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Fall Prevalence and Contributors to the Likelihood of Falling in Persons With Upper Limb Loss

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Abstract

Background.—Arms are important for locomotor stability and preventing falls by controlling whole-body angular momentum, redirecting the body's center-of-mass, and providing support to arrest descent. Hence, upper limb loss (ULL) may increase fall risk. Unfortunately, prevalence of falls and factors that influence fall risk have not previously been reported for people with ULL.

Objective.—This study quantified fall prevalence in persons with ULL at or proximal to the wrist and identified clinical factors that contributed to the likelihood of falling.

Design.—This was a cross-sectional study.

Methods.—Factors including body and health characteristics, activity level, fall history, prosthesis use, and balance confidence were collected on persons with ULL proximal to the wrist using an online survey. Logistic regression analyses assessed the contribution of these factors to the classification of fallers (≥ 2 falls in previous year) and non-fallers.

Results.—A percentage (28.6%) of participants (n = 105) reported experiencing two or more falls in the past year. The regression model ($R^2 = 0.473$) correctly classified 84.5% of cases and indicated that increased likelihood of falling was significantly influenced by lower balance confidence, use of upper limb prostheses, and lower physical capabilities.

Limitations.—Data were collected online from a convenience sample and fall classification was based on retrospective data.

Conclusions.—Falls in persons with ULL are prevalent, suggesting that clinicians should use screening methods to identify at-risk individuals. Balance confidence, use of upper limb prostheses, and perceived physical capabilities may be useful screening metrics. Research is warranted to better understand the factors that underlie fall risk in persons with ULL and efficacy of therapeutic interventions capable of mitigating fall risk.

Keywords

Accidental Falls; Prostheses and Implants; Balance; Anatomy: Upper Extremity: Arm

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Disclosure

The authors completed the ICJME Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

Introduction

Arm mechanics play an important role in dynamic stability of bipedal locomotion, defined as the ability to maintain balance following a postural disturbance¹. Arm swing that is synchronized in an anti-phase pattern with leg swing during steady-state walking minimizes whole-body angular momentum (WAM) by counterbalancing leg-generated angular momentum^{2,3}, which has been suggested to aid dynamic stability^{4,5}. Accordingly, arm swing restraint of non-impaired adults during walking appears to alter temporal-spatial gait parameters⁶⁻⁸ and interrupt natural pelvic-thoracic motion^{7,8}. Although there is some indication that arm swing restraint may have a minimal or even negative effect on steady-state gait stability⁹⁻¹¹, increasing evidence suggests that dynamic stability can be enhanced by exaggerating natural arm swing^{9,10,12}. As such, unilateral arm swing restriction in healthy adults tends to elicit increased contralateral arm swing as a compensatory means to maintain upper and lower body coordination¹³. Bilateral arm swing restriction also increases the metabolic cost of walking^{2,6,14} which could impair stability and increase fall risk through inducing physical fatigue^{5,15,16}. The benefits of arm swing to locomotor stability and efficiency extend to running as well¹⁷.

Given the role of arm swing to stability to steady-state locomotion, it is reasonable that reactive arm mechanics are crucial when responding to a perturbation and avoiding a fall. For successful recovery, the body center-of-mass (BCoM) and its associated velocity must be redirected efficiently and effectively towards a stable base-of-support¹⁸. Arm reactions contribute to recovery success through manipulations of the BCoM dynamics and segmental inertial properties for controlling WAM^{11,19-22}. After someone experiences a perturbation during walking their arms often elevate and/or move forward rapidly, with the shoulder muscles activated almost simultaneously with lower limb muscles^{19,21-23}. For example, the arms move forward during a slip to shift the BCoM anteriorly^{19,23}, and upward and laterally during a trip to delay angular momentum transfer and possibly elevate the BCoM to provide sufficient time for an appropriate recovery step^{20,21}. When also considering evidence suggesting the neural coupling of upper and lower limb muscle activations²⁴, it is perhaps not surprising then that reactive lower extremity muscle activity following a walking perturbation has been observed to increase when the arms are restricted, likely as a form of postural control compensation²⁵. Even when walking over an irregular surface, lateral arm swing velocity increases as a possible means to more rapidly redirect the BCoM²⁶. Moreover, arresting a fall with outstretched arms is a commonly employed strategy to avoid bodily injury^{27,28}. These descriptions clearly highlight the importance of arm dynamics to stability and preventing injury to the body resulting from a fall. Such injuries are a considerable economic burden^{29,30} and can lead to long-term diminished quality of life^{30,31}.

The importance of natural and responsive arm dynamics to efficient and safe ambulation has significant implications for persons with upper limb loss (ULL). Individuals with ULL who have lost the musculature for producing rapid and controlled arm movements to aid postural control might be at a higher risk of falling. Additionally, the mass and inertial characteristics of upper limb prostheses may not match intact limbs³², thereby impairing stability mechanisms associated with redirecting the BCoM and controlling WAM. The few biomechanics studies on individuals with unilateral ULL have noted that loss of part or all of

an arm creates asymmetric posture during walking and standing^{32,33} and that walking without a prosthesis generates increased contralateral arm swing³². This suggests an influence on stability given the noted contributions of these dynamics to postural control. The impact of ULL on stability would be distinct to that of lower limb loss, of which evidence already exists characterizing the detrimental impact of lower limb loss on postural control^{34–38}. There is also evidence that walking and standing behavior is affected by the type of upper limb prosthesis³² and user embodiment of their device³³, which can influence whole-body internal models that direct motor responses to a postural disturbance³⁹. Poor upper limb prosthetic embodiment has been shown to impair postural control³³, suggesting that particular model updates to account for prosthesis use may impair stability. Moreover, whether an individual with ULL is wearing an upper limb prosthesis or not, they may lack the ability to quickly grasp or support themselves to arrest a fall. However, while non-users may be more conscious of their upper extremity functional capabilities, upper limb prosthesis users may be at greater risk of a fall if the prosthesis is used to redirect the BCOM and limb trajectories following a disturbance (eg, grasping, supporting) when the device is not intended for that purpose. Overall, use of an upper limb prosthesis may ultimately increase fall risk by generating a destabilizing effect as dynamics of the impaired limb are maladapted for aiding balance regulation (ie, causing a departure from rather than convergence on a correction for balance recovery).

Given the importance of the arm dynamics to stability, it is surprising that no studies have reported the prevalence of falls in persons with ULL or sought to better understand factors that influence the likelihood of falls. Quantifying fall prevalence will help identify if this health hazard poses a considerable threat to persons with ULL, and if clinicians should apply interventions to minimize the risk of falls and fall-related injuries. Importantly, identifying clinically-relevant factors related to falls in persons with ULL may provide insight into useful methods for screening and treating at-risk patients. The purpose of this study was to investigate fall prevalence and clinical factors that may contribute to faller classification in persons with major ULL (at or proximal to the wrist). Given the expectation that falls would be prevalent in people with ULL, we sought to understand which factors most influenced the odds of falling. We hypothesized that use of a prosthesis increases the likelihood of experiencing a fall as device users may deploy motor responses to postural disturbances that are inadequate for regaining balance, including using their device for body support to arrest a fall, and the prosthesis itself may provide a postural disturbance if not adequately embodied.

Methods

The study design was a cross-sectional observation which collected quantitative data on individuals with ULL. Data on body and health characteristics, upper and lower limb loss characteristics (number, level, etiology, time since ULL), activity level, fall history and surrounding circumstances, upper limb prosthesis use (type and indoor/outdoor activities of use), and balance confidence were collected through a 35 multiple-choice, English-language online survey (SurveyMonkey, Palo Alto, CA, USA) between April 2016 and January 2017 (Appendix). Research participants were permitted to skip any question by selecting “I prefer not to answer” and provide write-in responses when the “other” option was available.

Participants were required to be at least 18 years of age with limb loss at or proximal to the wrist, and accessed the survey through the web address that collected data anonymously. Recruitment involved advertisements on listservers frequented by individuals with ULL and their care providers, as well as clinicians and institutions that provide prosthetics services and educational programs in prosthetics. The study was approved by the Northwestern University Institutional Review Board and participants provided informed consent prior to answering the questions. To estimate an adequate sample size for this observation study, a power analysis was conducted to identify the minimum number of participants that would be classified as fallers based on random sampling⁴⁰. Using a conservative estimate of 50% for the proportion of the population of persons with ULL classifying as a faller, a confidence level of 95%, and a margin of error of 10%, the estimated minimal sample size was 96 persons.

A fall was defined to participants as “coming to rest accidentally on the ground or other lower level, other than as a consequence of lost consciousness, a violent blow, stroke, or epileptic seizure”⁴¹. The definition was similar to that used for studies capturing fall frequency in persons with lower limb loss (LLL)^{42,43}. Participants were asked how many falls they experienced in the past twelve months. With regard to their most recent fall, participants were asked to describe: if they were injured and surrounding circumstances including perceived cause. Inspired from initial pilot testing, details on only the most recent fall were requested to minimize participant burden and increase the rate of complete responses. Participants also completed the Activities-specific Balance Confidence (ABC) Scale⁴⁴; a 16-item self-report questionnaire quantifying perceived levels of balance confidence (0 to 100%) when executing various activities of daily living. This instrument possesses high levels of validity and reliability in patient groups prone to unsteadiness^{44–47} including community-dwelling lower-limb prosthesis users⁴⁸. There is strong evidence suggesting ABC scores are related to fall risk in multiple populations^{45,49–54}. To capture information on perceived functional level, participants were also asked to rate their physical capabilities using a question adopted from the Trinity Amputation and Prosthesis Experience Scales: “In general, how would you say your physical capabilities are?”⁵⁵ Responses were scored on a five-point ordinal scale (very good, good, fair, poor, or very poor). Similarly, participation in physically demanding activity was captured using a single question with evidenced high levels of validity and reliability in able-bodied individuals: “In the past week, on how many days have you done a total of 30 minutes or more of physical activity, which was enough to raise your breathing rate? This may include sport, exercise, and brisk walking or cycling for recreation or to get to and from places, but should not include housework or physical activity that may be part of your job”^{56,57}.

Statistical Analysis

Following a check for missing data, data were coded and then summary statistics were prepared. Falls were classified as either extrinsic (environment related) or intrinsic (eg, loss of balance) based on the taxonomies defined by Lach et al. for older adults.⁵⁸ Participants could select more than one factor (see Appendix), but the fall was classified as extrinsic or intrinsic if only extrinsic (external force, slipping, tripping) or intrinsic (loss of balance, dizziness, fatigue or tiredness, feeling ill, prosthesis detached, failed to arrest with arms or

legs) factors were selected, respectively. Falls were classified as intrinsic if surrounding circumstances involved both intrinsic and extrinsic factors. The intrinsic factor *loss of balance* refers to a generalized condition considered separate to the other factors.

To identify the effects of clinically-relevant factors on the likelihood on being classified as a faller, a binomial logistic regression analysis was conducted. The binary dependent variable was faller classification: faller (≥ 2 falls in the past twelve months), non-faller (< 1 fall in the past twelve months). For this study, a faller was defined by two or more falls as frequent faller status may be indicative of a systemic issue and the purpose of this investigation was to assess variables that influenced the odds of falling and may warrant further attention to better characterize factors that underlie falls in this cohort. Specifically, frequent falls in older adults “have been associated with greater physician contact, functional decline, admission to long-term care facilities, and mortality”⁵⁹. Moreover, sensory-motor function (eg, reaction time, body sway, quadriceps strength, proprioception, cadence, and stance time) have been found to be similar for older ‘single fallers’ and non-fallers (assessed 12 months prospectively), but significantly worse for multiple fallers^{60,61}. Prevalence data for single falls is also provided to aid with comparison of these results to literature on falls in other patient groups.

A two-stage process was used to conduct the logistic regression analysis to minimize the number of independent variables included in the final model. This process has been effectively employed in a similar study on logistic regression analysis of fall classification of community-living persons with lower limb loss⁶² and is advocated as a systematic process to building multiple variable regression models⁶³. The first step involved conducting a binomial regression analysis with faller classification (ie, fallers and non-fallers as previously defined) as the dependent variable but using only a single independent variable. Independent variables were only considered for the multiple variable regression analysis if they were a statistically significant contributor to the dependent variable at a critical α level of 0.2. This α level was selected to screen potential candidate contributors to fall classification for further inspection in the full regression model⁶³, and is also in accordance with the similar study for lower limb loss⁶². The analysis used available data for the independent variables of interest that could potentially influence falls: gender (male/female), age (years), body mass index (BMI = weight (kg)/height (m) squared), physical activity (days), presence of LLL (yes/no), balance confidence (ABC score), time since most recent major ULL (years), use of an upper limb prosthesis inside or outside of home (yes/no), ULL etiology (congenital/other), most proximal level of ULL (above/below elbow), and physical capabilities (very poor to fair/good or very good). Presence of LLL was considered in this analysis as participants with ULL may also experience LLL due to the nature of their pathology, and persons with LLL experience a high prevalence of falls^{42,43,62}. Importantly, inclusion of individuals with ULL and LLL enhanced generalizability and clinical relevance of study results given that individuals with such polytrauma represent a relevant subset of persons with ULL that seek prosthetics care, especially for Veterans and Service Members⁶⁴, and so this variable was controlled for in the analysis. Variables of ULL etiology, ULL level, and physical capabilities were reduced to binary variables given the number of factors and sample size required to adequately power the statistical analysis.

Independent variables that reached α of 0.2 were then used for the binomial multiple variable logistic regression analysis. Several test assumptions were assessed: (1) absence of multicollinearity (ie, high correlations) amongst independent variables, (2) linear relationships between continuous independent variables and the logit transformation of the dependent variable, and (3) presence of outliers. Multicollinearity was assessed through computation of the Variance Inflation Factors (VIFs) for each variable, where a value equal to or greater than 10 was considered evidence of multicollinearity⁶⁵. The Box-Tidwell method⁶⁶ was used to evaluate linear relationships between the continuous independent variables and the logit transformed dependent variable, with a Bonferroni correction applied to the critical α of 0.05 based on the number of terms in the model analysis⁶⁷. Outliers were identified as those samples with studentized residuals greater than ± 2 standard deviations, and further inspected to assess if their removal was justified based on any unique participant characteristics. The final regression model was assessed for goodness of fit using the Hosmer and Lemeshow test⁶⁸, and variance explained by estimating the Nagelkerke R^2 value⁶⁹. Classification accuracy, sensitivity, specificity, positive predictive value, and negative predictive value were also calculated. The critical α applied to the final regression model was set at 0.1. This value is reduced from 0.2 as applied to the single variable analysis to be a more conservative but recommended approach to evaluating statistical significance⁶³ and is also in accordance with the similar study on lower limb loss⁶². However, all p-values were reported to aid with results interpretation. All statistical analyses were conducted using SPSS (v24, IBM Corp, Armonk, New York, USA).

Role of the Funding Source

The US Department of Veterans Affairs supported effort on this study as part of a Career Development Award (CDA-2). Northwestern University funded hosting of the online survey.

Results

A total of 109 persons responded to the survey. Summary statistics of participant characteristics and outcome measures are displayed in Table 1. These data match well with recent cross-sectional survey-based studies of individuals with ULL^{70,71}, although notably this cohort contained a more balanced sample of gender (male, female) and etiology (congenital, acquired) and included individuals who on average had limb loss for longer. Of those who responded to the falls questions ($n = 105$), 28.6% of participants reported two or more falls in the past year (45.7% experienced at least one fall). With knowledge of the effects of lower limb loss on fall likelihood⁶², if individuals with both upper and lower limb loss ($n = 14$) are excluded from the analysis then 22.0% of participants reported two or more falls in the past year (40.7% experienced at least one fall). For those who reported falls and responded to questions on injuries ($n = 41$), 31.7% indicated that their most recent fall resulted in injury with 14.6% requiring medical attention or a hospital visit (or 30.0% and 13.3%, respectively, if excluding subjects with both upper and lower limb loss). Figures 1 and 2 display the proportion ($n = 44$) of activities during which the most recent fall occurred and the intrinsic and extrinsic factors of the fall, respectively. Accordingly, the most recent reported falls were categorized as 54.6% intrinsic and 45.5% extrinsic.

Regarding the first stage of the regression analysis, seven of the original eleven independent variables satisfied the criterion: BMI ($p = .056$), physical activity ($p = .161$), presence of LLL ($p < .001$), ABC score ($p < .001$), time since ULL ($p = .148$), use of an upper limb prosthesis ($p = .048$), and physical capabilities ($p < .001$). After removing incomplete records, 84 cases included complete data suitable for the regression analysis (Fig. 3). The final logistic regression model containing these seven variables satisfied the assumptions of an absence of multicollinearity (VIF = 1.710) and all continuous independent variables were found to be linearly related to the logit transformation of the dependent variable using the Box-Tidwell method and adjusted α of 0.013 ($p = .039$). Five outliers were identified (studentized residuals between 2.147 and 3.275), but these data were kept in the analysis as removal was not justified because: 1) these participants did not possess unique qualities relative to the group mean, and 2) excluding these data did not considerably change the model outcome.

The final model ($n = 84$, $\chi^2(7) = 33.256$) to classify fallers and non-fallers was statistically significant ($p < .001$), correctly classified 84.5% of cases, and explained 47.3% of the data variance (Nagelkerke R^2). Regarding model diagnostics, sensitivity was 60.9%, specificity was 93.4%, the positive predictive value was 77.8%, and the negative predictive value was 86.4%. For context, the sensitivity and specificity of the regression model to classify fallers amongst persons with lower limb loss in the seminal study by Miller et al, 2001,⁶² was 69.3% and 63.3%, respectively. The Hosmer and Lemeshow test suggested that the model was a good fit ($p = .78$). Three of the seven variables in the model were significant (Tab. 2): ABC Score ($p = .021$), use of an upper limb prosthesis ($p = .027$), and perceived physical capabilities ($p = .03$). Accordingly, increased likelihood of being classified as a faller was associated with lower balance confidence, use of an upper limb prosthesis, and low perceived physical capabilities. Although some independent variables demonstrated relatively large Odds Ratios (Tab. 2), their level of variability rendered these effects non-significant. To engender confidence in the results, a second regression model was analyzed after subjects with upper and lower limb loss and the variable of lower limb loss presence were excluded. Results from this second regression model ($n = 71$, $\chi^2(7) = 26.715$, 46.8% of data variance explained, $p < 0.001$) were similar to the original model but with two of six variables significant: ABC Score ($p = .022$, $\beta = -0.058$) and use of an upper limb prosthesis ($p = .005$, $\beta = 3.217$). Based on these results and given the enhanced generalizability of inclusion of polytrauma subjects while controlling for the influence of lower limb loss, it was decided that the original model was an appropriate approach for this analysis.

Discussion

The objectives of this study were to quantify the prevalence of falls in persons with ULL and identify contributions of factors to the likelihood of frequent falling. The expectation that individuals with ULL at or proximal to the wrist would demonstrate an elevated falls prevalence was supported, as nearly a third of participants fell twice or more in the past year and almost half experienced at least one fall. This prevalence of a single fall is above that reported for older individuals (33%)^{30,31} and community-living stroke survivors (about 40%)^{72,73}, and is comparable to that of community-living individuals with major (ie, proximal to the ankle) LLL with a mean age greater than this study (52%)⁶². This result has

considerable clinical importance as it suggests presence of a critical health hazard for individuals with ULL.

The results suggest that the majority (70%) of falls in persons with ULL can be categorized as trips, slips, and loss of balance, and occur primarily while walking outdoors and negotiating stairs. The majority of falls were categorized as intrinsic (55%) including those that also involved an extrinsic factor, and this is partially due to the high prevalence of participants reporting that the fall resulted from a generalized loss of balance. These results provide some insight into the means by which persons with ULL could undergo targeted physical therapy to enhance postural control and minimize fall risk. Similar therapeutic paradigms which have been developed and effectively address trip recovery in the elderly⁷⁴ could potentially be implemented among people with ULL. Given the essential role of arm dynamics to locomotor stability as described previously, exposure to balance-targeted therapies would encourage persons with ULL to explore and refine their motor response to perturbations and enhance overall stability. Further research is warranted to better understand the biomechanical and motor control factors that underlie stability in persons with ULL. As the majority of falls were the result of intrinsic factors, research should focus on identifying modifiable factors that can be addressed by therapists in both clinical and home environments (eg, muscle strength, coordination).

Interestingly, 46.2% of injurious falls required medical attention (44.4% if excluding subjects with upper and lower limb loss) which is equivalent to the proportion observed in persons with only LLL who fall⁶². This result seems reasonable given that bodily harm may not be as readily avoided without using arms to arrest or control a fall. Indeed, 10% of falls reported in this study were due in part to this inability (Figure 2). Given the implications of these findings to healthcare costs and quality of life²⁹⁻³¹, it seems imperative that clinicians consider both upper extremity functional capabilities of these individuals and their risk to falls. Monitoring these patients during rehabilitation would help create awareness of this health concern, and identify individuals at risk of falling in the community who could benefit from intervention. Furthermore, a recent study assessed risk factors of fall-related injuries in persons with LLL to inform intervention programs⁷⁵, and similar research on persons with ULL seems warranted based on these results.

Contributors to faller classification (2 falls in the past year) identified in this study appeared reasonable, given relationships between these variables and health and mobility established in other studies. Although not significant contributors to the final model which accounts for shared variance and confounding influences, several variables were significant in the single variable analysis at an α of 0.2: BMI, physical activity and LLL. Increased BMI and decreased physical activity increased the likelihood of faller classification. Both factors suggest improved general health status and have demonstrated relationships with lower fall risk⁷⁶⁻⁷⁸. Although reasonable to believe that participation in physical activity may expose individuals to fall hazards, in a controlled environment it could also serve as a vehicle for improving cardiovascular fitness, muscle strength, and coordination to help improve balance and reduce falls⁷⁹. Finally, given the elevated prevalence of falls in persons with LLL⁶², it is not surprising that presence of this condition would contribute to the likelihood of falling in

people with ULL. The finding that these factors were not influential in the final model suggests that further research is needed to explore their true impact on fall likelihood.

In this study, participants with positive perceived physical capabilities and higher balance confidence had reduced likelihood of being classified as a faller. General physical capability was quantified in this study through a simple ordinal scale rating, but remarkably suggested that persons with ULL had much lower odds of being classified a faller if an individual perceived their capability positively (Tab. 2). Positive perceived physical capability would suggest better functional mobility⁵⁵ and, as with higher balance confidence, has been associated with reduced fall risk in those with Parkinson's disease⁸⁰, multiple sclerosis⁸¹, and of older age⁸². Importantly, as ABC score has demonstrated relationships with fall risk in multiple patient groups^{45,49–54}, this measure may hold particular clinical value. Overall, these results and consistent evidence of a relationship between balance confidence and falls suggest that monitoring the construct of perceived functional capabilities in persons with ULL could help identify at-risk individuals. The self-report measures used in this study have the advantage of ease-of-administration in clinical environments. However, use of the ABC as a screening instrument is cautioned prior to additional psychometric evaluation in this patient group to fully understand its clinical utility (eg, establishing cut-off scores to classify fallers). Additionally, research is needed to understand the nature by which high balance confidence lowers falls likelihood. Moreover, these results do not identify causal effects (eg, if better perceived capabilities are responsible for reduced fall likelihood or vice-versa) and these findings should be interpreted accordingly.

In support of the primary hypothesis, persons with ULL had nearly 6 times higher odds of being classified as a faller if they reported use of an upper limb prosthesis (Tab. 2). This hypothesis was based on the concept of deploying an inadequate or maladapted motor response to a postural disturbance which generates a further destabilization rather than a correction for balance recovery. First, it is understood that prosthesis users do not use their device, or the same device, for every activity and throughout the entirety of the day⁸³. Consequently, their whole-body internal model must be updated to account for device use. This behavior is in contrast to individuals who never wear a prosthesis and do not require periodic model updates specific to a prosthesis. Given evidence to suggest that a poor sense of prosthetic embodiment may impair postural control³³, it may be that device use results in development of an inaccurate whole-body internal model which is critical for deploying an appropriate perturbation response³⁹ (eg, controlling WAM and redirecting the body BCoM^{11,19–22}). Second, it is possible that some prosthesis users attempt to use their device for supporting their body to arrest a fall (eg, outstretched arm, grasping an object). Such a response may be risky for commonly-prescribed devices not intended for this purpose and hence result in a failed recovery or additional injury. Overall, the body system must account for presence of the prosthesis to optimize motor responses to a postural disturbance, and this could be encouraged through the balance-targeted physical therapies such as those recommended for lower limb prosthesis users⁸⁴. Further research is warranted to better understand the factors that underlie the relationship between upper limb prosthesis use and the likelihood of falling to direct interventions for maximizing stability. It is important to recognize that this finding does not suggest upper limb prostheses should not be prescribed or used, as these devices facilitate participation in a wide range of work, recreational, and

domestic activities. Given this utility, there are no grounds to ethically deny people with ULL a prosthesis based on this research.

There are several key study limitations that should be considered when interpreting the results. First, these data were collected from participants who had ability to access and operate a computer. This methodology may explain why the sample was biased toward younger individuals and those with unilateral ULL. However, this protocol eased recruitment challenges for generating a sufficient sample size which satisfied results of the power analysis. Additionally, the participants were on average many years since limb loss and may have masked a true effect of this variable on falls likelihood. Moreover, due the recruitment methods, participants who experienced falls may have been more interested in completing the survey, thereby increasing the number of fallers. Second, fall classification was based on prior experiences and may suffer from recall bias. This methodology for collecting fall information is common⁶², but would be less reliable than data collected prospectively. However, studies in the elderly suggest that recall periods of 12 months may be equally as accurate as more recent time periods⁸⁵. Third, the decision to collect details of only the most recent fall was made to minimize participant burden and facilitate data collection but may have biased the results as some falls were not classified. The characterization results should therefore be interpreted accordingly. Fourth, although falls were classified based on past occurrence, many of the independent variables (eg, BMI, balance confidence) were quantified based on the participant status at the time they completed the survey. Consequently, as with any regression modelling, these results are not evidence of causal relationships. Finally, the regression model did not include interaction terms due to insufficient evidence suggesting their inclusion especially when considering limitations imposed by the sample size. Based on these limitations, it is recommended that future work consider: (1) alternative recruitment efforts and data collection techniques for obtaining a more generalizable sample to enhance validity, (2) prospective fall data collection to enhance reliability, and (3) inclusion of regression model interactions to assess the influence of such terms on fall classification.

Conclusion

In conclusion, this study suggests that nearly a third of persons with ULL experience two or more falls within a year and almost half fall at least once. This finding suggests that factors that underlie falls in persons with ULL warrant further investigation, including studies on the utility of therapeutic interventions aimed at maximizing postural control. Importantly, these results suggest that individuals with ULL may benefit from monitoring by clinicians to identify those at risk of falling. As lower balance confidence, low perceived physical capabilities, and use of an upper limb prosthesis were significant contributors to an increased likelihood of falling, these characteristics may be useful for screening and should be validated through future prospective studies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Presentations

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Figure 1.
Proportion of activities occurring during participants' most recent fall.

Figure 2.

Proportion of intrinsic and extrinsic factors of participants' most recent fall. Sections referring to extrinsic factors (slipping, tripping, and external force) are shaded.

Figure 3. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) flow diagram.

Table 1.

Participant Characteristics and Outcome Measure Results.

Characteristic	Average $\pm$ St. Dev. [Range]	n	Missing n
Age (y)	43 $\pm$ 17 [18–82]	98	7
Weight (kg)	77.8 $\pm$ 26.2 [36.3–181.4]	93	12
Height (m)	1.71 $\pm$ 0.14 [1.02–1.96]	97	8
Time since upper limb loss (y)	28.5 $\pm$ 20.1 [$<$ 1–79]	98	7
Physical activity (d in last wk)	3.6 $\pm$ 2.0 [0–7]	91	14
	Median [Interquartile Range]	n	Missing n
ABC score (0–100%)	95 [79.5–100]	92	13
	Category	n	Missing n
Sex	Male	50	7
	Female	48	
Upper limb loss etiology ^a	Congenital	47	7
	Other	51	
Number of upper limbs with loss	Unilateral	82	7
	Bilateral	16	
Most proximal upper limb loss level	Through-elbow or proximal	66	7
	Below elbow	32	
Presence of lower limb loss ^b	Yes	14	7
	No	84	
Physical Capabilities	Very poor to Fair	21	13
	Good or Very good	71	
Type of upper limb prosthesis used inside and/or outside the home	Do not own or use a prosthesis	42	11
	Cosmetic	17	
	Body powered	19	
	Externally (electric) powered	22	
	Hybrid (Body + Externally powered)	1	
	Passive with terminal device	6	
	Sport and/or recreation	10	

^aEtiologies which formed the “Other” category included cancer/tumor (n = 5), accident/trauma (n = 42), and infection (n = 6).

^bLower limb loss is inclusive of partial foot (n = 2), transtibial (n = 5), transfemoral (n = 7), knee disarticulation (n = 1), and hip disarticulation (n = 2) levels.

Table 2.Statistical Results of the Binary Multiple Variable Logistic Regression Model. ^a

Independent Variable	β Coefficient	SE	df	p-value	Odds Ratio	95% CI
<i>BMI</i>	0.041	0.043	1	0.341	1.041	0.958–1.132
<i>Physical activity</i>	−0.039	0.157	1	0.803	0.962	0.707–1.307
<i>Presence of lower limb loss</i>	1.140	0.945	1	0.228	3.125	0.491–19.912
<i>ABC score</i>	−0.048	0.021	1	0.021	0.953	0.915–0.993
<i>Time since upper limb loss</i>	0.007	0.017	1	0.671	1.007	0.975–1.040
<i>Use of an upper limb prosthesis</i>	1.760	0.798	1	0.027	5.814	1.217–27.783
<i>Physical capability</i>	−1.507	0.693	1	0.030	0.222	0.057–0.862

^aSE = standard error; df = degrees of freedom; CI = confidence interval.