Gait & Posture 37 (2013) 598–602

Contents lists available at SciVerse ScienceDirect

Gait & Posture

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

Measuring movement fluency during the sit-to-walk task

A. Kerr [a,*], V.P. Pomeroy [b], P.J. Rowe [a], P. Dall [c], D. Rafferty [c]

[a] Department of Biomedical Engineering, University of Strathclyde, 106 Rottenrow, Glasgow G4 0NW, United Kingdom
[b] Faculty of Medicine and Health Sciences, University of East Anglia, Queen's Building, Norwich NR4 7TJ, United Kingdom
[c] School of Health and Life Sciences, Glasgow Caledonian University, Cowcaddens Road, Glasgow G4 0BA, United Kingdom

ARTICLE INFO

Article history:
Received 9 December 2011
Received in revised form 19 September 2012
Accepted 30 September 2012

Keywords:
Fluency
Smoothness
Co-ordination
Sit-to-walk

ABSTRACT

Background: Restoring movement fluency is a key focus for physical rehabilitation; it's measurement, however, lacks objectivity. The purpose of this study was to find whether measurable movement fluency variables differed between groups of adults with different movement abilities whilst performing the sit-to-walk (STW) movement. The movement fluency variables were: (1) hesitation during movement (reduction in forward velocity of the centre of mass; CoM), (2) coordination (percentage of temporal overlap of joint rotations) and (3) smoothness (number of inflections in the CoM jerk signal).
Methods: Kinematic data previously collected for another study were extracted for three groups: older adults ($n = 18$), older adults at risk of falling (OARF, $n = 18$), and younger adults ($n = 20$). Each subject performed the STW movement freely while a motion analysis system tracked 11 body segments. The fluency variables were derived from the processed kinematic data and tested for group variation using analysis of variance.
Findings: All three variables showed statistically significant differences among the groups. Hesitation ($F = 15.11$, $p < 0.001$) was greatest in the OARF 47.5% (SD 18.0), compared to older adults 30.3% (SD 15.9) and younger adults 20.8% (SD 11.4). Co-ordination ($F = 44.88$, $p < 0.001$) was lowest for the OARF (6.93%, SD 10.99) compared to both the young (31.21%, SD 5.48) and old (26.24%, SD 5.84). Smoothness ($F = 35.96$, $p < 0.001$) was best in the younger adults, 18.3 (SD 5.2) inflections, compared to the old, 42.5 (SD 11.5) and OARF, 44.25 (SD 7.29).
Interpretation: Hesitation, co-ordination and smoothness may be valid indicators of movement fluency in adults, with important consequences for research and clinical practice.

1. Introduction

Visual observation of movement fluency is used by therapists to guide the planning and evaluation of interventions aimed at restoring movement [27]. Improving movement fluency is perceived by therapists to be associated with improvements in function [6], and has been shown to relate to energy cost [33]. It is a key objective of the predominant approach to neurorehabilitation in the United Kingdom [23,31]. There is an underlying assumption, however, that therapists have a tacit and common understanding of what constitutes fluent movement [28]. This assumption, rarely tested, could undermine the rigour of clinical assessment and create an obstacle to the scientific scrutiny of physical rehabilitation.

Tools for measuring movement fluency have been developed previously using normal movement as a reference for trained observers [2]. In some cases these scales have demonstrated good prognostic and diagnostic properties [26]. However their subjective nature causes reliability problems [21], and they rely on substantial experience and training of observers [20]. To avoid these hindrances Malouin et al. [19] introduced an objective method for quantifying fluency based on a threshold drop in forward momentum while performing the sit-to-walk (STW) movement. The resulting dichotomous (fluent or not fluent) index was subsequently adapted into a clinical scale by Dion et al. [8]. This objective method of judging movement fluency from a change in forward momentum is promising; with evidence of validity as a screening tool for mobility problems, e.g. identifying a risk of falling (sensitivity 0.96 and specificity 0.89) [15]. However, as a measure with a single dimension, it lacks content validity.

To improve patient assessment and provide a research tool for the study of movement disorders and their rehabilitation, valid, objective measurements of movement fluency are needed [20]. The multifarious nature of movement fluency, and lack of clear definition, may contribute to the paucity of objective measures. A way forward is to deconstruct fluency into separate variables that can be clearly defined, are clinically useful, and, critically, can be measured.

* Corresponding author.
E-mail address: a.kerr@strath.ac.uk (A. Kerr).

0966-6362/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gaitpost.2012.09.026

Normal movement is characteristically smooth, co-ordinated and efficient [30] without unnecessary hesitation or repetition. A working definition of fluent movement, therefore, should include measurable definitions of these terms: hesitation, co-ordination and smoothness.

Movement hesitation is frequently described in neurological conditions [9,22] and musculoskeletal conditions [13] but less frequently quantified. The freezing of gait questionnaire [12] has been used in Parkinson's disease to rate frequency and magnitude of movement hesitations with good reliability (Cronbach alpha = 0.94) and validity (correlation to a standard function scale during the "on" period was 0.66) but is a subjective, disease specific, tool. Using motion analysis technology both Kerr et al. [15] and Malouin et al. [19] quantified movement hesitation during the STW movement as a percentage drop in forward movement of the centre of mass, and this is probably the only reported objective method for measuring hesitation during movement.

Co-ordination is consistently reported as a characteristic of normal fluent movement, for upper and lower limb movements, although the term tends to be applied generically, without reference to a measurable definition [23]. Metrics based around the relative timing of joint movements, most notably temporal overlapping, have been developed [16,17] as possible objective measures of co-ordination with higher percentages of temporal overlap indicating a more fluent movement.

Movement smoothness, and associated terms such as quality and efficiency of movement are used by therapists to express impaired motor control as well as a guiding principle for therapy [5,23,31]. The absence of a measurable definition, however, hampers both scientific scrutiny and patient assessment. Definitions based on jerk (third time derivative of position) have been applied to upper limb therapeutic robots with mean and variation calculated as metrics of smoothness [25].

Although this method could be applied to any movement, as yet it has not been applied to whole body movements such as walking or STW.

The merging of two separate movements during the STW movement (sit-to-stand and gait initiation [18]) has been recognised as a suitable testing ground for movement fluency [1,3,8,11,15]. Sit-to-walk is a functional, whole body movement. To date, however, the only fluency measurement recorded for the STW movement has been the drop in CoM velocity, previously mentioned.

The primary aim of this paper was to present novel analytical tools to express movement fluency in a manner that is sympathetic to therapy objectives and which may uncover new understanding of human movement. The secondary aim was to determine if any of these tools could statistically distinguish groups of individuals with expected differences in movement fluency when performing the STW movement.

2. Methods

2.1. Design and ethics

Biomechanical data were extracted from the electronic records of a previous observational study of the STW movement [15], which had ethical approval from the University and NHS ethics committees. All participants gave written informed consent for the earlier study.

2.2. Participants

Three groups were recruited: (1) young adults (n = 20, age 33.1 years (SD, 8), mass 71.9 kg (SD, 11.6), height 1.72 m (SD, 0.1)), (2) older adults (n = 18, age 70.3 years (SD, 5.4), mass 65.8 kg (SD, 25.8), height 1.66 m (SD,0.1)) and (3) older adults at risk of falling (OARF) (n = 18, age 79.6 years (SD, 7.5), mass 66.2 kg (SD, 16.7), height 1.53 m (SD 0.1)). Participants were recruited from the local community (old and young groups) and a falls prevention programme (OARF group), respectively.

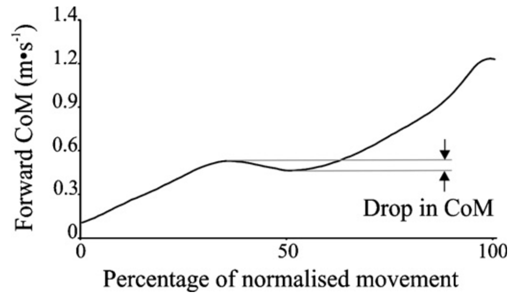

Fig. 1. Hesitation; defined as the percentage drop in forward velocity.

2.3. Procedure

All measurements were made in a movement laboratory. Participants wore tight fitting shorts, t-shirt and trainers and sat on a standard chair (0.44 m in height, armless but with a 10° reclined backrest). Reflective markers (diameter 0.02 m, mass 0.03 kg) were mounted onto the skin and, where necessary, the clothing overlying anatomical landmarks so that 11 segments (feet, lower legs, thighs, trunk, upper and lower arms) could be constructed using a rigid body model [24].

2.4. The movement task

Each participant started the test in sitting, and was requested to walk to another chair placed six metres in front of them. Participants selected their starting position and performed the movement in their own preferred manner. Each participant performed five repetitions of the movement with data from the first three successful (all marker trajectories captured) repetitions used for analysis. Participants were given up to 5 min to rest between repetitions.

2.5. Equipment

2.5.1. Marker

Marker trajectories were tracked in three dimensions by seven Motion Capture Units (Qualisys Medical AB, Gothenburg, Sweden). Data were recorded at a sampling rate of 50 Hz and the system calibrated to collect a volume of 4 m (saggital plane – X axis – direction of travel) by 1.8 m (Z axis – height) by 1.5 m (Y axis – coronal plane) metres using Qualysis TrackManager.

2.6. Data analysis

Marker trajectories were filtered using a low-pass 4th order Butterworth filter with cut-off frequency of 6 Hz, and interpolated with a maximum gap fill of 10 frames using a non-uniform rational B-spline [10]. The resulting data were used to construct a model of the body using Visual 3D (Version 3.28, C-Motion, Inc., Rockville, MD, USA) allowing calculation of joint angles and total body centre of mass (CoM) in three dimensions.

The onset time (first continuous forward movement of the CoM) and end time (end of the first swing phase, i.e. first initial contact) were recorded for each movement to allow normalisation of the data to 100% of the movement. The three fluency variables: hesitation, co-ordination and smoothness, were then calculated from the resulting processed data.

Hesitation was defined as the maximum drop in forward velocity of the COM from the initial peak generated during the seated phase, expressed as a percentage of the initial peak value, see Fig. 1.

Co-ordination was calculated as the temporal overlap between the knee and hip in the saggital plane (as a percentage of the whole movement time) during two

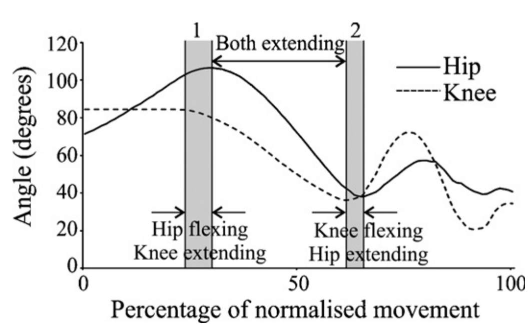

Fig. 2. Co-ordination; defined as the temporal overlap between hip and knee movements in the saggital plane.