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BRIEF REPORT

# Assessing Gait Variability in Transtibial Amputee Fallers Based on Spatial-Temporal Gait Parameters Normalized for Walking Speed

Brenton G. Hordacre, PhD,[a] Christopher Barr, PhD,[a] Benjamin L. Patritti, PhD,[b] Maria Crotty, PhD[a]

*From the [a]Department of Rehabilitation, Aged and Extended Care, Flinders University, Adelaide, South Australia; and [b]Department of Rehabilitation, Aged and Extended Care, Repatriation General Hospital, Adelaide, South Australia, Australia.*

**Abstract**

**Objective:** To determine whether normalizing spatial-temporal gait data for walking speed obtained from multiple walking trials leads to differences in gait variability parameters associated with a history of falling in people with transtibial amputations.

**Design:** Cross-sectional study.

**Setting:** Rehabilitation center.

**Participants:** People with unilateral transtibial amputations (N=45; mean age ± SD, 60.5±13.7y; 35 men [78%]) were recruited.

**Interventions:** Not applicable.

**Main Outcome Measures:** Participants completed 10 consecutive walking trials using an instrumented walkway system. Primary gait parameters were walking speed and step-length, step-width, step-time, and swing-time variability. A retrospective 12-month fall history was obtained from participants.

**Results:** Sixteen amputees (36%) were classified as fallers. Variation in gait speed across the 10 walking trials was 2.9% (range, 1.1%−12.1%). Variability parameters of normalized gait data were significantly different from variability parameters of nonnormalized data (all $P<.01$). For nonnormalized data, fallers had greater amputated limb step-time ($P=.02$), step-length ($P=.02$), swing-time ($P=.05$), and step-width ($P=.03$) variability and nonamputated limb step-length ($P=.04$) and step-width ($P=.01$) variability. For normalized data, only 3 variability parameters were significantly greater for fallers. These were amputated limb step-time ($P=.05$), step-length ($P=.02$), and step-width ($P=.01$) variability.

**Conclusions:** Normalizing spatial-temporal gait data for walking speed before calculating gait variability parameters may aid in discerning variability parameters related to falls histories in people with transtibial amputations. This may help focus on the initial rehabilitation efforts of amputees with a fall history.

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Variability in spatial-temporal features of gait has gained increased attention as a potential biomarker to characterize disturbances in the regulation of gait.[1-5] However, appropriate procedures to assess gait variability are a subject of debate.[6] A key issue is whether normalizing for walking speed is necessary. Differences in walking speed may occur through spatial and temporal adjustments of stepping during the gait cycle, which can affect the magnitude of spatial-temporal gait variability.[1] Most protocols record multiple overground walking trials using instrumented walkway systems[4] or motion capture systems.[5] The intermittent nature of the walking trials in these protocols will likely lead to increased intrasubject variability in walking speed, particularly for patients with existing gait deficits such as transtibial amputees. Accordingly, intrasubject variability in walking speed should be accounted for prior to calculating gait variability parameters by normalizing them for walking speed. Previous studies have attempted to control intra-subject variability in walking speed through paced walking or the use of treadmills[7]; however, this risks imposing an atypical gait

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pattern and may increase fall risk. Controlling statistically for mean walking speed across trials has limitations, and it may remove important gait parameters relevant to aspects of pathology.[8]

Although previous work has attempted to normalize for walking speed when assessing gait parameters,[9] it has not been investigated whether this affects spatial-temporal parameters associated with a fall history in amputees.[4,5] Understanding this relation may have important clinical implications for determining fall risk in lower limb amputees because this population frequently experiences falls.[10] The aim of this study was to determine whether normalizing spatial-temporal gait data for walking speed leads to differences in gait variability parameters associated with falls histories in people with transtibial amputations. We hypothesized that fewer spatial-temporal variability parameters associated with a fall history would remain significant after normalizing for walking speed.

## Methods

### Participants

Forty-five people with unilateral transtibial amputations (35 men [78%]; mean age ± SD, 60.5±3.7y; mean time since amputation ± SD, 25.9±19.1y) and well-fitting prostheses as determined by the participant's prosthetist were recruited. Data on standard clinical characteristics were collected (sex, age, stump length, amputation pathology). Amputation pathologies included peripheral vascular disease (N=17; 38%), trauma (N=17; 38%), tumor (N=4; 9%), congenital disease (N=4; 9%), and infection (N=3; 6%). Ethical approval was provided by the local ethics committee, and all participants provided written informed consent.

### Procedures

Gait was assessed with an instrumented GAITRite walkway system[a] that captured individual footfall data over a 4.9m×0.6m area, at a sampling rate of 120Hz. Participants completed 10 consecutive walking trials (avg, 5.5 foot strikes per trial) at their self-selected comfortable walking speed, starting and stopping 2m before and after the ends of the walkway. Step parameters were selected in preference to stride parameters for their improved clinimetric properties.[3] In addition to walking speed, the primary gait parameters were step-length, step-width, step-time, and swing-time variability as these are common measures studied in amputees and older adults.[2,4,5] To determine the effect of intrasubject variability in walking speed on gait variability, spatial-temporal gait data of each walking trial were normalized by dividing variability parameters by the walking speed of the respective trial. Mean variability (coefficient of variation) parameters were then calculated for the 10 walking trials. A retrospective 12-month fall history was obtained from participants classified as nonfallers (0 falls) and fallers (≥1 falls).

### Statistical analysis

Normality of data was assessed, and where assumptions were not met, nonparametric statistics were used. Separate independent *t* tests analyzed age, stump length, and walking speed associated with a fall history. Separate chi-square tests analyzed amputation pathology and sex associated with a fall history. Mann-Whitney *U* tests analyzed intrasubject variability in walking speed and time since amputation associated with a fall history. Wilcoxon signed-rank tests analyzed differences between individual nonnormalized and normalized gait variability parameters. Mann-Whitney *U* tests analyzed both nonnormalized and normalized gait variability parameters based on falls classification. The significance level was set at $P \leq .05$, and SPSS software (version 19.0)[b] was used for analyses.

***List of abbreviations:***

**IQR** **interquartile range**

## Results

Sixteen amputees (36%) were classified as fallers (12 [27%] were recurrent fallers). No differences existed between fallers and nonfallers in sex ($P=.07$), amputation pathology ($P=.09$), age ($P=.16$), stump-length ($P=.33$), time since amputation ($P=.22$), or walking speed (mean speed, 1.13m/s; $P=.09$). The median intrasubject variability in walking speed was 2.9% (interquartile range [IQR], 1.1%−12.1%); it was greater in fallers (median, 3.6%; IQR, 2.5%−5.2%) than in nonfallers (median, 2.8%; IQR, 2.3%−3.7%), although it did not reach statistical significance ($P=.09$). All normalized gait variability parameters were significantly different from nonnormalized parameters (table 1). In general, for both normalized and nonnormalized parameters, fallers showed greater gait variability than did nonfallers (table 2).

### Nonnormalized spatial-temporal gait variability

For nonnormalized parameters, fallers had greater amputated limb step-length ($U_{(43)}=135.0$; $P=.02$), step-width ($U_{(43)}=151.0$; $P=.03$), step-time ($U_{(43)}=136.0$; $P=.02$), and swing-time ($U_{(43)}=154.5$; $P=.05$) variability. For the nonamputated limb, fallers had greater step-length ($U_{(43)}=144.0$; $P=.04$) and step-width ($U_{(43)}=138.0$; $P=.01$) variability. No other parameters reached statistical significance (see table 2).

### Normalized spatial-temporal gait variability

For normalized parameters, fallers had greater amputated limb step-length ($U_{(43)}=134.0$; $P=.02$), step-width ($U_{(43)}=138.0$; $P=.01$), and step-time ($U_{(43)}=149.0$; $P=.05$) variability. No other parameters reached statistical significance (see table 2).

## Discussion

It is reasonable to expect that natural variations in walking speed will be increased for protocols using multiple overground walking trials to assess spatial-temporal gait variability because of the

**Table 1** Median (interquartile range) nonnormalized and normalized spatial-temporal gait variability parameters

| Parameter | Nonnormalized Gait Variability | Normalized Gait Variability | *P* |
|---|---|---|---|
| Step-length AL (%) | 4.2 (2.8−5.3) | 2.6 (1.7−3.4) | <.001 |
| Step-length NAL (%) | 4.4 (2.9−6.1) | 2.4 (1.8−3.6) | <.001 |
| Step-width AL (%) | 15.9 (11.4−20.9) | 11.8 (8.5−15.7) | <.001 |
| Step-width NAL (%) | 15.9 (12.1−21.4) | 11.6 (8.2−15.1) | <.001 |
| Step-time AL (%) | 3.2 (2.4−4.1) | 4.4 (3.4−7.2) | <.001 |
| Step-time NAL (%) | 3.4 (2.5−4.3) | 4.7 (3.8−6.7) | <.001 |
| Swing-time AL (%) | 3.5 (2.8−5.1) | 4.5 (3.6−6.3) | <.001 |
| Swing-time NAL (%) | 4.2 (3.1−5.4) | 4.6 (3.9−6.5) | .009 |

Abbreviations: AL, amputated limb; NAL, nonamputated limb.