0 of AP COP	0.13	0.017	0.22
<u>Quiet Standing, eyes-closed ($N=90$)</u>			
AP Romberg quotient	-0.10	0.012	0.32
ML Romberg quotient	-0.12	0.014	0.26
<u>Gait ($N=72$)</u>			
Walking velocity	0.70	0.29	<0.001 *
Double support time (% gait cycle)	-0.37	0.20	<0.001 *
Step length variability	-0.19	0.047	0.072
Step width variability	-0.22	0.069	0.026
Step time variability	-0.28	0.11	0.005 ♦
<u>Reactive Stepping ($N=65$)</u>			
Number of steps #	0.005	0.053	0.068

Rank transformations for continuous measures that violated the assumption of normality;

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

Significant model following

* initial ($\alpha=0.004$) and ♦ further ($\alpha=0.005$) Holm-Bonferroni adjustment.

Table 4

Odds ratios and p-values for balance confidence, from binary logistic regression. The Holm-Bonferroni corrected alpha was 0.004.

	Increment	Odds ratio [95% confidence interval]	P-value
<u>Reactive Stepping (N=65)</u>			
Grasp reactions	1.0	0.98 [0.95, 1.01]	0.23
Assists	1.0	0.98 [0.96, 1.00]	0.086