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Quantifying lumbar–pelvis coordination during gait using a modified vector coding technique

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ABSTRACT

The complexity of human gait patterns has become a topic of major interest in motor control and biomechanics. Range of motion is still the preferred method to quantify movement impairment, however, within these traditional linear measures, the inter-segmental coordination and movement variability is normally ignored. A dynamical systems approach using vector coding and circular statistics provides non-linear techniques to quantify coordination and variability. This study provides comprehensive vector coding and circular statistics calculations. Additionally, pelvis–lumbar coordination and coordination variability data obtained from ten healthy young male participants during five walking trials using an optoelectronic system is provided. This novel data can form the baseline information for future studies in this area of research. Finally, a new illustration to present coordination and coordination variability information of gait kinematics, combining the output from the modified vector coding technique with traditional time-series segmental angle data is presented. This technique, when applied to single patients can be beneficial to assess the effect of an intervention on the patient-specific inter-segmental coordination pattern with implications to the clinical setting.

1. Introduction

Static postural observations and dynamic assessment in a standing position are common examination techniques used by clinicians to determine the severity of spinal dysfunction (Cox et al., 2000). Furthermore, range of motion (ROM) is still the preferred method to quantify impaired movements, with subsequent information used to guide treatment and to assess an individual's progress (Hindle et al., 1990; Intolo et al., 2009). Conventional measures such as ROM do not take into account inter-segmental coordination, movement variability and the different control mechanisms experienced during routine daily activities. From a dynamical systems perspective of motor control, a movement pattern is arranged from constraints imposed from the complex relationships between control parameters; task, organism and environment (Bernstein, 1967; Turvey, 1990). Dynamical system can have implications in assessment of coordination, and Vector Coding (VC) and Continuous Relative Phase (CRP) are common non-linear techniques employed by dynamical system theorists to quantify coordination and variability.

During gait coordination and variability have been linked to the health of biological systems (Harbourne and Stergiou, 2009). Using healthy participants and CRP technique, Lamoth et al. (2002) reported pelvic–trunk coordination is generally in-phase (when the pelvis and trunk are moving in the same direction) at lower walking speeds with transition to anti-phase at higher speeds. In contrast, individuals with chronic low back pain (LBP) have a reduced ability to transfer pelvic–trunk coordination from in-phase to anti-phase as walking speed increases (Lamoth et al., 2006; Selles et al., 2001). Recently using a VC technique, Seay et al. (2011) investigated pelvic–trunk coordination and reported similar findings to studies that employed CRP, indicating that individuals with low back pain (LBP) spent more time in an in-phase relationship as walking speed increases. The authors further concluded that this increase in the in-phase relationship resulted from an increase in pelvis frontal plane ROM. Although the technique utilised to assess coordination and variability should be based on the question asked in the study (Hamill et al., 2012) the use of CRP limits the analysis of coordination to the phase relationship between two segments. On the other hand, vector coding and the proposed four coordination phases (Chang et al., 2008) provides an additional insight to the dominancy of one segment over another and this can offer more valuable information in a clinical setting (Seay et al., 2011). Analysis of coordination variability also reveals important information regarding changes in motor strategies. While there is conflicting evidence to suggest greater variability emerges before the transition from one stable coordination phase to another (Diedrich and Warren, 1995; Haken et al., 1985; Kao et al., 2003; Miller et al., 2010; Seay et al., 2006), recently Miller et al. (2010) associated greater variability with a functional event such as toe-off during gait. However, there is paucity of research regarding coordination and coordination

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variability with other known phases of gait (Perry and Burnfield, 2010; Levine et al., 2012). Therefore, a new illustration combining coordination, coordination variability, ROM and the phases of gait can allow for easier interpretation of the biomechanical data.

Vector coding measures the continuous dynamic interaction between segments by determining the vector orientation between two adjacent data points in time on an angle–angle diagram relative to the right horizontal (Fig. 1b). The outcome measure is referred to as the coupling angle (γ_i) (Fig. 1c) and is represented by a value between 0° and 360° (Sparrow et al., 1987; Hamill et al., 2000). Due to the γ_i being directional in nature circular statistics (Batschelet, 1981; Hamill et al., 2000) are applied to calculate mean γ_i and coordination angle variability (CAV_i) from multiple cycles. Recently it has been proposed the γ_i can be classified into one of four coordination patterns (Chang et al., 2008). Although previous investigations have examined γ_i and CAV_i in healthy and/or pathological groups (Dierks and Davis, 2007; Ferber et al., 2005; Pollard et al., 2005; Pohl and Buckley, 2008; Seay et al., 2011) a lack of clarity in the employed mathematical equations makes between study comparisons difficult and represents possible clinical misinterpretations. This paper aims to (1) present a step by step approach for calculating γ_i and CAV_i (2) provide pelvis–lumbar coordination information during gait in healthy individuals (3) provide new a illustration to present γ_i and CAV_i data.

2. Methodology

Ten male participants (mean ± SD age: 22.4 ± 2.46 years, height: 180.3 ± 7.18 cm, mass: 74.97 ± 11.02 kg) with no history of musculoskeletal impairments gave written consent to participate in the study. Ethical Approval was sought and received from the University Research Ethics Committee.

3. Protocol

Prior to kinematic data collection and to allow familiarisation to the laboratory environment each participant performed walking trials to determine their starting position and preferred walking speed (PWS). Timing gates (Brower Timing Systems, USA) were used during data collection to ensure PWS was achieved. Recording at 100 frames per second, an 8 camera motion capture system (VICON, Oxford, UK) was used to collect pelvis and lumbar segment angular position during five walking trials. Two AMTI-OR6 force platforms (AMTI, USA) collected kinetic data (1000 Hz) to assist in the identification of gait events (heel strike and toe off).

4. Pelvis and lumbar segment coordinate systems

Using double sided adhesive tape reflective markers (14 mm) were attached to the following anatomical landmarks: right and left anterior-superior-iliac spine (ASIS), right and left post-superior-iliac spine (PSIS), sacrum (S1) and spinous process of L1. The lumbar cluster was placed over the spinous process of L3 (Konz et al., 2006).

The global coordinate system (GCS) was defined with the *X*-axis corresponding to the anterio-posterior direction (positive *x*-direction indicated forward progression). The *Y*-axis was defined as medio-lateral direction perpendicular to the *X*-axis parallel to the ground (positive *y*-direction pointing to the left). The *Z*-axis corresponded to the vertical direction (positive *z*-direction pointing upwards). The origin of the pelvis segment coordinate system was the mid-point between the 2 ASIS markers that defined the *Y*-axis. The *X*-axis was directed in an anterior direction perpendicular to the *Y*-axis from the mid-point of the ASIS markers and mid-point between the PSIS markers. The *Z*-axis was formed by the cross product of the *X*- and *Y*-axis. The lumbar coordinate system was defined using the three markers on the rigid cluster (Fig. 2). The *Y*-axis was defined as a line passing through the two markers mounted on the lateral ends of the rigid cluster, with its positive direction to the left. The *Z*-axis was defined from the mid-point of the horizontal markers and the vertical marker with its positive direction aligned with L1. The *X*-axis was the cross product of the *Y*- and *Z*-axis with its positive direction forwards (Needham et al., 2012).

5. Data reduction

Three-dimensional pelvis and lumbar segment kinematic angles relative to the global coordinative system were processed in Visual3D (C-motion-Inc, MD) using a low-pass Butterworth filter with a cut-off frequency of 6 Hz (Winter et al., 1974). Segment angles were normalised and time scaled to 100% of the gait cycle, from right heel strike to consecutive right heel strike. Angle–angle diagrams were created for all three planes of motion with the proximal oscillator on the horizontal axis and the distal

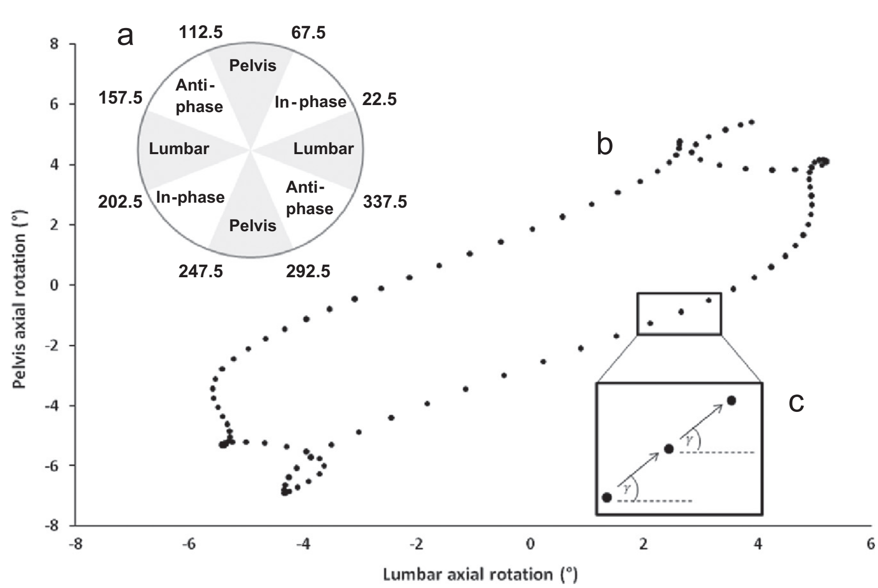

Fig. 1. (a) Classification of coordination pattern from the coupling angle (Chang et al., 2008). (b) Angle–angle diagram of pelvis–lumbar coordination in the transverse plane representing mean data from 10 participants. (c) Coupling angle (γ_i) determined by the vector orientation between two adjacent data points in time on an angle–angle diagram relative to the right horizontal.