Gait & Posture 42 (2015) 85–90

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Quantifying the cadence of free-living walking using event-based analysis

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ARTICLE INFO

Article history:
Received 4 December 2014
Received in revised form 27 March 2015
Accepted 20 April 2015

Keywords:
Accelerometry
Stepping rate
Physical activity
Intermittent claudication

ABSTRACT

Purpose: Free-living walking occurs over a wide range of durations and intensities (cadence). Therefore, its characterisation requires a full description of the distribution of duration and cadence of these walking events. The aim was to use event-based analysis to characterise this in a population with intermittent claudication (IC) and a healthy matched control group.
Methods: Seven-day walking activity was recorded using the activPAL activity monitor in a group of people with IC ($n = 30$) and an age-matched control group ($n = 30$). The cadence, number of steps and duration of individual walking events were calculated and outcomes were derived, and compared ($p < 0.05$), based on thresholds applied.
Results: Both groups had similar number of walking events per day (392 ± 117 vs 415 ± 160). The control group accumulated a greater proportion of their walking at higher cadences and 32% of their steps were taken at a cadence above 100 steps/min, for the IC group this was 20%. Longer walking events had higher cadences and the IC group had fewer of these. As walking events became longer the cadence increased but the inter-event cadence variability decreased. More purposeful walking might occur at a higher cadence, and be performed at a preferred cadence. Individuals with IC had a smaller volume of walking, but these differences occurred almost entirely above a cadence of 90 steps/min.
Conclusions: This is the first study which has quantified the cadence of continuous periods of free-living walking. The characteristics (duration, number of steps and cadence) of all the individual walking events were used to derive novel outcomes, providing new insights into free-living walking behaviour.

1. Introduction

Cadence, or stepping rate, is one of the spatio-temporal properties of gait, usually reported with a unit of steps per minute. The intensity of walking has often been inferred from the cadence of the walking period. In treadmill and constrained over-ground studies, with participants walking continuously for periods of at least 6 min, a cadence of 100 steps/min has been shown to be a good threshold for moderate physical activity [13,16,21].

Whilst the cadence of walking may be easily assessed over short 'test' walks it is the cadence of free-living walking that best characterises an individual's real world performance. In the free-living environment walking activity can be recorded for extended periods of time. Continuous periods of free-living walking tend to occur across a wide range of durations with periods of less than 1-min being very common in healthy individuals [1,15].

The intensity of walking in the free-living environment has often been quantified by counting the number of steps taken within a defined time period, usually 1 min. This might best be referred to as step accumulation per epoch of time, although it has been called cadence. True cadence can be defined as the number of steps taken in actual time spent stepping. It has been demonstrated

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http://dx.doi.org/10.1016/j.gaitpost.2015.04.012
0966-6362/

that step accumulation is a very different outcome measure from true cadence as walking continuously for a full minute is relatively rare [3,19].

At present there is limited understanding of the true cadence of free-living walking. In order to understand this the true cadence of every continuous walking period must be quantified. This requires information of both the number of steps taken and the duration of the continuous walking period allowing the calculation of the average cadence for each period. This approach, focussing on the assessment of continuous periods of activity, is an event-based approach [9], and within the current work a continuous period of walking will be referred to as a walking event.

Clinical conditions may affect walking performance in a way that impacts on cadence used. One such clinical condition is peripheral arterial disease which leads to walking difficulties due to intermittent claudication (IC), whereby leg pain is caused by inadequate peripheral circulation. This pain leads to the person needing to stop regularly whilst walking or to limit their cadence for prolonged walking activity [5,7,14]. It has been shown that by monitoring an individual's free-living activity, using a body-worn activity monitor, it is possible to quantify these free-living symptoms [2,6]. Such techniques could aid in the assessment of this condition and also quantify the effectiveness of interventions.

The full characterisation of free-living walking cadence requires a description of the distribution of several aspects. This includes the duration of events, the number of steps accumulated within these events and the cadences at which events of these durations are performed. To date, there has not been any characterisation of this either in healthy populations or those with disease. The aim of this study was to use event-based analysis to examine the cadence of free-living walking in a population with IC and a healthy matched control group.

2. Methods

Thirty patients with IC were recruited from a vascular outpatient clinic within NHS Forth Valley (Stirling, Scotland, UK), and thirty controls, matched for gender and age, were selected from the Glasgow Caledonian University (Glasgow, Scotland, UK) physical activity database. Data from the study, examining the broken nature of walking, have previously been reported [2].

Ethical approval was obtained from NHS Tayside B Research Ethics Committee (IC group) and from the Glasgow Caledonian University School of Health and Life Sciences Ethics Committee (control group).

Free-living activity of all participants was recorded using the activPAL^{TM} activity monitor (PAL Technologies Ltd, Glasgow, UK). This instrument is a small and unobtrusive light-weight device which is attached to the anterior aspect of the thigh [2]. The device was worn continuously to provide seven consecutive days of data.

Data from this instrument classifies activities into sedentary, standing and stride events. Consecutive stride events are combined to give walking events. The output from the instrument has been validated for classification of sedentary, upright, standing and walking activities in a range of populations including older adults [4,8,10–12,17].

Data from the instrument was downloaded and a file of sedentary, standing and stride events was obtained. Using a Matlab script all walking events were extracted together with the properties of these events: start time, duration, number of steps and average cadence.

2.1. Analysis

Two approaches were taken. The first was to analyse all walking events and determine the distribution and relative contributions of these events within different cadence bands to the overall volume of walking. The second approach explored the cadence of purposeful walking. This was achieved by analysing only those events which were longer than a set duration.

2.2. Cadence across all walking events

2.2.1. Number of minutes spent walking within specified cadence bands

The distribution of cadence by walking event duration was calculated for each group. For each event, the number of minutes spent walking was allocated to a cadence band representing the average cadence of the event, to examine the time spent walking at each cadence band.

2.2.2. Proportion of steps taken above a specified cadence and the cadence below which a set percentage of steps were taken

The accumulation of walking by cadence was examined, starting at the lowest cadence and increasing to the maximum cadence accomplished. To do this all walking events were ordered by cadence, from lowest to highest. The steps taken within these events were then sequentially summed. The plot of steps taken below this specified cadence was standardised to 100% of all steps taken, to allow the proportion of steps taken below a specified cadence to be examined.

The defined outcomes were the percentage of steps taken above a set cadence (100 steps/min), and the cadence below which a set percentage of steps were taken (25%, 50% and 75% of steps).

2.3. Cadence of purposeful walking

The preceding outcome measures do not take into account the duration of the walking events. To look at 'purposeful walking' cadence outcome measures were derived using only the events above set durations. To explore the definition of purposeful walking, three duration thresholds were used (30 s, 60 s and 120 s).

Two sets of outcomes were calculated for walking events above each of these thresholds. The first set gave an indication of the volume of activity; these were the number of walking events and the number of steps. The second set of outcomes described the cadence of the walking events. These outcomes were the mean and, to give an indicator to the inter-event cadence variability, the standard deviation of the cadence of the events.

All outcomes were calculated for each individual separately and reported as mean ± standard deviation for the population group.

2.4. Statistical analysis

Data were checked for normality by use of Kolmogorov–Smirnov tests and visual inspection of Q–Q plots. All outcomes were compared between groups using independent *t*-tests (SPSS statistical software). Statistical significance was set at $p < 0.05$.

3. Results

3.1. Sample

The mean age was 67.2 ± 9.7 years for the IC group (18M/12F) and 66.8 ± 10.5 years for the control group (18M/12F). More detailed characteristics of the IC group are reported elsewhere [2].

Complete seven-day activity recordings were obtained from all 30 IC participants and for 28 control subjects (two wore the device for only five days). Outcomes are reported as per day.

3.2. Volume outcomes

Control participants walked for significantly more time per day (126 ± 48 min compared with 90 ± 36 min, $p = 0.002$) and took significantly more steps per day (8692 ± 2945 compared with 6526 ± 2711, $p = 0.003$).