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Assessing gait variability in transtibial amputee fallers based on spatial-temporal gait parameters normalised for walking speed

Abstract

Objective: To determine if normalising spatial-temporal gait data for walking speed when obtained from multiple walking trials leads to differences in gait variability parameters associated with a history of falling in transtibial amputees.

Design: Cross-sectional study of transtibial amputees with and without histories of falling in the past 12 months.

Setting: Rehabilitation centre.

Participants: Forty-five unilateral transtibial amputees (35 male, age 60.5 (SD13.7) years) were recruited.

Main outcome measures: Participants completed 10 consecutive walking trials over an instrumented walkway. Primary gait parameters were walking speed and step-length, step-width, step-time, and swing-time variability. Participants provided a retrospective 12-month falls history.

Results: Sixteen (36%) amputees were classified as fallers. Variation in gait speed across the 10 walking trials was 2.9% (range 1.1%-12.1%). Variability parameters of normalised gait data were significantly different to variability parameters of non-normalised data (all $p<0.01$). For non-normalised data, fallers had greater amputated limb step-time ($p=0.02$), step-length ($p=0.02$), swing-time ($p=0.05$), step-width ($p=0.03$) variability and non-amputated limb step-length ($p=0.04$) and step-width ($p=0.01$) variability. For normalised data only three variability parameters remained significantly greater for fallers. These were amputated limb step-time ($p=0.05$), step-length ($p=0.02$), and step-width ($p=0.01$) variability.

Conclusion: Normalising spatial-temporal gait data for walking speed before calculating gait variability parameters may aid in discerning the variability parameters related to falls history in transtibial amputees. This may help focus initial rehabilitation efforts of amputee patients with falls history.

Key words: Accidental Falls; Amputees; Rehabilitation; Gait; Walking Speed; Falls; Gait Variability.

List of Abbreviations

CV coefficient of variation

Introduction

Variability in spatial-temporal features of gait has gained increased attention as a potential biomarker to characterise 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 normalising 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 over-ground walking trials using instrumented walkways[4] or motion capture systems.[5] The intermittent nature of the walking trials in these protocols will likely lead to increased intra-subject variability of walking speed, particularly for patients with existing gait deficits such as transtibial amputees. Accordingly intra-subject speed variability should be accounted for prior to calculating gait variability measures by normalising for walking speed. Previous studies have attempted to control intra-subject variability of walking speed through the use of paced walking or treadmills,[7] however this risks imposing an atypical gait pattern and may increase falls risk. Controlling statistically for mean walking speed across trials has limitations and may remove important gait parameters relevant to aspects of pathology.[8]

While previous work has attempted to normalise for walking speed when assessing gait parameters,[9] it has not been investigated whether this affects spatial-temporal parameters which are associated with a history of falling in amputees.[4, 5] Understanding this relationship may have important clinical implications for determining falls risk in lower-limb amputees as this population frequently experiences falls.[10] The aim of this study was to determine if normalising spatial-temporal gait data for walking speed leads to differences in gait variability parameters associated with falls histories in transtibial amputees. We hypothesised that fewer spatial-temporal variability parameters associated with a falls history would remain significant after normalising for walking speed.

Methods

Participants

Forty-five unilateral transtibial amputees (35 male, age 60.5(SD 13.7) years, 25.9(SD 19.1) years since amputation) with well-fitting prostheses as determined by the participant's prosthetist were recruited. Standard clinical characteristics were collected (gender, age, stump-length, and amputation pathology). Amputation pathologies included peripheral vascular disease (38%), trauma (38%), tumour (9%), congenital (9%) and infection (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 (CIR-Systems Inc., NJ, USA) which captured individual footfall data over an area 4.9mx0.6m, sampling at 120Hz. Participants completed 10 consecutive walking trials (average 5.5 foot-strikes per trial) at their self-selected comfortable walking speed starting and stopping two metres before and after the ends of the walkway. Step parameters were selected in preference to stride parameters for improved clinometric properties.[3] In addition to walking speed the primary gait parameters were step-length, step-width, step-time, and swing-time variability due to previous use with amputees and older adults.[2, 4, 5] To determine the effect of intra-subject variability of walking speed on gait variability, spatial-temporal gait data of each walking trial were normalised by dividing by the walking speed of the respective trial. Mean variability (coefficient of variation, CV) parameters were then calculated for the 10 walking trials. A retrospective 12-month falls history was obtained with participants classified as a non-faller (no falls) or faller (one or more falls).

Analysis

Normality of data was checked and where assumptions were not met, non-parametric statistics were applied. Separate independent t-tests analysed age, stump-length and walking speed for falls history. Separate chi-square analyses tested amputation pathology and gender for falls history. Intra-subject speed variability and time since amputation were analysed for falls history with a Mann-Whitney U-test. Wilcoxon Signed-Rank Tests analysed differences between individual non-normalised and normalised gait variability parameters. Mann-Whitney U-tests analysed both non-normalised and normalised gait variability parameters for falls history. Significance level was set at $p \leq 0.05$ and SPSS software was used for analyses (IBM SPSS Statistics for Windows, Version 19.0).

Results

Sixteen (36%) amputees were classified as fallers (12 were recurrent fallers). No differences existed between fallers and non-fallers for gender (p=0.07), amputation pathology (p=0.09), age (p=0.16), stump-length (p=0.33), time since amputation (p=0.22) or walking speed (p=0.09, mean speed 1.13m.s^{-1}). Median intra-subject speed variability was 2.9% (range 1.1%-12.1%), and was greater in fallers (median 3.6%, IQR 2.5-5.2) than non-fallers (median 2.8%, IQR 2.3-3.7), although this did not reach significance (p=0.09). All normalised gait variability parameters were significantly different to non-normalised parameters. In general, for both normalised and non-normalised parameters, fallers showed greater gait variability than non-fallers (table 2).

Non-Normalised Spatial-Temporal Gait Variability

For non-normalised parameters, fallers had greater amputated limb step-length ($U_{(43)}$=135.0, *p*=0.02), step-width ($U_{(43)}$=151.0, *p*=0.03), step-time ($U_{(43)}$=136.0, *p*=0.02), and swing-time variability ($U_{(43)}$=154.5, *p*=0.05). On the non-amputated limb, fallers had greater step-length ($U_{(43)}$=144.0, *p*=0.04) and step-width variability ($U_{(43)}$=138.0, *p*=0.01). No other parameters reached significance (table 2).

Normalised Spatial-Temporal Gait Variability

For normalised parameters, fallers had greater amputated limb step-length ($U_{(43)}$=134.0, *p*=0.02), step-width ($U_{(43)}$=138.0, *p*=0.01), and step-time variability ($U_{(43)}$=149.0, *p*=0.05). No other parameters reached significance (table 2).

Discussion

It is reasonable to expect natural variations in walking speed will be increased for protocols using multiple over-ground walking trials to assess spatial-temporal gait variability due to the intermittent nature of the trials. In this study transtibial amputees showed up to 12% intra-subject speed variability which is greater than that of age- and gender-matched able-bodied adults from our laboratory (range 1.6-5.2%, unpublished data). Normalising spatial-temporal gait data for walking speed will help minimise any confounding speed dependent effects which may otherwise be reflected in the magnitude of associated gait variability measures. We showed that the magnitude of variability from speed normalised spatial-temporal gait parameters was significantly different to the variability of non-normalised parameters. This finding supports previous work indicating that normalising for walking speed is an important consideration when assessing gait variability.[1, 9] The reduction in spatial variability and increase in temporal variability following normalisation is likely a reflection of the amputees making small adjustments in spatial features, more than temporal features, of their stepping pattern for varied walking speeds across the walkway (table 1). Importantly, normalising spatial-temporal gait parameters for walking speed assisted in discerning between gait variability parameters associated with histories of falling in this group of transtibial amputees. The clinical significance of this finding remains to be determined, but it is interesting to note that when normalising for walking speed the variability in the stepping pattern of the amputated limb distinguished fallers from non-fallers for three of the assessed parameters, while variability associated with the non-amputated limb did not discriminate between the groups. We suggest variability associated with the amputated limb may be more important for determining falls risk due factors such as altered motor control, and loss of proprioception and sensory feedback distal to the site of amputation.

Study Limitations

There are limitations to the present study. First, this was a cross sectional study and the falls history relied on participant’s retrospective recall. Second, this small opportunity sample may not be generalizable to the wider amputee population.

Conclusion

The present data suggests that when assessing gait in transtibial amputees, normalising for intra-subject walking speed variability may aid in discerning gait variability parameters associated with a history of falls. Our results indicate that normalised spatial-temporal variability of the amputated limb during gait may best differentiate between fallers and non-fallers. This information may help clinicians focus on specific approaches in the initial stages of gait rehabilitation for amputees who have a history of falls. Further investigation of this technique is required before implementation into clinical practice.

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