Journal of Biomechanics xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

Validation of gait event detection by centre of pressure during target stepping in healthy and paretic gait

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ARTICLE INFO

Article history:
Accepted 31 July 2018
Available online xxxx

ABSTRACT

Background: Target-stepping paradigms are increasingly used to assess and train gait adaptability. Accurate gait-event detection (GED) is key to locating targets relative to the ongoing step cycle as well as measuring foot-placement error. In the current literature GED is either based on kinematics or centre of pressure (CoP), and both have been previously validated with young healthy individuals. However, CoP based GED has not been validated for stroke survivors who demonstrate altered CoP pattern.
Methods: Young healthy adults and individuals affected by stroke stepped to targets on a treadmill, while gait events were measured using three detection methods; verticies of CoP cyclograms, and two kinematic criteria, (1) vertical velocity and position and of the heel marker, (2) anterior velocity and position of the heel and toe marker, were used. The percentage of unmatched gait events was used to determine the success of the GED method. The difference between CoP and kinematic GED methods were tested with two one sample (two-tailed) t-tests against a reference value of zero. Differences between group and paretic and non-paretic leg were tested with a repeated measures ANOVA.
Results: The kinematic method based on vertical velocity only detected about 80% of foot contact events on the paretic side in stroke survivors while the method on anterior velocity was more successful in both young healthy adults as stroke survivors (3% young healthy and 7% stroke survivors unmatched). Both kinematic methods detected gait events significantly earlier than CoP GED ($p < 0.001$) except for foot contact in stroke survivors based on the vertical velocity.
Conclusions: CoP GED may be more appropriate for gait analyses of SS than kinematic methods; even when walking and varying steps.

1. Introduction

Force instrumented treadmills facilitate online kinetic measurement of a high volume of steps in a small space with the safety of support harnesses (Merholz and Elsner, 2014) and, combined with visual projection, can allow practice of altering walking in response to cues (e.g. stepping to targets, over or around obstacles (Heeren et al., 2013). For these reasons use of instrumented treadmills for rehabilitation and clinical assessment is increasing (Bank et al., 2011; Duysens et al., 2012; Heeren et al., 2013; Hollands et al. (2014); Hollands et al., 2013; Mazaheri et al., 2015; Mazaheri et al., 2014; Peper et al., 2015; Timmermans et al., 2016; van Ooijen et al., 2015; Weerdesteyn et al., 2006).

Single uniaxial force instrumentation of the treadmill belt affords centre of pressure (CoP) gait event detection (GED) as a proxy for gold standard kinetic (dual, multi-axial, force-plates) or kinematic GED. CoP GED has been shown to correspond well with kinematic GED during steady-state treadmill walking in young healthy adults (Roerdink et al., 2008). However, it is not known whether CoP GED corresponds with kinematic GED when steps are altered in response to environmental cues, or when alterations in CoP trajectories occur due to pathology (i.e. stroke (Wong et al 2004)).

To support valid gait assessment in the context of growing treadmill use in clinical assessment, this study aimed to determine if there are differences in CoP and kinematic GED in young healthy

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https://doi.org/10.1016/j.jbiomech.2018.07.039
0021-9290/

(YH) and stroke survivors (SS) during treadmill walking. We compare GED methods in the walking condition of varying steps; the context in which they are increasingly being applied. Specific questions are:

(1) Are there significant differences between methods within groups?
(2) Are differences between methods greater in SS than YH (and according to paretic and non-paretic limbs)?

2. Methods

2.1. Participants

YH, aged 18–35 years, were recruited by poster advertisement across the University. SS were recruited from community stroke support and exercise groups in Greater Manchester. Participants were included if they could walk ten-metres within 30 s, had no visual impairments preventing sight of stepping targets, and no co-morbidities affecting walking.

The University of Salford, College of Health and Social Care Research Ethics Committee approved the study, and all participants provided written informed consent.

2.2. Procedures

Self-selected walking speed (SSWS), functional mobility (10 m walking test (Green et al., 2002); Timed Up and Go (Hiengkaew et al., 2012) and Dynamic Gait Index (Jonsdottir and Cattaneo, 2007)) were collected to ascertain mobility status of the SS.

Participants were acclimatised with walking on the treadmill without stepping targets for approximately 3 min. Each participant's SSWS was determined by increasing speed from 1 km/h until participants were walking faster than preferred, then decreasing speed to a comfortable pace. Participants walked to targets located at their usual step lengths and widths (established when walking during earlier no-target acclimatisation period) for 1 min, to become acquainted with target stepping. Step characteristics such as speed, step length and width were recorded as a basis for programming the location of targets for subsequent personalised target-stepping tasks.

Participants stepped to targets located according to their personalised protocol, projected on the treadmill belt while walking at SSWS (Fig. 1) according to a previously described paradigm (Hollands et al., 2015). 12 targets (8 cm wide × 40cm long) were projected at preferred step length and 12 of the same size for both shortening and lengthening steps (±25% of preferred step length). A further 24 targets of different shape (20 cm wide × 15cm long) were projected on the midline of the treadmill to elicit narrow foot placements. Participants were not allowed to use a handrail for stability; however, SS wore a harness for safety.

2.3. Kinetics

Signals from a single large (0.8 × 3.0 m) uniaxial force plate was conditioned (100 Hz low-pass filter) and recorded at 500 Hz using CueFors1 software in the C-Mill (MotekforceLink, Culemborg, The Netherlands). CueFors1 analyses CoP cyclogram, also defined as gaitogram (Roerdink et al., 2014) (Fig. 2), to generate gait events.

2.4. Kinematics

Kinematics were collected with a six-camera motion capture system (Qualysis, Gothenburg, Sweden) at 126 Hz for healthy participants and at a minimum sampling rate of 31 Hz for SS (due to synchronisation of high speed video for some participants); kinematic data was subsequently spline interpolated to 500 Hz to match the C-Mill data. Toe and heel markers on the 2nd distal phalangeal head and the calcaneus were used for kinematic GED. The C-Mill and motion capture systems were synchronised with an electronic pulse generated by CueFors1 software that triggered the start of motion capture. Kinematic gait events were detected offline after interpolating and filtering (2th order bidirectional 6 Hz low pass Butterworth filter).

Two GED algorithms were used to define gait events: the first defined FC as the minima of the vertical displacement of the heel marker (VFC) and FO at the maxima in vertical velocity of the heel marker (VFO) (Pijnappels et al., 2001; Roerdink et al., 2008). The second defined FC as the maximum anterior displacement of the heel marker (AFC) and FO as the instant that the anterior velocity of the toe marker is zero (AFO) when it transitions from posterior to anterior velocity (Zeni et al., 2008).

2.5. Statistical analysis

At least 30 gait events, FC and FO, were detected by both kinematic and CoP algorithms per participant per foot. Data comprised 10 normal steps (before the adjustment protocol) and 60 adaptation steps (30 per foot). CoP events were matched to the kinematic events occurring within 200 ms, if no such match could be made they were recorded as the proportion of steps that could not be matched (unmatched, see Table 2).

To determine if there are significant differences between methods within groups: Differences between matched CoP and kinematic gait event for paretic and non-paretic and left and right side of SS versus YH were compared using a one-sample (two tailed) T-test against a reference value of 0 ms (i.e. no difference) (Roerdink et al., 2008).

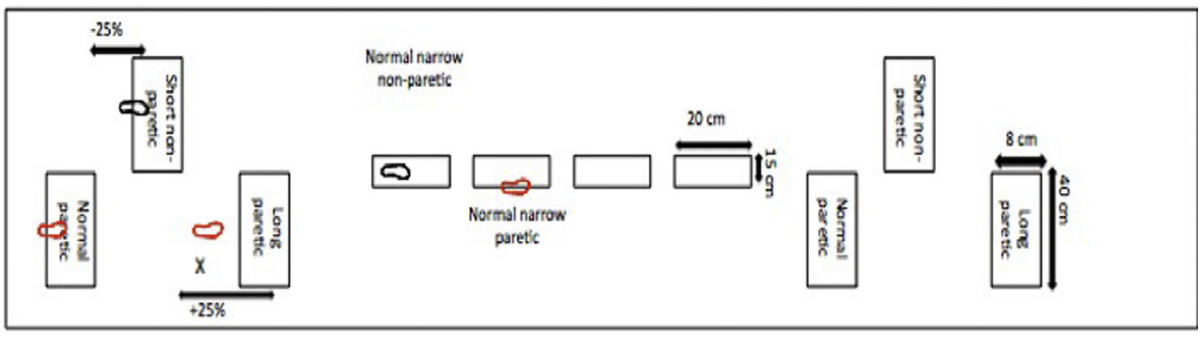

Fig. 1. Schematic representation of the layout of stepping targets (normal, short, long, and medial).

Please cite this article in press as: van der Veen, S.M., et al. Validation of gait event detection by centre of pressure during target stepping in healthy and paretic gait. J. Biomech. (2018), https://doi.org/10.1016/j.jbiomech.2018.07.039