ORIGINAL ARTICLE

Community activity and participation are reduced in transtibial amputee fallers: a wearable technology study

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ABSTRACT

Wearable technology is an important development in the field of rehabilitation as it has the potential to progress understanding of activity and function in various patient groups. For lower limb amputees, falls occur frequently, and are likely to affect function in the community. Therefore, the purpose of this study was to use wearable technology to assess activity and participation characteristics in the home and various community settings for transtibial amputee fallers and non-fallers. Participants were provided with an accelerometer-based activity monitor and global positioning system (GPS) device to record activity and participation data over a period of seven consecutive days. Data from the accelerometer and GPS were linked to assess community activity and participation. Forty-six transtibial amputees completed the study (79% male, 35% identified as fallers). Participants with a history of falls demonstrated significantly lower levels of community activity (p=0.01) and participation (p=0.02). Specifically, activity levels were reduced for recreational (p=0.01) and commercial roles (p=0.02), while participation was lower for recreational roles (p=0.04). These findings highlight the potential of wearable technology to assist in the understanding of activity and function in rehabilitation and to further emphasise the importance of clinical falls assessments to improve the overall quality of life in this population.

INTRODUCTION

The use of wearable technology is an important development in the field of rehabilitation. The ability to remotely monitor activity can provide rehabilitation clinicians with accurate objective data, otherwise unobtainable and difficult to replicate in a clinic setting. Global positioning system (GPS) devices, a form of wearable technology, have recently gained popularity as a method to monitor the locations visited, and participation in the community for various patient groups including amputees,[1 2] stroke,[3 4] multiple sclerosis[5] and following orthopaedic surgery.[6–8] The use of GPS was found to be a feasible and reliable method of collecting community visit data with greater accuracy than self-reported travel diaries.[3] GPS devices have primarily been used to identify community visits out of home,[1 3 4 7] or speeds and distances travelled.[5 6] While some studies supplemented GPS devices with accelerometers to assess activity in greater depth,[1 2 4 7 8] few have successfully linked data from these two wearable technology devices to provide detailed information on activity in various community locations.[1 2] One of these studies obtained step count and location data for a single transfemoral amputee over a month, demonstrating the capacity to reliably obtain data over extended periods.[1] A larger study demonstrated that data obtained from linked wearable technology may better differentiate functional abilities of transtibial amputees than current clinical assessments.[2] For these studies which have linked data from wearable technology, a greater understanding of activity and participation was obtained with relatively little data loss associated with the use of GPS. Activity and participation are important domains of the International Classification of Functioning, Disability and Health,[9 10] and characterising community activity and participation would most likely enhance an understanding of amputee rehabilitation and reintegration. The potential of wearable technology to expand the understanding of activity and participation should be investigated.

Wearable technology has previously been used to identify that transtibial amputees achieve relatively low levels of community activity and participation.[2] Deciphering the implications of reduced activity and participation levels may be important in this population. For older adults, experiencing a fall, or fear of falls, has been linked to reduced functional mobility, a decline in independence and self-imposed restriction of community activity.[11–13] This is yet to be objectively investigated in lower limb amputees, but given the high incidence of falls experienced by amputees,[14] it is plausible that reduced community activity and participation may be related to falls. Identifying potential relationships between falls and community activity and participation in lower limb amputees would highlight the importance of clinical falls assessments and further demonstrate the importance of wearable technology as an objective assessment of community integration. Therefore, the purpose of this study was to use wearable technology to assess activity and participation characteristics in the home and various community settings for transtibial amputee fallers and non-fallers. We hypothesised that amputees with a history of falls would have lower levels of community activity and participation.

METHODS

Participants

Forty-seven rehabilitated unilateral transtibial amputees were recruited from a metropolitan prosthetics service in Adelaide, South Australia. All participants were fitted with a definitive prosthesis at least 6 months prior to recruitment. The prosthetic fit and comfort were confirmed with the participant and their prosthetist prior to inclusion in the study. Participants were eligible if they achieved prosthetic mobility, and those not provided with a prosthesis for mobility were excluded. Ethical approval was provided by the Southern Adelaide Clinical Human Research ethics committee and all participants provided written informed consent in accordance with the Declaration of Helsinki.

Equipment

Participants were provided with an accelerometer-based activity monitor and GPS device to record activity and participation data over a period of seven consecutive days. The StepWatch3 Activity Monitor (SAM) (Cyma Corp, Seattle, Washington, USA) is a commercially available step counter, which has previously been validated for use in people with lower limb amputations.[15] The SAM is an accelerometer-based and microprocessor-based activity monitor measuring 6.5 cm×5.0 cm×1.5 cm. It was attached to the participant's prosthesis in accordance with the manufacturer's recommendations. The SAM was set to record the stride count data at 1 min intervals for a period of seven consecutive days. Step count data were obtained by multiplying the stride count by 2. Data from the SAM were downloaded using StepWatch software (V.3.1b) and stored within the software database.

Participants were also provided with a commercially available QStarz BT-Q1000XT (Qstarz International Co, Ltd, Taipei, Taiwan) 66-channel tracking GPS travel recorder. The GPS device recorded the latitude, longitude, local date and time at 5 s intervals for a period of seven consecutive days. The device measures 7.2 cm×4.7 cm×2.0 cm, has a battery life of 42 h and an accuracy error of less than 3 m. Data from the GPS unit were imported to QTravel software (V.1.46) and stored within the software database.

Procedure

Participants attended a single data collection session to provide SAM and GPS devices, and obtain demographics (age, gender and employment status) and clinical characteristics (date of amputation, reason for amputation, stump length, amputee K-level, amputee mobility predictor (AMP-PRO) score and history of falls). Amputee K-levels categorise amputees based on functional ability, with K-1 describing a household ambulator, K-2 a limited community ambulator, K-3 a community ambulator capable of traversing most environmental barriers and K-4 a high functioning and energy level amputee.[16] The AMP-PRO assessment is a functional assessment used to predict amputee function with higher scores (maximum 47) indicating greater function.[16] A retrospective 12-month history of falls was determined with an interview. Falls were defined as an event which caused the participant to end up on the ground or lower surface unintentionally.[17] Participants were classified as fallers (one or more falls in the past 12 months) or non-fallers (no falls in the past 12 months). The SAM and GPS devices were programmed for data collection using separate networked computers. This ensured identical time stamps for each device, assisting the data linkage process. The SAM and GPS devices were secured to the participant's prosthesis with a single Velcro strap (see figure 1), where they remained for the duration of the study period. Participants were supplied with a battery charger and clear written instructions for charging the GPS device nightly.[2] Both the SAM and GPS devices were returned after a minimum of seven complete days of data recordings.

Data linkage

Linkage of SAM and GPS data has been described previously.[2] Briefly, a unique time–date stamp generated for both SAM and GPS data sets was used to merge data to a single data set. This master data set included step count data, latitude, longitude, local date and local time at 1 min intervals for seven consecutive days. Community participation and activity

Figure 1 The StepWatch3 Activity Monitor (SAM) and global positioning system device were attached to a prosthesis. The SAM was attached according to the manufacturer's recommendations of positioning the device slightly above the position of the lateral malleolus.

were analysed from this master data set. Community participation was defined as an event where the participant left their home and attended a location in the community.[10] Locations within the community were analysed by recounting latitude and longitude data in chronological order over the 7-day period within QTravel (V.1.46). QTravel incorporates Google Maps and Google Earth software to provide geographic information. Community visit events were visually identified from this geographic information. If required, verbal confirmation was obtained from participants to ensure accurate identification of community participation. These events were coded as one of seven community participation categories external to the participant's home, and analysed as a continuous variable for each participation category (see figure 2 for a description of categories). Community activity (step count) was assessed as a continuous variable for each participation category. In addition, home activity was calculated as step counts in the home setting.

Statistical analysis

The normality of data was checked with a Shapiro-Wilk normality test, and where assumptions for parametric tests were not met, non-parametric statistics were used. GPS data were initially assessed for completeness by calculating missing GPS data points

Community Participation Categories

Category	Examples
Employment	Paid employment activities
Residential	Housing other than own home
Commercial	Shopping centres, local shops
Health services	Hospital, general practitioner, physiotherapist, chiropractor, pharmacist
Recreational	Oval, sports, beach, walk in community
Social	Restaurant, café, hotel, cinema
Other	Petrol station, council chambers

Figure 2 The seven community categories with examples which were used to assess community activity and participation in transtibial amputee participants.

(%) prior to linkage. Missing GPS data were assessed by comparing the expected number of cells with recorded data (n=120 960) to the observed number of cells with recorded data. As a result of any missing GPS data, missing step count data were calculated in the linked master data set as the difference between step counts in the linked master data set and total step counts from the SAM. Descriptive statistics were used to characterise community activity (steps) and participation (visits) for each community participation category.

Potential contributions to differences in activity and participation between fallers and non-fallers were investigated. Differences in age and stump length for history of fall were investigated with separate independent t tests. Differences in time since amputation and AMP-PRO scores for history of fall were investigated with separate Mann-Whitney U tests. Differences in gender, indication for amputation, K-levels and employment status for history of fall were investigated with separate χ^2 analyses. Activity and participation were compared between amputees with a history of falls and those with no history of falls with separate Mann-Whitney U tests overall, and for each community category. Significance level was set at $p\leq 0.05$ and SPSS software was used for all statistical analyses (IBM corp. Released 2010; IBM SPSS Statistics for Windows, V.19.0, Armonk, New York, USA).

RESULTS

A total of 47 transtibial amputees were recruited to participate in the study. Recruited participants were primarily male (79%), aged 59.7 years (range 19–98) and were 16.2 (SD 18.9) years since amputation. Primary indications for amputation were trauma (38%) or peripheral vascular disease (38%). One was

Table 1 A summary of community activity and participation for each participation category

Community categories	Activity *Step count per day* Median (IQR)	Participation *Community visits per day* Median (IQR)
Employment	1529 (627–4474)	0.7 (0.6–1.9)
Residential	238 (34–593)	0.3 (0.1–0.6)
Commercial	317 (76–946)	0.7 (0.3–1.0)
Health service	10 (0–145)	0.1 (0.0–0.5)
Recreational	0 (0–309)	0.0 (0.0–0.3)
Social	69 (0–221)	0.3 (0.1–0.4)
Other	0 (0–42)	0.0 (0.0–0.1)
Total for community categories	2124 (495–3466)	2.3 (1.3–2.8)
Home	3441 (2047–4976)	–

Employment step count and visit are representative of amputees who were employed (n=15). All other categories were representative of all amputee participants (n=46).

excluded due to incomplete GPS data as a result of failure to charge the GPS battery as required. For the remaining 46 data sets, 6.5% (SD 7.3%) of the expected GPS data were not available due to inadequate satellite signal. These incomplete GPS data resulted in 5.3% (mean 336 steps) of all steps recorded by the SAM not being linked to the GPS latitude and longitude data in the master data set. Fifteen amputees (33%) were employed during the period of data collection. A summary of community activity and participation is provided in table 1.

Sixteen (35%) amputees had reported experiencing a fall in the preceding 12 months. The characteristics of the fallers and non-fallers are summarised in table 2. There were no significant differences between fallers and non-fallers for age, gender, indication for amputation, time since amputation, K-level, AMP-PRO score or stump length (all p>0.08). There was a significant difference for employment status for fallers and non-fallers ($\chi^2_{(1)}$=4.51, p=0.05), as amputees with a history of falls were less likely to be employed (see table 2). There was a significant difference between fallers and non-fallers for commercial activity (U=136.0, z=2.40, p=0.02), recreational activity (U=144.5, z=2.43, p=0.01) and total community activity (U=129.0, z=2.56, p=0.01; see table 3). There were no significant differences between fallers and non-fallers for activity in employment roles, residential, health, social, other or the home setting (all p>0.16; see table 3). There was a significant difference between fallers and non-fallers for recreational participation (U=156.5, z=2.11, p=0.04) and total community participation (U=140.0, z=2.31, p=0.02; see table 4). There were no significant differences between fallers and non-fallers for participation in employment roles, residential, commercial, health, social or other (all p>0.18; see table 4).

Table 2 Demographics and clinical characteristics between fallers and non-fallers

Demographics and comorbidities	Faller (n=16)	Non-faller (n=30)	Statistic, p value
Age (years, mean (SD))	64.4 (13.5)	58.5 (13.3)	0.17
Gender (n (%) male)	10 (63)	26 (87)	0.08
Indication for amputation (n (%))			0.51
PVD	9 (56)	9 (30)	
Trauma	6 (38)	11 (37)	
Other	1 (6)	10 (33)	
Time since amputation (years, mean (SD))	13.2 (19.1)	18.0 (19.2)	0.20
K-level (n (%))			0.13
K-1	1 (6)	0 (0)	
K-2	3 (19)	1 (3)	
K-3	4 (25)	9 (30)	
K-4	8 (50)	20 (67)	
AMP-PRO score (mean (SD))	39.6 (7.2)	43.2 (3.0)	0.23
Stump length (cm, mean (SD))	17.7 (2.6)	16.6 (3.3)	0.29
Employment status (n (%) employed)	2 (13)	13 (43)	**0.05**

Bold text highlights significant difference at p≤0.05 between fallers and non-fallers.
AMP-PRO, amputee mobility predictor; PVD, peripheral vascular disease.

DISCUSSION

This study used linked data from an accelerometer and GPS device to objectively measure community activity and participation over a period of seven consecutive days in a cohort of transtibial amputees. For the first time, the results from this study demonstrate that transtibial amputees with a history of falls have reduced community activity and participation compared to amputees without a history of falls. These results underline the importance of clinical falls assessments and the need to address falls in this population to improve the overall quality of life.

Restoring functional gait and mobility is a key prosthetic rehabilitation goal to ensure that optimal community activity and participation are achieved.[18] However, recent reviews of contemporary rehabilitation services highlight the difficulties and challenges that prosthetic rehabilitation services are facing in achieving this goal.[19,20] Similar to previous studies,[1,2] this study has further demonstrated the potential role that wearable technology devices may play in the assessment of community activity and participation for lower limb amputees. Wearable technology devices, such as the SAM and GPS used here, are likely to be appropriate objective community measures in this population. These devices have the potential to greatly assist clinical amputee prosthetic rehabilitation and serial measures would provide accurate information of the achievement of meaningful goals.

Falls are a significant adverse event and many negative consequences. For example, falls are often associated with institutionalisation, hospitalisation, injury

Table 3 Community activity for fallers and non-fallers, separated by participation categories

Community categories	Activity *Step count per day* Median (IQR) Faller	Non-faller	Statistic, p value
Employment	2753.7 (1033.7–4473.7)	1528.6 (557.6–3334.9)	0.80
Residential	109.9 (8.6–484.8)	287.4 (41.6–635.7)	0.41
Commercial	98.9 (25.1–583.4)	543.4 (230.6–1007.4)	**0.02**
Health	49.6 (0.0–218.9)	2.1 (0.0–126.6)	0.48
Recreational	0.0 (0.0–0.0)	21.7 (0.0–670.7)	**0.01**
Social	72.7 (28.4–182.1)	58.0 (0.0–264.6)	0.76
Other	0.0 (0.0–1.3)	0.0 (0.0–84.3)	0.16
Total community	779.6 (352.8–2598.1)	2738.9 (1608.5–3547.8)	**0.01**
Home	3203.6 (1556.4–5291.6)	3440.6 (2126.3–4795.5)	0.78

Employment step count and visit are representative of amputees who were employed (n=15). All other categories were representative of all amputee participants (n=46).
Bold text highlights significant difference at p≤0.05 between fallers and non-fallers.

and immobilisation and impose a significant cost on the healthcare system.[21 22] For older adults, falls have been linked to decreased mobility, reduced independence, diminished confidence and self-restriction of community activity.[11–13] However, this study advances these findings by demonstrating that a history of falls is associated with reduced community activity and participation for transtibial amputees. Conversely, activity within the home setting was similar between groups. This is an interesting finding and may reflect the increased confidence of the faller group within a familiar setting, despite previous literature indicating the home setting as being the most common location of falls in older adults.[23] While the overall community activity and participation levels were significantly lower in amputees with a history of falls, it appears that activity in recreation and commercial areas, and participation in recreation roles were specifically reduced in this group. It should be expected that reduced recreational participation in the community would result in reduced activity levels; however, it is interesting to observe that commercial activities were reduced in fallers while participation in this category was similar between groups. This indicates that fallers do still participate in attending commercial facilities, potentially to perform important tasks such as grocery shopping; however, the activity performed in these locations is reduced. It is also surprising that amputees with a history of falls do still participate in social activities, indicating some level of community integration. However, it was somewhat expected that no differences would be observed in health-related activity and participation given the similar demographics and clinical characteristics between fallers and non-fallers. In addition, a longer study period may be required to elucidate differences in this community category as the current 7-day period may not capture all regular health-related activities. Future studies may be required to investigate why amputees with a history of falls selectively participate at lower levels in commercial and recreational facilities. Nevertheless, given the prevalence of falls observed in this study (35%), and also reported previously,[14] these findings further emphasise the importance of clinical falls assessment for lower limb amputees (for a review of amputee falls assessments, see ref. 24). Not only is there likely to be some form of physical or psychological injury result from a fall,[25] but also evidence from the current study demonstrates that fallers achieve suboptimal levels of community activity and participation and may therefore not successfully achieve the rehabilitation goal of functional mobility.[18] The findings from this study may be used to target interventions aiming to reduce falls or increase community activity and participation. For example, future studies may investigate promoting increased activity and participation in recreational and

Table 4 Community participation for fallers and non-fallers, separated by participation categories

Community categories	Participation *Community visits per day* Median (IQR) Faller	Non-faller	Statistic, p value
Employment	1.0 (0.1–1.4)	0.7 (0.6–2.1)	0.71
Residential	0.3 (0.1–0.4)	0.3 (0.1–0.7)	0.61
Commercial	0.4 (0.2–1.1)	0.7 (0.4–1.1)	0.18
Health	0.1 (0.0–0.4)	0.1 (0.0–0.2)	0.44
Recreational	0.0 (0.0–0.1)	0.1 (0.0–0.3)	**0.04**
Social	0.3 (0.1–0.4)	0.2 (0.0–0.4)	0.76
Other	0.0 (0.0–0.1)	0.0 (0.0–0.2)	0.21
Total community	1.4 (0.8–2.6)	2.4 (2.0–2.8)	**0.02**

Employment step count and visit are representative of amputees who were employed (n=15). All other categories were representative of all amputee participants (n=46).
Bold text highlights significant difference at p≤0.05 between fallers and non-fallers.

commercial facilities for amputees with a history of falls. Similarly, balance and gait interventions to reduce falls risk should consider the assessment of quality of life and community integration.

Many factors, apart from a history of falls, may contribute to the differences in levels of community activity and participation assessed in this study. However, we have demonstrated that demographics and clinical characteristics including age, gender, indication for amputation, time since amputation and stump length were not different between fallers and non-fallers. While we acknowledge that this study has only demonstrated a relationship between community activity and participation and history of falls, the strong results presented here do warrant further consideration. Future studies using a prospective design may seek to determine if experiencing a fall contributes reduced levels of community activity and participation, or alternatively, if reduced levels of community activity and participation predispose an amputee to experiencing a fall potentially due to reduced mobility confidence or endurance.

There are several limitations to this study which must be considered when interpreting these findings. First, the retrospective history of falls obtained for this study may limit the accuracy of falls data. Falls were determined by a self-report over the previous 12 months, which is limited by recall bias. While an option may be to reduce the time frame over which participants are asked to recall falls data (ie, falls over the past 3 months), previous data suggest that participant recall is more accurate for 12 months compared to 6 or 3 months in elderly adults.[26] However, future studies should consider using prospective falls data. Additionally, only 16 participants of this study were categorised as fallers, potentially limiting the reliability of falls data described. Furthermore, GPS devices are reliant on satellite signals to record data. While a relatively small proportion (6.5%) of data was lost due to the inadequate satellite signal, the potential for an incomplete data set and data bias may limit translation to clinical practice. It should be highlighted that the data loss of this study compared well with that of a similar previous GPS study.[3] We acknowledge that the participation characterised in this study may fail to recognise participation events such as employment, social and recreational roles, which may be fulfilled from within a person's home. However, by selectively defining participation in this study as community participation, we have attempted to specifically characterise activities outside of the home setting.[27] We sought to do this as participation outside of the home is likely to present greater mobility and social challenges and therefore greater community integration. Finally, the results from this study are only relevant for unilateral transtibial amputees. Future studies would be required to determine if similar results are observed in other lower limb amputee populations.

In conclusion, this study has demonstrated that the use of wearable technology may be an important adjunct in the field of amputee rehabilitation. We applied a previous methodology to assess community activity and participation,[2] an important domain of the International Classification of Functioning, Disability and Health.[10] Amputees with a history of falls demonstrated reduced levels of community activity and participation. It appears that reduced levels of community activity and participation occur specifically in commercial and recreational roles. These findings further emphasise the importance of clinical falls assessments. Future studies should continue to explore the use of wearable technology in amputees as a means to objectively and accurately assess patient behaviour in the community to further enhance rehabilitation practices and outcomes.

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