JRRD
Volume 51, Number 9, 2014
Pages 1353–1364

Role of balance ability and confidence in prosthetic use for mobility of people with lower-limb loss

Christopher Kevin Wong, PT, PhD;[1*] Christine C. Chen, OTR/L, ScD;[1] Stephany A. Benoy, PT, DPT;[2] Rana T. Rahal, PT, DPT;[2] Wren M. Blackwell, PT, DPT[2]
[1]*Department of Rehabilitation and Regenerative Medicine, Columbia University Medical Center, New York, NY;* [2]*Program in Physical Therapy, Columbia University, New York, NY*

Abstract—For people with lower-limb loss, impaired balance is common and limits prosthetic function within the community. This cross-sectional study (1) analyzed relationships among prosthetic use for mobility, balance ability and confidence, and amputation-related variables and (2) determined multivariate models to identify level of prosthetic use. Subjects included 46 community-dwelling adults (mean age 56.2 yr) with limb loss (91.3% unilateral) of varied levels (52.2% transtibial) and etiologies (69.6% vascular). A three-variable linear regression model including balance ability, balance confidence, and years since amputation explained 63.7% of variance in the Houghton scale of prosthetic use score. A logistic regression model including the 14-task Berg Balance Scale, balance confidence, years since amputation, age, and number of comorbidities correctly differentiated between people who had reached a satisfactory level of prosthetic use or not 89.1% of the time. The first three variables demonstrated moderate accuracy with positive likelihood ratios from 2.34 to 4.35. The regression model was further reduced to correctly classify 87.0% of cases with three balance ability tasks (retrieving objects from floor, turning to look behind, and placing alternate foot on stool), balance confidence, and numbers of comorbidities. Logistic models that include balance ability, balance confidence, and numbers of comorbidities can identify level of prosthetic use in people with lower-limb loss. Increased balance confidence and ability when retrieving objects from floor, turning to look behind, and placing alternate foot on stool were most indicative of successful prosthetic use for mobility.

Key words: accidental falls, amputation, balance measurement, gait, injuries, locomotion, lower limb, physical activity, prosthesis, rehabilitation.

INTRODUCTION

Balance ability is frequently impaired after lower-limb loss and has been implicated as a primary contributor to decreased walking function when using a prosthesis [1]. For community-dwelling elderly [2] and people with neurologic disorders [3], the Berg Balance Scale (BBS) has demonstrated excellent psychometric properties and has been widely used as an objective assessment of balance ability. Recent research has determined that the BBS is a valid assessment of balance ability in people with lower-limb amputations, including prosthetic and nonprosthetic users [4]. The BBS also demonstrated moderate concurrent validity with the Frenchay Activities Index and the two-minute walk test [5]. The BBS has also demonstrated excellent intrarater [5–6] and interrater reliability for people from the highest to the lowest balance ability strata [6].

Abbreviations: +LR = positive likelihood ratio, ABC = Activities-Specific Balance Confidence scale, AUC = area under the curve, BBS = Berg Balance Scale, CI = confidence interval.

***Address all correspondence to Christopher Kevin Wong, PT, PhD; Associate Professor of Rehabilitation and Regenerative Medicine (Physical Therapy), Columbia University Medical Center, 710 West 168th St, Neurological Institute 8-818, New York, NY 10032; 212-305-0683.**
Email: ckw7@cumc.columbia.edu
http://dx.doi.org/10.1682/JRRD.2013.11.0235

Among the 14 balance tasks of the BBS [7], several have been identified through Rasch analysis as particularly difficult for people with lower-limb loss: standing one foot in front, placing alternate foot on a stool, turning 360°, and standing on one leg (from most to least difficult) [4]. Performance on standing on one leg, the task most often investigated as a separate variable, was correlated with self-reported functional mobility scales and performance measures like the Timed "Up and Go" test [8] and has been included as a significant independent variable in a predictive model for the six-minute walk test [9]. People with unilateral lower-limb loss may develop the ability to stand on the intact leg more consistently than other tasks performed less often due to necessity [4]. Studies assessing balance with standing on one leg in people with lower-limb loss have not typically included the other individual BBS tasks in multivariate analyses.

Balance training is an important component of rehabilitation after amputation, and comprehensive rehabilitation for people with lower-limb loss incorporates balance development with gait training to facilitate safety, prosthetic function, and ultimately participation in social activity [10]. Prosthetic componentry and functional gait training have both been shown to improve gait performance ability, as measured by outcomes such as the two-minute walk test [11–12]. However, development of balance ability alone has also been shown to improve gait performance measured with the Timed "Up and Go" test [13]. In addition, the psychological awareness of the movement patterns required for functional gait has been shown to affect prosthetic gait function [14].

Prosthetic functioning requires an individual to have both sufficient physical performance ability and the motivation and confidence to try to use the prosthesis in different ways in the course of life's activities [15]. The psychological willingness to use the prosthesis, expressed as the motivation to walk, was found to be significantly different between older individuals who successfully functioned with their prosthesis and those who were unsuccessful [15]. Miller et al. also found that balance confidence, measured by the Activities-Specific Balance Confidence scale (ABC), played a significant role in predicting prosthetic use, mobility, and participation in community and social activities [16]. The Miller et al. study, however, did not include a performance-based assessment of balance ability as an independent variable together with the ABC [16]. Thus, the relative contributions of balance ability and balance confidence on prosthetic use for mobility after lower-limb loss have not been explored.

Balance ability assessed using the BBS, balance confidence measured with the ABC, and other individual characteristics and elements of the medical history, when considered together, may help identify people with lower-limb loss who are likely to have low prosthetic functioning and thus benefit from additional rehabilitative care. The purposes of this study were to (1) analyze the relationships among self-reported prosthetic use for mobility (Houghton), balance ability (BBS), balance confidence (ABC), and individual characteristics and (2) determine multivariate regression models that differentiate between satisfactory and unsatisfactory prosthetic use. The hypothesis was that balance ability would be a significant contributor in regression models of prosthetic use for mobility.

METHODS

The protocol for this cross-sectional study was approved by and conducted in accordance with the institutional review board of the participating university medical center.

Subjects

Subjects were recruited by flyer and word of mouth from local prosthetic clinics and support groups as part of an ongoing longitudinal study. Inclusion criteria for the study were community-dwelling individuals with bilateral or unilateral lower-limb amputations of any level or etiology who had completed initial prosthetic training. Exclusion criteria included medical issues that affected balance including uncontrolled cardiovascular disorders, neurological disorders such as stroke or vestibular disorders, blindness, or cognitive disability preventing understanding of the study purpose and procedures.

The sample size was determined in two ways. First, variables anticipated to be of clinical relevance to prosthetic function based on clinical experience and past literature were initially included: age, years since amputation, amputation etiology, amputation level, unilateral or bilateral amputation, BBS score (balance ability), and ABC score (balance confidence). Given that seven variables were expected to be of interest and that five subjects per variable entered was the minimum required number to produce stable results not due to chance [17], a minimum sample size of 35 was deemed sufficient. Second, appropriate sample size was also determined using more specific parameters by taking into account past research that found variables including ABC score determined over 60 percent of the variance in prosthetic use for mobility when measured by the Houghton scale [16]. For a three-variable model with $R^2 = 0.60$ and good predictive level, a sample size of 33 was required, while a larger sample of 45 was required when $R^2 = 0.50$ [18]. The projected sample size was thus set at 50, sufficient for a minimum of 5 subjects for up to 10 variables entered, to assure an adequate sample size to provide enough power even with attrition [17].

Measurements

The primary outcome of interest was self-reported prosthetic use for mobility, as quantified by the Houghton Scale [19]. The Houghton scale is a self-administered questionnaire recommended for routine clinical use specifically for people with lower-limb amputations [20]. Scores for four questions addressing the duration of daily prosthesis wear, use of prosthesis and assistive device, and perceived stability when using the prosthesis for mobility on various terrains are summated, with the total score reported. Houghton scale scores range from 0 to 12, with higher scores indicating better function. Scores of 9 or greater have been suggested as representing rehabilitation to a satisfactory level of prosthetic use [19]. Houghton scale scores correlate moderately with physical walking ability measures with better convergent validity with the Timed "Up and Go" and two-minute walk test than more detailed self-report measures like the Prosthetic Evaluation Questionnaire [21–22]. Houghton scale internal consistency has been moderate [21]. Test-retest reliability of the Houghton scale has been excellent [22]. Like the Prosthetic Evaluation Questionnaire, the Houghton scale differentiates between people with different amputation etiologies and functional walking levels, though only the Houghton scale differentiates between different amputation levels [22]. The Houghton scale has also been observed to be responsive to change after a course of rehabilitation [21].

Balance confidence was assessed using the ABC. The self-reported ABC quantifies the individual's balance confidence when performing 16 different activities, with the average percent confidence reported [23]. The activities range from retrieving an object from the floor, at eye level, and above one's head to walking in a parking lot, up and down ramps, and on icy sidewalks. Rasch analysis has shown that the 16 activities represent a hierarchy of difficulty without redundancy [24]. Validity [21] and reliability [22] of the ABC have been established for people with lower-limb amputations.

Performance-based balance ability was measured with the BBS, which consists of 14 tasks that challenge static and dynamic balance in a variety of ways [7]. Each task is scored from 0 to 4, with the total score reported [7]. The BBS performed without using an assistive device has been demonstrated to be a valid assessment of balance ability for people with lower-limb loss with the following modifications [4]. Tasks that can emphasize one leg over another (stand one foot in front, stand on one leg) were performed both ways with the best score recorded. An ability score of zero was assigned to subjects unable to attempt any particular task [4]. Inter- and intrarater reliability of the BBS for people with lower-limb loss have also been excellent [5–6].

Procedure

After informed consent was obtained, subjects were interviewed and completed questionnaires and the balance assessment in a single session. Data collected through self-reported paper questionnaire included age, sex, race, weight, height, consumption of alcohol, medical comorbidities, amputation etiology and level, years since amputation, prosthesis use, and number of falls in the past 12 mo. Alcohol consumption was rated as any or none. Falls were defined as loss of balance events resulting in the subject on the ground. After filling out the ABC and Houghton scale, the balance ability of each subject was assessed using the BBS by testers that had demonstrated excellent interrater reliability in a separate testing [6], as administered for people with limb loss [4].

Statistical Analyses

Variables associated with the Houghton scale of prosthetic use for mobility were identified for further analysis by calculating Spearman correlation coefficients. In addition to the seven variables initially anticipated to be clinically or theoretically relevant, variables with significant correlations at the rho > 0.50 levels [17] were identified for inclusion in the multiple-regression analyses. Two additional variables were included to account for general health: body mass index unadjusted for amputation and number of comorbidities counted from a list of potential medical issues. Thus, nine total variables were entered into the regression analyses: BBS, ABC, age, years since amputation, amputation etiology, most proximal amputation level, unilateral or bilateral amputation status, body mass index, and number of comorbidities. The subject with ankle disarticulation was grouped with subjects with transtibial amputation because all used a prosthetic foot/ankle but not a knee unit. Variables with missing data for ≥10 percent of the subjects or collinearity with the Houghton scale, such as prosthesis, assistive device, and wheelchair use, were not included.

Multivariate linear regression was performed using a manual backward deletion process with variables demonstrating the weakest associations removed first to the $p > 0.10$ level. Inclusion of variables with *p*-values between 0.10 and 0.15 was considered to maintain the most authentic confounding variables if deemed clinically important [25]. Variables with high levels of collinearity as demonstrated by values of tolerance <0.20 or variance inflation factor >5.0 would have been excluded. A simple bootstrapping procedure was performed with 95 percent confidence interval (CI) and 1,000 samples per step to reduce the effect of distribution variability and the small sample size [26]. Bootstrapping results in wider confidence intervals and a conservative estimate of model strength [25]. Regression model significance level was set at $p < 0.05$, and the adjusted R^2, which accounts for the number of variables entered, was reported. In addition, the Hosmer and Lemeshow test ($p > 0.05$) was used to ensure goodness of fit, and visual inspection of the normal probability plot was used to determine whether data fell in a normal distribution.

Logistic regression including the same nine variables selected for clinical and theoretical relevance [25,27] was conducted to determine which set of variables identified the binary outcome of unsatisfactory or satisfactory prosthetic use as defined by the suggested Houghton score ≥ 9 [19]. Such a model may be useful clinically in determining functional prognoses. The initial model was adjusted using the same process of manual backward deletion used for the multivariate linear regression analysis, preserving variables with significance to $p < 0.10$ [25] and applying the 1,000 samples per step bootstrapping procedure [26]. Individual BBS tasks were substituted for the total BBS score and the model was further reduced. Model significance level was set at $p < 0.05$ with percent correct classifications reported.

Receiver operating curves were charted for variables that remained significant ($p < 0.05$) in the final regression model. Area under the curve (AUC) values were calculated with 95 percent CIs and significance levels set at $p < 0.05$, with values > 0.70 considered to indicate moderate accuracy and usefulness [28]. Relevant cut-points were identified, with relevant sensitivity, specificity, and positive likelihood ratio (+LR) reported.

t-Tests were performed to determine whether differences existed between people with satisfactory (Houghton ≥ 9) and unsatisfactory levels of prosthetic use (Houghton < 9) with regards to age, body mass index, number of comorbidities, years since amputation, ABC, BBS total score, and BBS item scores; Fisher exact tests were conducted to examine the differences between sex, vascular etiology, amputation level, and unilateral and bilateral amputations.

RESULTS

Of the 60 subjects initially recruited for the study, 6 dropped out before completing the assessments and 8 were not using their prosthesis at the time of assessment. Information for the 46 subjects who completed the assessments and were included in the study analysis has been described in **Tables 1** and **2**.

Correlations

Spearman correlations for the Houghton scale of prosthetic use for mobility found two variables with significant correlations and coefficients of rho > 0.50: ABC scale score (rho = 0.77) and BBS score (rho = 0.73).

Table 1.
Subject information.

Subject Descriptor	*n*	%
Sex		
Women	14	30.4
Men	32	69.6
Etiology		
Vascular (peripheral vascular disease and/or diabetes)	32	69.6
Nonvascular (trauma and other medical diagnoses)	14	30.4
Amputation Levels		
Unilateral	42	91.4
Transtibial	24	52.2
Transfemoral	17	37.0
Ankle disarticulation	1	2.2
Bilateral	4	8.6
Transtibial	2	4.3
Transtibial-Transfemoral	2	4.3

Table 2.
Subject information.

Subject Descriptor	Mean	SD	Range
Age (yr)	56.2	11.0	34–82
Years Since Amputation	6.7	10.4	<1–47
Body Mass Index	27.9	6.9	15.2–43.7
Number of Comorbidities	1.6	1.6	0–7
Falls in 1 Yr	0.9	0.8	0–2
Houghton Score	7.5	3.8	0–12
ABC (%)	65.1	28.8	0–100
Berg Balance Scale	43.0	13.3	1–56

ABC = Activities-Specific Balance Confidence, SD = standard deviation.

Younger age and more years since amputation had significant bivariate correlations but were only weakly correlated with higher prosthetic use scores. Every BBS task, except BBS 3 (sitting-unsupported), was correlated with prosthetic use for mobility with rho values ranging from 0.39 to 0.78, with BBS 11 (turning 360°) and 12 (placing alternate foot on stool) demonstrating the strongest correlations with rho values exceeding that of the total BBS score. None of the BBS tasks correlated with each other or the total BBS score with coefficients > 0.90.

Linear Regression

After the initial nine-variable model was reduced, the final model ($p < 0.001$) included three variables and explained 63.7 percent of the variance in prosthetic use for mobility. Balance ability and balance confidence both remained significant independent variables in the model (see **Table 3**). When the individual BBS tasks were substituted for the total BBS score in the regression analysis, the resulting final model explained 68.3 percent of the variance in Houghton scale score ($p < 0.001$) with only two variables: self-reported ABC score and performance on BBS 11 (turning 360°).

Table 3.
Linear regression model for prosthetic function.

Variable	Unstandardized B	CI 95% of B	SE	*p*-Value
BBS	0.13	0.04–0.22	0.047	0.01
ABC	0.05	0.01–0.10	0.022	0.03
Years Since Amputation	0.05	0.01–0.16	0.035	0.07

ABC = Activities-Specific Confidence scale, BBS = Berg Balance Scale, CI = confidence interval, SE = standard error.

Logistic Regression

Logistic regression using patient and clinical information determined whether subjects had a satisfactory or unsatisfactory level of prosthetic use, using the suggested Houghton scale cut-off score of ≥9 [19]. The multivariate logistic regression model ($p < 0.001$) correctly differentiated between satisfactory and unsatisfactory prosthetic use for 89.1 percent of the subjects with all five variables significantly contributing (**Table 4**). Receiver operating curves identified three variables that demonstrated moderate accuracy with AUC values >0.70 [28]. The BBS AUC was 0.83 with a cut-off score of 46, such that a score ≥46 indicated satisfactory prosthetic use with 81.8 percent sensitivity, 75.5 percent specificity, and a +LR of 3.27. The AUC value for ABC was 0.84 with a cut-off score of 77.1 and +LR of 4.35. Years since amputation had AUC of 0.74 and a cut-off score of 2.5 yr with a +LR of 2.34. Age and number of comorbidities had nonsignificant receiver operating curves ($p > 0.05$). (**Table 4**).

When individual BBS tasks were entered into the multivariate analysis in place of the total BBS score, age and years since amputation were not retained in the final logistic regression model that classified 87.0 percent of the cases correctly as having satisfactory or unsatisfactory

Table 4.
Logistic regression model for satisfactory prosthetic function (89.1%).

Variable	OR	95% CI OR	SE	*p*-Value	AUC	95% CI	Sn	Sp	+LR
BBS	1.21	1.01–1.46	0.10	0.02	0.83	0.72–0.95	81.8	75.0	3.27
ABC	1.12	1.02–1.24	0.05	0.01	0.84	0.73–0.96	72.7	83.3	4.35
Years Since Amputation	1.21	0.99–1.49	0.11	0.01	0.72	0.57–0.87	68.2	70.8	2.34
Age	1.21	1.03–1.42	0.08	0.03	0.44	0.27–0.61	—	—	—
Number of Comorbidities	3.46	1.22–9.78	0.53	0.02	0.47	0.30–0.65	—	—	—

+LR = positive likelihood ratio, ABC = Activities-Specific Confidence scale, AUC = area under the curve, BBS = Berg Balance Scale, CI = confidence interval, OR = odds ratio, SE = standard error, Sn = sensitivity, Sp = specificity.

prosthetic use ($p < 0.001$). The final model combined BBS 9 (retrieving object from floor), BBS 10 (turning to look behind), BBS 12 (placing alternate foot on stool), ABC, and number of comorbidities (**Table 5**). Receiver operating curves (**Figure**) revealed a cut-off score of 4 for each BBS item with +LR ranging from 2.18 to 5.46, and a 77.1 ABC score with +LR of 4.35 [28]. The AUC curves revealed high accuracy for the ABC and BBS 12 scores and moderate accuracy for the BBS 9–10 scores. (**Table 5**) Number of comorbidities had nonsignificant receiver operating curves ($p > 0.05$)

Subgroup Comparisons

Comparisons between people with satisfactory and unsatisfactory prosthetic use suggested the dichotomous subgroups were significantly different. Fisher exact test ($p = 0.05$) suggested a trend toward vascular etiology being associated with less than satisfactory levels of prosthetic use. No significant differences were found for sex, amputation level, or unilateral versus bilateral amputations. Subjects in the satisfactory prosthetic use group had significantly more years since amputation and higher ABC and BBS scores than subjects with Houghton scores <9 (**Table 6**). No significant difference was found in any variables between men and women or transtibial and transfemoral amputation levels.

DISCUSSION

This study analyzed the multivariate relationship among balance ability (BBS), balance confidence (ABC), and other individual characteristics potentially relevant to prosthetic use for mobility in people with lower-limb loss. While previous research had revealed a relationship between balance confidence and prosthetic functional use, no performance-based balance ability measure was included [16]. Since both self-confidence and the physical ability to maintain balance in functional activities may be important to prosthetic function, it is important to include both physical balance ability and subjective confidence together within multivariate analyses. The hypothesis that balance ability would be an important variable in a model for prosthetic use was confirmed in several ways through multivariate linear and logistic regression and bivariate correlations.

Both balance ability and balance confidence along with years since amputation remained in the linear regression model for prosthetic use after controlling for age, amputation etiology and level, number of amputated limbs and comorbidities, and body mass index. Balance ability and self-reported subjective balance confidence were the most strongly correlated with prosthetic use for mobility in the bivariate analysis. Some subjects with low balance ability who primarily used a wheelchair for mobility reported high confidence even in performing standing and walking activities, potentially reflecting an overestimation of their ability. Others with low ability may have lost confidence after finding their actual function limited. Because the ability to function with a prosthesis requires the actual physical ability to both balance and walk [29], analyzing the roles of balance ability and confidence in prosthetic function was critical.

Analysis with individual BBS tasks may provide useful information regarding satisfactory prosthetic use for mobility since BBS tasks range in difficulty and may not be equally influential [4]. In this study, two individual task scores had higher correlations with the Houghton score than the total BBS score. When individual tasks

Table 5.
Potential screening method for satisfactory prosthetic function.

Variable	OR	95% CI OR	SE	*p*-Value	AUC	95% CI	Sn	Sp	+LR
BBS 9: Retrieving Object from Floor	7.05	1.43–34.72	0.81	0.012	0.77	0.63–0.91	81.8	66.7	2.46
BBS 10: Turning to Look Behind	0.04	0.00–0.90	1.60	0.016	0.74	0.59–0.88	81.8	62.5	2.18
BBS 12: Placing Alternate Foot on Stool	3.18	0.82–12.40	0.69	0.020	0.88	0.77–0.98	68.2	87.5	5.46
ABC	1.14	1.00–1.31	0.07	0.016	0.84	0.73–0.96	72.7	83.3	4.35
Number of Comorbidities	3.63	1.02–12.94	0.65	0.028	0.47	0.30–0.65	—	—	—

+LR = positive likelihood ratio, ABC = Activities-Specific Confidence scale, AUC = area under the curve, BBS = Berg Balance Scale, CI = confidence interval, OR = odds ratio, SE = standard error, Sn = sensitivity, Sp = specificity.

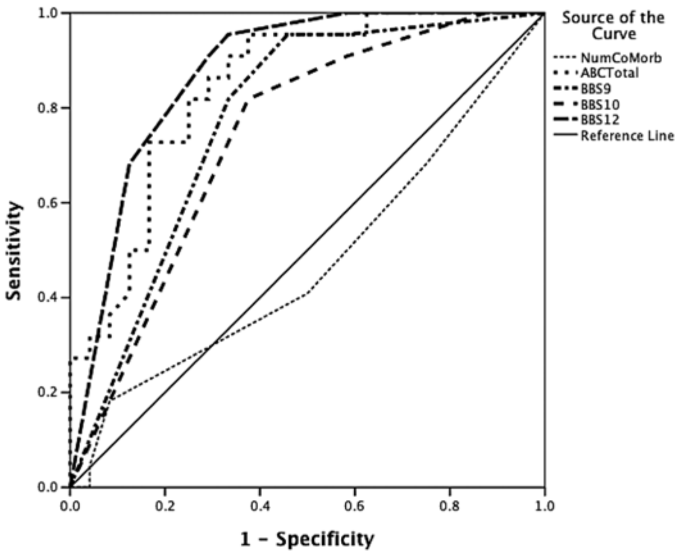

Figure.
Receiver operating curves (ROC) for screening variables in logistic regression model for successful or unsuccessful prosthetic function. Note: Diagonal segments are produced by ties. ABC = Activities-Specific Balance Confidence scale, BBS = Berg Balance Scale, NumCoMorb = number of comorbidities.

were substituted for the total BBS score, the linear regression model explained 68.3 percent of the variance in Houghton score with only two items: ABC and BBS 11. Turning 360° (BBS 11) has been identified as one of the most difficult BBS tasks [4] and correlated most highly with both the Houghton and total BBS scores in this study. The results of the multivariate linear regression analysis suggest that balance confidence was important to encourage an individual to attempt to use the prosthesis in his or her environment and community while physical balance ability was an important factor in actually performing those functions.

Determining which variables contribute most to a satisfactory level of prosthetic use for mobility, defined by Houghton scores ≥9 [19], may help identify individuals with lower-limb loss who could benefit from further care. In the logistic regression model differentiating between people with satisfactory and unsatisfactory prosthetic use, balance ability was an important variable (**Table 4**). The total BBS score and years since amputation demonstrated the highest odds ratio, indicating that for every unit increase in BBS score and years since amputation there was a 21 percent increase in the odds of being satisfactory in prosthetic use. The ABC score odds ratio indicated a 12 percent increase in the odds of being satisfactory in prosthetic use for every unit increase in ABC. The cut-off ABC score of 77 percent, which exceeded the average 70 percent for community-dwelling people with lower-limb loss [30] and approached the normal level for nondisabled elderly [23], was the most accurate discriminator between satisfactory and unsatisfactory prosthetic use for mobility. The cut-off total BBS score was similar to the 46 identified previously as a reasonable cut-off score for identifying elderly people at risk to fall [31].

Table 6.
Comparing group means between satisfactory (Houghton score ≥ 9) and unsatisfactory (Houghton score < 9) prosthetic users.

Variable	Successful Prosthetic Users, *n* = 24, Mean ± SD	Unsuccessful Prosthetic Users, *n* = 16, Mean ± SD	*p*-Value
Age	54.9 ± 11.8	57.5 ± 10.4	>0.05
Body Mass Index	26.7 ± 5.5	29.1 ± 7.9	>0.05
Number of Comorbidities	1.6 ± 1.6	1.6 ± 1.6	>0.05
Years Since Amputation	10.2 ± 13.6	3.5 ± 4.7	0.04
ABC Total Score	83.1 ± 16.0	48.6 ± 28.2	<0.01
BBS Total Score	50.6 ± 6.6	36.0 ± 14.1	<0.01
BBS 7: Standing feet together	3.7 ± 0.9	2.8 ± 1.5	0.02
BBS 9: Retrieving object from floor	3.7 ± 0.9	1.8 ± 1.8	<0.01
BBS 10: Turning to look behind	3.7 ± 0.6	2.7 ± 1.3	0.02
BBS 11: Turning 360°	3.6 ± 0.8	1.4 ± 1.5	<0.01
BBS 12: Placing alternate foot on stool	3.6 ± 0.8	1.3 ± 1.5	<0.01

Note: Separate BBS tasks that correlate with Houghton score (rho > 0.6) presented.
ABC = Activities-Specific Balance Confidence scale, BBS = Berg Balance Scale, SD = standard deviation.

Analyzing separate BBS tasks in place of the total BBS score, an approach taken in people with stroke [32], was helpful in identifying a screening method to classify people as achieving a satisfactory or unsatisfactory level of prosthetic use for mobility. All separate BBS tasks except for BBS 3 (sitting with back unsupported) were significantly correlated with prosthetic use. Spearman correlation coefficients for BBS 11 (turning 360°) and BBS 12 (placing alternate foot on step) were more highly correlated with prosthetic use than the total BBS score. BBS 11 alone combined with ABC in the linear regression model explained more of the Houghton score than the model including the total BBS score, ABC, and years since amputation. Perhaps more revealing was the logistic regression model that correctly differentiated between satisfactory and unsatisfactory prosthetic use in 87.0 percent of the cases with a model that included three BBS tasks, ABC, and number of comorbidities (**Table 5**). Except for number of comorbidities, each variable in this model had +LRs > 2.0 with scores of 4 on the above-average difficulty tasks (BBS 9 and BBS 10), and the difficult BBS 12 task had a 318 percent greater likelihood of satisfactory prosthetic use for mobility. The ABC score contributed 14 percent greater likelihood of differentiating between satisfactory and unsatisfactory prosthetic use (**Table 5**). Combining three simple balance tasks, a self-report completed in a clinic waiting room, and the number of comorbidities obtained from the medical record, has potential as a clinical screening tool to identify people with lower-limb loss who have not yet achieved satisfactory prosthetic use and may benefit from further rehabilitation to enhance their mobility.

Analysis of the specific BBS tasks may shed insight into their importance. BBS 12 (placing alternate foot on step) requires cyclical weight bearing and most closely simulates walking, and it has been repeatedly reported as among the more difficult BBS tasks to perform [4,33]. Walking tasks such as the two-minute walk test have strongly correlated with prosthetic function [9,29] but require time and space to assess, which can prove difficult in a clinic office. BBS 12 may be a useful shortcut to quickly determine prosthetic use for mobility and establish a prognosis that could include referral for additional rehabilitation. BBS 12 has been documented to be among the hardest tasks for people with lower-limb loss [4] and is appropriately a mainstay of prosthetic rehabilitation [10]. BBS 9 (retrieving object from floor) and BBS 10 (turning to look behind) have been shown to be above-average difficulty tasks [4]. Both confound to a degree the visual and vestibular systems, the primary systems of balance [34]. In addition, common strategies for retrieving objects from the floor involve bending from the waist, which requires gluteal strength, or bending at the knee, which requires quadriceps strength—both muscles significantly weakened after lower-limb amputation. Turning to look behind requires weight shifting onto each leg and transverse plane rotation not typically provided in prosthetic components. Including visual and vestibular confounding in a multisystem approach to improve balance [35] is recommended to encourage development of the proprioceptive system contribution to balance [36], particularly in the rehabilitation of people with lower-limb loss who adaptively place more weight bearing on one leg [37]. Notably, BBS 14 (standing on one leg) was not an independent variable for prosthetic success in this study. Even low functioning people with limb loss may stand on their intact leg reasonably well because of frequent practice, which may explain why stand on one leg was not found to be one of the three most difficult balance tasks [4]. Standing on the intact leg may produce false negatives when used as a clinical test, especially if investigated without exploring multivariate relationships among other balance tasks of particular difficulty to people with lower-limb loss.

Further prospective research is required to determine whether these models for prosthetic use for mobility can predict future prosthetic use in other populations with lower-limb loss, whether using the BBS total score or specific tasks. In addition, a Houghton classification of satisfactory prosthetic use may best describe the outcome after initial prosthetic rehabilitation. While people with lower-limb loss completing inpatient rehabilitation reported better physical outcomes than those discharged home or to a skill-nursing facility [38], home discharges have increased as hospital lengths-of-stay have decreased [39]. A satisfactory level of prosthetic use on the self-report Houghton scale can be obtained easily in a variety of settings but should not be construed as representing optimal use. For instance, most high performing servicemembers with lower-limb loss, who would score at the top of the Houghton scale, did not yet perform at the ability of their nondisabled peers [40]. Regardless, obtaining prognostic information about a person's ability to use his or her prosthesis for mobility with easily accessible medical history data, a self-report scale completed in a clinic waiting room, and physical assessment of three simple physical tasks is an important development.

Limitations

It should be noted that the regression models derived from this cross-sectional study should not be interpreted as prognostic. Future prospective studies should be performed to determine whether the multivariate models have the power to predict future prosthetic use for mobility. Although the sample size was determined sufficient a priori, the small sample size remains a primary weakness of this study. A larger sample would have allowed analysis of more variables, such as sex, residual limb or generalized pain, height, and weight, or more subjects per variable to be included in the analysis. For the population of people with lower-limb amputation, within which there can be numerous subgroupings of amputation number, level, and etiology, a larger number of subjects per variable could have been an advantage. Other limitations included (1) using self-reported height and weight to calculate body mass index without adjustment for the amputated limb; (2) possible Houghton scale ceiling effects that could limit measurement of the highest functioning individuals [21–22], although this would not influence differentiation between satisfactory and unsatisfactory prosthetic use; (3) lack of specific information about the subjects' initial prosthetic training; and (4) lack of clinical measures that contribute to balance ability, such as range of motion, strength, and proprioception. Analysis using individual BBS tasks should be interpreted with caution because the BBS tasks were included as variables only after the final model had been determined to include the total BBS scores. To include the individual tasks at the start of the process would have exceeded the number of variables recommended for the number of subjects in the study.

CONCLUSIONS

Balance ability has been noted to be the most important factor in the gait of people with lower-limb loss [1], and the results of this study confirmed that balance ability was a significant independent variable of prosthetic use for mobility. People with lower-limb loss who have achieved a satisfactory or unsatisfactory level of prosthetic use can be identified by a model including balance ability, balance confidence, years since amputation, age, and number of comorbidities that correctly classified over 89 percent of the subjects with moderate predictive accuracy. Increased balance ability, particularly when turning to look behind, retrieving object from floor, and stepping to place alternating feet on a stool, were most indicative of satisfactory prosthetic use. Further prospective longitudinal research is needed to determine whether screening people with these three balance tasks combined with the self-report ABC and numbers of comorbidities will facilitate the identification of people with lower-limb loss who have yet to achieve a level of satisfactory prosthetic use and may benefit from additional care.

ACKNOWLEDGMENTS

Author Contributions:
Study concept and design: C. K. Wong.
Acquisition of data: S. A. Benoy, R. T. Rahal, W. M. Blackwell.
Analysis and interpretation of data: S. A. Benoy, R. T. Rahal, W. M. Blackwell, C. K. Wong, C. C. Chen.
Drafting of manuscript: C. K. Wong.
Critical revision of manuscript for important intellectual content: C. C. Chen, S. A. Benoy, R. T. Rahal, W. M. Blackwell.
Financial Disclosures: The authors have declared that no competing interests.
Funding/Support: This material was based on work supported in part by the National Center for Injury Prevention and Control, Centers for Disease Control and Prevention to the Center for Injury Epidemiology and Prevention at Columbia University (grant 1R49 CE002096). This material was also supported in part by The National Center for Advancing Translational Sciences, National Institutes of Health (grant UL1 TR000040), formerly the National Center for Research Resources (grant UL1 RR024156).
Additional Contributions: Stephany A. Benoy is now with the Rehabilitation Institute of Chicago, Chicago, Illinois. Rana T. Rahal is now with the Physical Therapy Program, Kessler Institute of Rehabilitation, Chester, New Jersey. Wren M. Blackwell is now with Physical Therapy Solutions, Richmond, Virginia.
Institutional Review: All participants received written and verbal information about the study from the experimenter and gave written informed consent. The study protocol met the institutional guidelines and was approved by the Institutional Review Board of Columbia University Medical Center.
Participant Follow-Up: The authors do not plan to inform participants of the publication of this study due to incomplete contact information.
Disclaimer: The content is solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention or the National Institutes of Health.

REFERENCES

1. van Velzen JM, van Bennekom CA, Polomski W, Slootman JR, van der Woude LH, Houdijk H. Physical capacity and walking ability after lower limb amputation: A systematic review. Clin Rehabil. 2006;20(11):999–1016.

[PMID:17065543]
http://dx.doi.org/10.1177/0269215506070700

2. Tyson SF, Connell LA. How to measure balance in clinical practice. A systematic review of the psychometrics and clinical utility of measures of balance activity for neurological conditions. Clin Rehabil. 2009;23(9):824–40. [PMID:19656816] http://dx.doi.org/10.1177/0269215509335018
3. La Porta F, Caselli S, Susassi S, Cavallini P, Tennant A, Franceschini M. Is the Berg Balance Scale an internally valid and reliable measure of balance across different etiologies in neurorehabilitation? A revisited Rasch analysis study. Arch Phys Med Rehabil. 2012;93(7):1209–16. [PMID:22521926] http://dx.doi.org/10.1016/j.apmr.2012.02.020
4. Wong CK, Chen C, Welsh J. Preliminary assessment of balance with the Berg Balance Scale in adults who have a leg amputation and dwell in the community: Rasch rating scale analysis. Phys Ther. 2013;93(11):1520–29. [PMID:23744457] http://dx.doi.org/10.2522/ptj.20130009
5. Major MJ, Fatone S, Roth EJ. Validity and reliability of the Berg Balance Scale for community-dwelling persons with lower-limb amputation. Arch Phys Med Rehabil. 2013; 94(11):2194–2202. [PMID:23856150] http://dx.doi.org/10.1016/j.apmr.2013.07.002
6. Wong CK. Interrater reliability of the Berg Balance Scale when used by clinicians of various experience levels to assess people with lower limb amputations. Phys Ther. 2014;94(3):371–78. [PMID:24092903] http://dx.doi.org/10.2522/ptj.20130182
7. Berg KO, Maki BE, Williams JI, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. Arch Phys Med Rehabil. 1992;73(11):1073–80. [PMID:1444775]
8. Schoppen T, Boonstra A, Groothoff JW, de Vries J, Göeken LN, Eisma WH. Physical, mental, and social predictors of functional outcome in unilateral lower-limb amputees. Arch Phys Med Rehabil. 2003;84(6):803–11. [PMID:12808530] http://dx.doi.org/10.1016/S0003-9993(02)04952-3
9. Raya MA, Gailey RS, Fiebert IM, Roach KE. Impairment variables predicting activity limitation in individuals with lower limb amputation. Prosthet Orthot Int. 2010;34(1): 73–84. [PMID:20196689] http://dx.doi.org/10.3109/03093640903585008
10. Wong CK, Edelstein JE. Chapter 27: Advanced rehabilitation for people with microprocessor knee prostheses. In: Lusardi MM, Nielsen CC, editors. Orthotics and prosthetics in rehabilitation. 3rd ed. St Louis (MO): Saunders Elsevier; 2013. p. 737–57.
11. Taheri A, Karimi MT. Evaluation of the gait performance of above-knee amputees while walking with 3R20 and 3R15 knee joints. J Res Med Sci. 2012;17(3):258–63. [PMID:23267378]
12. Rau B, Bonvin F, de Bie R. Short-term effect of physiotherapy rehabilitation on functional performance of lower limb amputees. Prosthet Orthot Int. 2007;31(3):258–70. [PMID:17979011] http://dx.doi.org/10.1080/03093640600994615
13. Matjaĉić Z, Burger H. Dynamic balance training during standing in people with trans-tibial amputation: A pilot study. Prosthet Orthot Int. 2003;27(3):214–20. [PMID:14727702] http://dx.doi.org/10.1080/03093640308726684
14. Sjödahl C, Jarnlo GB, Persson BM. Gait improvement in unilateral transfemoral amputees by a combined psychological and physiotherapeutic treatment. J Rehabil Med. 2001;33(3):114–18. [PMID:11482351] http://dx.doi.org/10.1080/165019701750165934
15. Hamamura S, Chin T, Kuroda R, Akisue T, Iguchi T, Kohno H, Kitagawa A, Tsumura N, Kurosaka M. Factors affecting prosthetic rehabilitation outcomes in amputees of age 60 years and over. J Int Med Res. 2009;37(6):1921–27. [PMID:20146892] http://dx.doi.org/10.1177/147323000903700630
16. Miller WC, Deathe AB, Speechley M, Koval J. The influence of falling, fear of falling, and balance confidence on prosthetic mobility and social activity among individuals with a lower extremity amputation. Arch Phys Med Rehabil. 2001;82(9):1238–44. [PMID:11552197] http://dx.doi.org/10.1053/apmr.2001.25079
17. Norman GR, Streiner DL. Multiple regression. In: Biostatistics: The bare essentials. 3rd ed. Hamilton (Canada): BC Decker Inc; 2008. p. 145–56.
18. Knofczynski GT, Mundfrom D. Sample sizes when using multiple linear regression for prediction. Educ Psychol Meas. 2008;68(3):431–42. http://dx.doi.org/10.1177/0013164407310131
19. Houghton AD, Taylor PR, Thurlow S, Rootes E, McColl I. Success rates for rehabilitation of vascular amputees: Implications for preoperative assessment and amputation level. Br J Surg. 1992;79(8):753–55. [PMID:1393461] http://dx.doi.org/10.1002/bjs.1800790811
20. Condie E, Scott H, Treweek S. Lower limb prosthetic outcome measures: A review of the literature 1995 to 2005. J Prosthet Orthot. 2006;18(1S):13–45. http://dx.doi.org/10.1097/00008526-200601001-00004
21. Devlin M, Pauley T, Head K, Garfinkel S. Houghton Scale of prosthetic use in people with lower-extremity amputations: Reliability, validity, and responsiveness to change. Arch Phys Med Rehabil. 2004;85(8):1339–44. [PMID:15295762] http://dx.doi.org/10.1016/j.apmr.2003.09.025
22. Miller WC, Deathe AB, Speechley M. Lower extremity prosthetic mobility: A comparison of 3 self-report scales.

Arch Phys Med Rehabil. 2001;82(10):1432–40. [PMID:11588750] http://dx.doi.org/10.1053/apmr.2001.25987

23. Myers AM, Fletcher PC, Myers AH, Sherk W. Discriminative and evaluative properties of the activities-specific balance confidence (ABC) scale. J Gerontol A Biol Sci Med Sci. 1998;53(4):M287–94. [PMID:18314568] http://dx.doi.org/10.1093/gerona/53A.4.M287
24. Sakakibara BM, Miller WC, Backman CL. Rasch analyses of the Activities-specific Balance Confidence Scale with individuals 50 years and older with lower-limb amputations. Arch Phys Med Rehabil. 2011;92(8):1257–63. [PMID:21704978] http://dx.doi.org/10.1016/j.apmr.2011.03.013
25. Sun GW, Shook TL, Kay GL. Inappropriate use of bivariable analysis to screen risk factors for use in multivariable analysis. J Clin Epidemiol. 1996;49(8):907–16. [PMID:8699212] http://dx.doi.org/10.1016/0895-4356(96)00025-X
26. Steyerberg EW, Eijkemans MJ, Harrell FE Jr, Habbema JD. Prognostic modelling with logistic regression analysis: A comparison of selection and estimation methods in small data sets. Stat Med. 2000;19(8):1059–79. [PMID:10790680] http://dx.doi.org/10.1002/(SICI)1097-0258(20000430)19:8<1059::AID-SIM412>3.0.CO;2-0
27. Harrell FE Jr, Lee KL, Mark DB. Multivariable prognostic models: Issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. Stat Med. 1996;15(4):361–87. [PMID:8668867] http://dx.doi.org/10.1002/(SICI)1097-0258(19960229)15:4<361::AID-SIM168>3.0.CO;2-4
28. Greiner M, Pfeiffer D, Smith RD. Principles and practical application of the receiver-operating characteristic analysis for diagnostic tests. Prev Vet Med. 2000;45(1–2):23–41. [PMID:10802332] http://dx.doi.org/10.1016/S0167-5877(00)00115-X
29. Gremeaux V, Damak S, Troisgros O, Feki A, Laroche D, Perennou D, Benaim C, Casillas J-M. Selecting a test for the clinical assessment of balance and walking capacity at the definitive fitting state after unilateral amputation: A comparative study. Prosthet Orthot Int. 2012;36(4):415–22. [PMID:22389424] http://dx.doi.org/10.1177/0309364612437904
30. Miller WC, Deathe AB. A prospective study examining balance confidence among individuals with lower limb amputation. Disabil Rehabil. 2004;26(14–15):875–81. [PMID:15497916] http://dx.doi.org/10.1080/09638280410001708887
31. Bogle Thorbahn LD, Newton RA. Use of the Berg Balance Test to predict falls in elderly persons. Phys Ther. 1996; 76(6):576–83, discussion 584–85. [PMID:8650273]
32. Alzayer L, Beninato M, Portney LG. The accuracy of individual Berg Balance Scale items compared with the total Berg score for classifying people with chronic stroke according to fall history. J Neurol Phys Ther. 2009;33(3): 136–43. [PMID:19809392] http://dx.doi.org/10.1097/NPT.0b013e3181b51307
33. Cowley A, Kerr K. Amputees and tightropes: A pilot study to measure postural control post-amputation. Phys Ther Rev. 2001;6:5–15. http://dx.doi.org/10.1179/108331901786161618
34. Grace Gaerlan M, Alpert PT, Cross C, Louis M, Kowalski S. Postural balance in young adults: The role of visual, vestibular and somatosensory systems. J Am Acad Nurse Pract. 2012;24(6):375–81. [PMID:22672489] http://dx.doi.org/10.1111/j.1745-7599.2012.00699.x
35. Kristinsdottir EK, Baldursdottir B. Effect of multi-sensory balance training for unsteady elderly people: Pilot study of the “Reykjavik model”. Disabil Rehabil. 2014;36(14): 1211–18. [PMID:24066849] http://dx.doi.org/10.3109/09638288.2013.835452
36. Hazime FA, Allard P, Ide MR, Siqueira CM, Amorim CF, Tanaka C. Postural control under visual and proprioceptive perturbations during double and single limb stances: Insights for balance training. J Bodyw Mov Ther. 2012;16(2):224–29. [PMID:22464121] http://dx.doi.org/10.1016/j.jbmt.2011.02.003
37. Vrieling AH, van Keeken HG, Schoppen T, Otten E, Hof AL, Halbertsma JP, Postema K. Balance control on a moving platform in unilateral lower limb amputees. Gait Posture. 2008;28(2):222–28. [PMID:18207407] http://dx.doi.org/10.1016/j.gaitpost.2007.12.002
38. Dillingham TR, Pezzin LE, MacKenzie EJ. Incidence, acute care length of stay, and discharge to rehabilitation of traumatic amputee patients: An epidemiologic study. Arch Phys Med Rehabil. 1998;79(3):279–87. [PMID:9523779] http://dx.doi.org/10.1016/S0003-9993(98)90007-7
39. Sauter CN, Pezzin LE, Dillingham TR. Functional outcomes of persons who underwent dysvascular lower extremity amputations: Effect of postacute rehabilitation setting. Am J Phys Med Rehabil. 2013;92(4):287–96. [PMID:23291599] http://dx.doi.org/10.1097/PHM.0b013e31827d620d
40. Gailey RS, Gaunaurd IA, Raya MA, Roach KE, Linberg AA, Campbell SM, Jayne DM, Scoville C. Development and reliability testing of the Comprehensive High-Level Activity Mobility Predictor (CHAMP) in male servicemembers with traumatic lower-limb loss. J Rehabil Res Dev. 2013;50(7): 905–18. [PMID:24301428] http://dx.doi.org/10.1682/JRRD.2012.05.0099

Submitted for publication November 3, 2013. Accepted in revised form July 31, 2014.

This article and any supplementary material should be cited as follows:
Wong CK, Chen CC, Benoy SA, Rahal RT, Blackwell WM. Role of balance ability and confidence in prosthetic use for mobility of people with lower-limb loss. J Rehabil Res Dev. 2014;51(9):1353–64.
http://dx.doi.org/10.1682/JRRD.2013.11.0235

ResearcherID/ORCID: Christopher Kevin Wong, PT, PhD: L-5051-2013