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Short communication

A new coordination pattern classification to assess gait kinematics when utilising a modified vector coding technique

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ABSTRACT

A modified vector coding (VC) technique was used to quantify lumbar–pelvic coordination during gait. The outcome measure from the modified VC technique is known as the coupling angle (CA) which can be classified into one of four coordination patterns. This study introduces a new classification for this coordination pattern that expands on a current data analysis technique by introducing the terms in-phase with proximal dominancy, in-phase with distal dominancy, anti-phase with proximal dominancy and anti-phase with distal dominancy. This proposed coordination pattern classification can offer an interpretation of the CA that provides either in-phase or anti-phase coordination information, along with an understanding of the direction of segmental rotations and the segment that is the dominant mover at each point in time. Classifying the CA against the new defined coordination patterns and presenting this information in a traditional time-series format in this study has offered an insight into segmental range of motion. A new illustration is also presented which details the distribution of the CA within each of the coordination patterns and allows for the quantification of segmental dominancy. The proposed illustration technique can have important implications in demonstrating gait coordination data in an easily comprehensible fashion by clinicians and scientists alike.

1. Introduction

Vector coding is a data analysis technique that can be applied to an angle–angle diagram to quantify the movement coordination between two body segments over time. Using a modified technique presented by Sparrow et al. (1987), Hamill et al. (2000) described the 'coupling angle' (CA) which refers to the vector orientation between two adjacent time points on an angle–angle diagram relative to the right horizontal (Fig. 1a). Based on the polar plot position which ranges between 0° and 360°, the CA can be classified to a coordination pattern. For example, a vector orientation of 0° or 180° indicates the proximal segment is moving and the distal segment is in a fixed position, while 90° and 270° specify the opposite (Hamill et al., 2000). However, during a dynamic movement it is uncommon for one segment to be in a fixed position for an extended period of time. Therefore, in an attempt to quantify rear-foot and fore-foot coordination, Chang et al. (2008) expanded on the original interpretation of the CA by dividing the unit circle into 45° 'bins' and classifying the coordination pattern as in-phase (two segments rotate in the same direction), anti-phase (two segments rotate in an opposite direction), proximal phase (rear-foot dominancy) or distal phase (fore-foot dominancy) (Fig. 1b). Whilst the results of this study provided an insight into the functional workings of the foot, and offered a new perspective for an understanding of a musculoskeletal condition such as plantar fasciitis, as such this is the only approach currently employed to classify the CA to quantify the coordination pattern.

Needham et al. (2014) implemented the data analysis technique by Chang et al. (2008) to quantify lumbar–pelvic coordination during gait. In this study a new illustration was also presented, which included time-series information of both the CA and global segmental angle data. Needham et al. (2014) noted that pelvis dominancy was the common coordination pattern during the loading response phase of gait, and this was attributed to a greater range of motion (ROM) of the pelvis in comparison to the lumbar spine. However, global segmental angle data revealed an anti-phase relationship during this pelvis dominated phase, and detailed important information which was not provided in the coordination pattern classification by a previous study (Chang et al., 2008).

Therefore, the aim of this paper was to classify the CA to a coordination pattern which represents phase dominancy (in-phase or anti-phase), segmental dominance and provides information on the direction of segmental rotations. Furthermore, this approach will help to assess the ROM in a continuous way rather than

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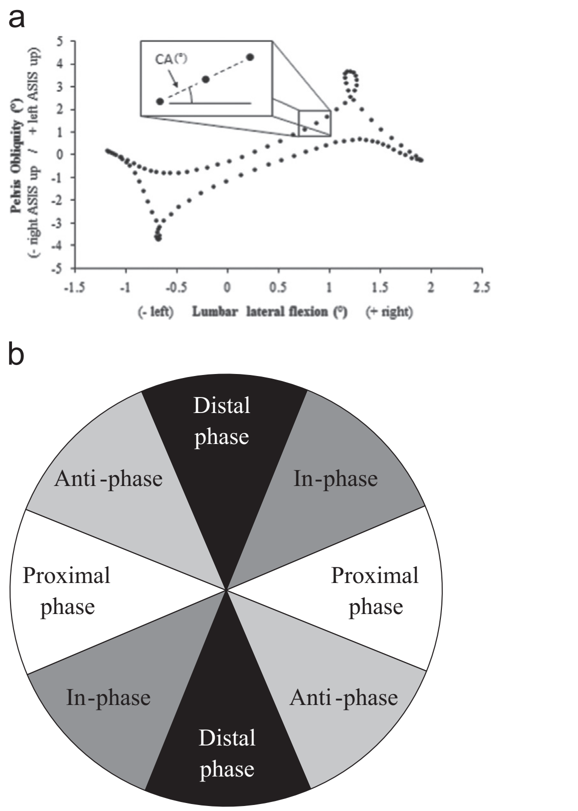

Fig. 1. An angle–angle plot representing pelvis obliquity and lumbar lateral flexion during gait. The inset provides an expanded view of one CA (a). A polar plot showing the coordination pattern classification scheme by Chang et al. (2008) (b).

measuring its magnitude within discrete time frames. Such information will assist in the interpretation of the CA and can have implications in clinical settings (Seay et al., 2011).

2. Methodology

Eight male participants (mean ± SD: age: 21 ± 2.83 years, height: 180.75 ± 96 cm, body mass: 72.86 ± 10.57 kg) with no history of musculoskeletal impairments gave written consent to participate in the study. Ethical approval was granted from the University Research Ethics Committee.

Pelvis and lumbar spine kinematic data was collected (100 frames per second) over five walking trials using an eight camera motion capture system (VICON, Oxford, UK). Gait events (heel strike and toe off) were identified using two AMTI-OR6 force platforms (AMTI, USA). The pelvis segment was defined by the placement of reflective markers on the anterior and posterior iliac spines, and a 3D cluster tracked lumbar spine movement in the region of L3 (Needham et al., In press). For further information on method procedures and for the calculations regarding the VC technique, readers are directed to a study by Needham et al. (2014).

2.1. *New coordination classification*

In Fig. 2, portions of the polar plot are colour coded and represent the four coordination patterns proposed in this study. These include in-phase with proximal dominancy (white), in-phase with distal dominancy (light grey), anti-phase with proximal dominancy (dark grey) and anti-phase with distal dominancy (black).

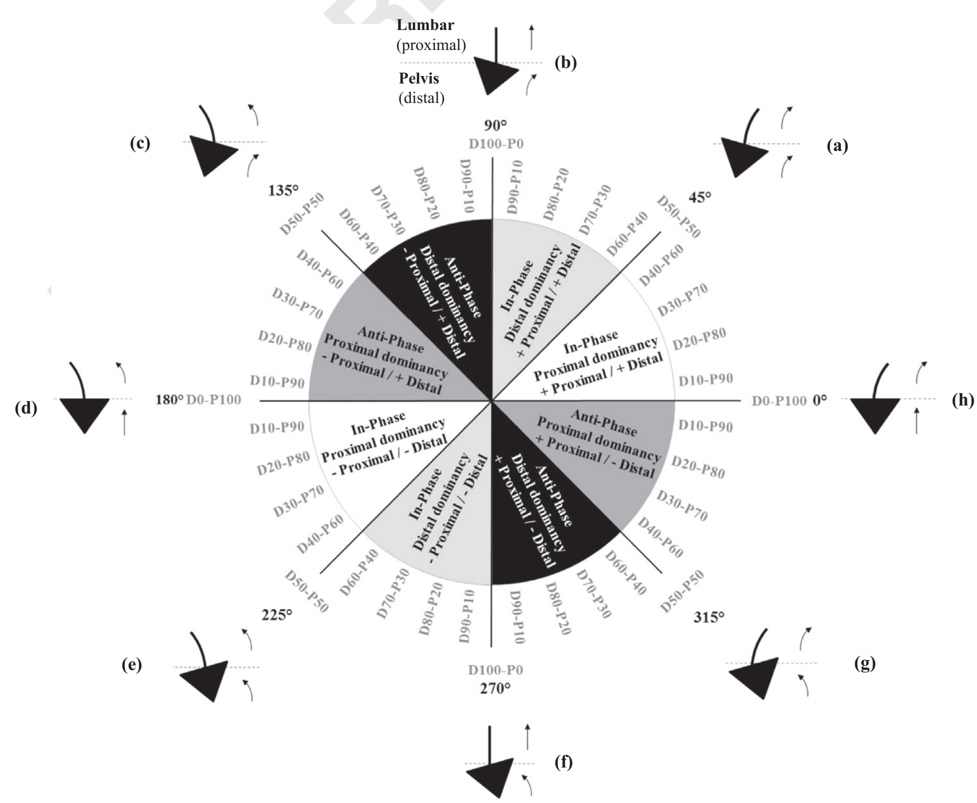

Fig. 2. The new coordination pattern classification proposed in the current study. Segmental dominancy is shown around the circumference of the polar plot (grey text) with the inclusion of visual illustrations to show the coordination pattern between the lumbar region (proximal) and the pelvis (distal) at specific CA's (a–h).

Segmental rotation direction for the proximal and distal segments is shown within each coordination pattern classification. This direction is determined by the polar position of the CA and the subsequent rectangular coordinates of the X and Y axes (+/−). For the current study, segmental rotations in a positive direction (+) signified lumbar lateral flexion to the right and pelvis obliquity, with the left side of the pelvis being higher than the right side.

The grey number around the circumference of Fig. 2 signifies a percentage and was used to quantify proximal (P) and distal (D) dominancy. Since there are 400 gradians in a unit circle, each quadrant is represented by 100 gradians. At 45° and 225° for example, an in-phase coordination pattern implies both segments are rotating in the same direction at the same rate. Therefore, converting gradians to a percentage, this equal contribution of both segments towards relative movement can be expressed as D50–P50 (Fig. 2a/e). Dominancy of a segment is recognised by a percentage over 50 until complete dominancy is achieved at right angles of 0–360°/180° (D0–P100) or 90°/270° (D100–P0).

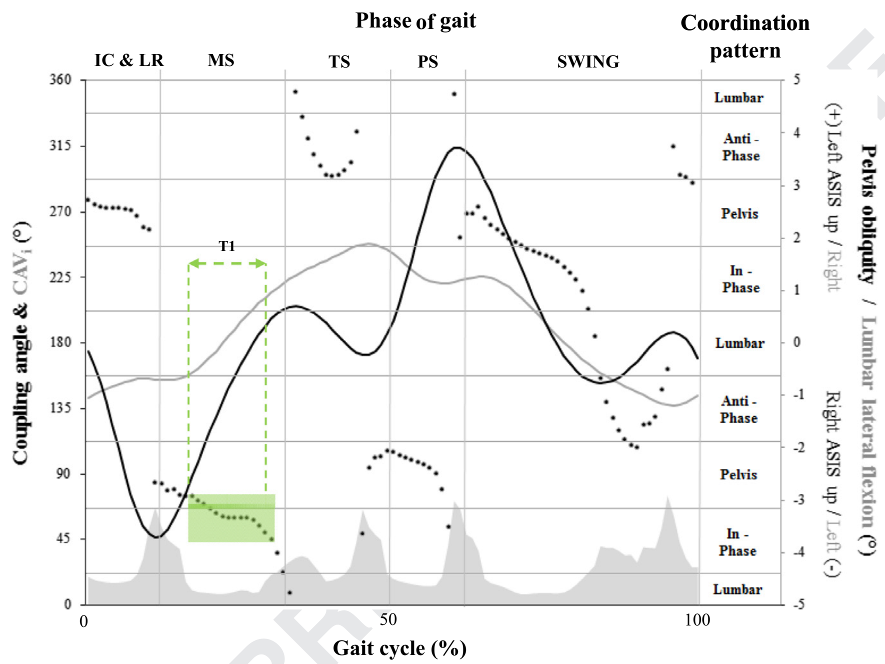

Fig. 3. Mean coupling angle for lumbar–pelvic coordination in the frontal plane during gait presented using the original illustration and coordination pattern classification (Needham et al., 2014). (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

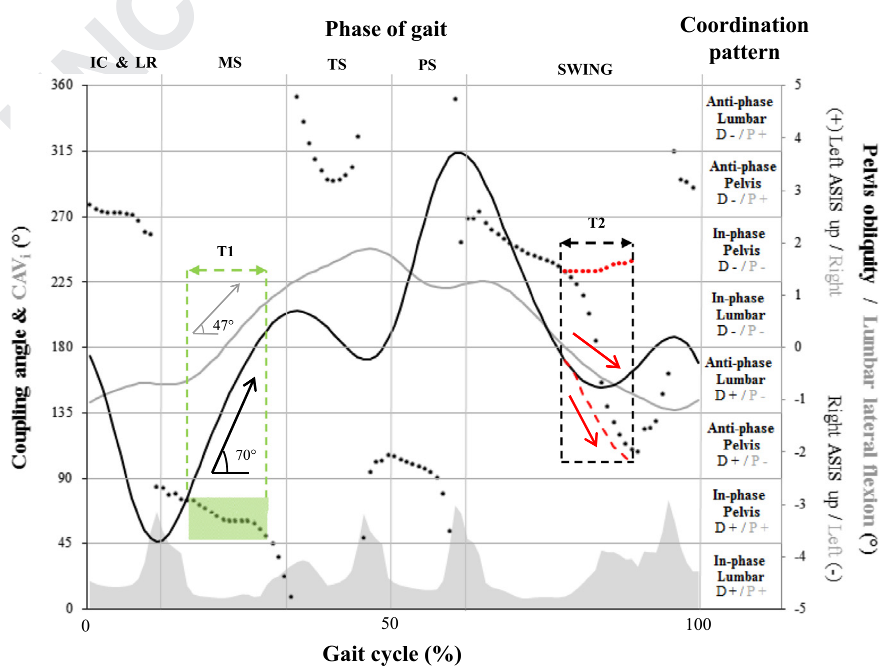

Fig. 4. Mean coupling angle for lumbar–pelvic coordination in the frontal plane during gait presented using the new illustration and coordination pattern classification proposed in the current study. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

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2.2. *Information to support the interpretation of new coordination pattern classification*

Figs. 3 and 4 present identical times-series CA and global data for the pelvis and lumbar spine in the frontal plane during gait. In Fig. 3 the CA is interpreted using the coordination patterns defined by Chang et al. (2008). In Fig. 4 the CA is deduced by the new coordination pattern classification proposed in the current study, and two working examples were provided to assist in this interpretation (Time 1 – *T*1/Time 2 – *T*2). For comparative purposes, green transparent rectangles (*T*1) were positioned over the CA in Figs. 3 and 4 and matched for time. The red dots and red dashed line in Fig. 4 (*T*2) signified hypothetical data representing CA and pelvis global angle data respectively. The orientation of the arrows used to support the interpretation of *T*1 and *T*2 reveals the dominancy of segmental movement, i.e. the greater the angle the greater the angular rotation for an instant in time (Fig. 4). For a description of the illustration used in Figs. 3 and 4, readers are directed elsewhere (Needham et al., 2014).

3. Results

3.1. *Time 1 (T1 – green rectangle)*

In Fig. 3, an analysis of the CA during Mid-Stance (MS) suggests there is pelvis dominancy before a transition to an in-phase coordination pattern. An examination of the same time period in Fig. 4 (green rectangle) further revealed information on the coordination pattern between the pelvis and lumbar spine. For instance, while pelvis dominancy is still reported at the beginning of MS, the new classification suggests an in-phase coordination pattern is also present. The orientation of the black and grey arrows within *T*1 highlighted pelvis and lumbar angular rotations

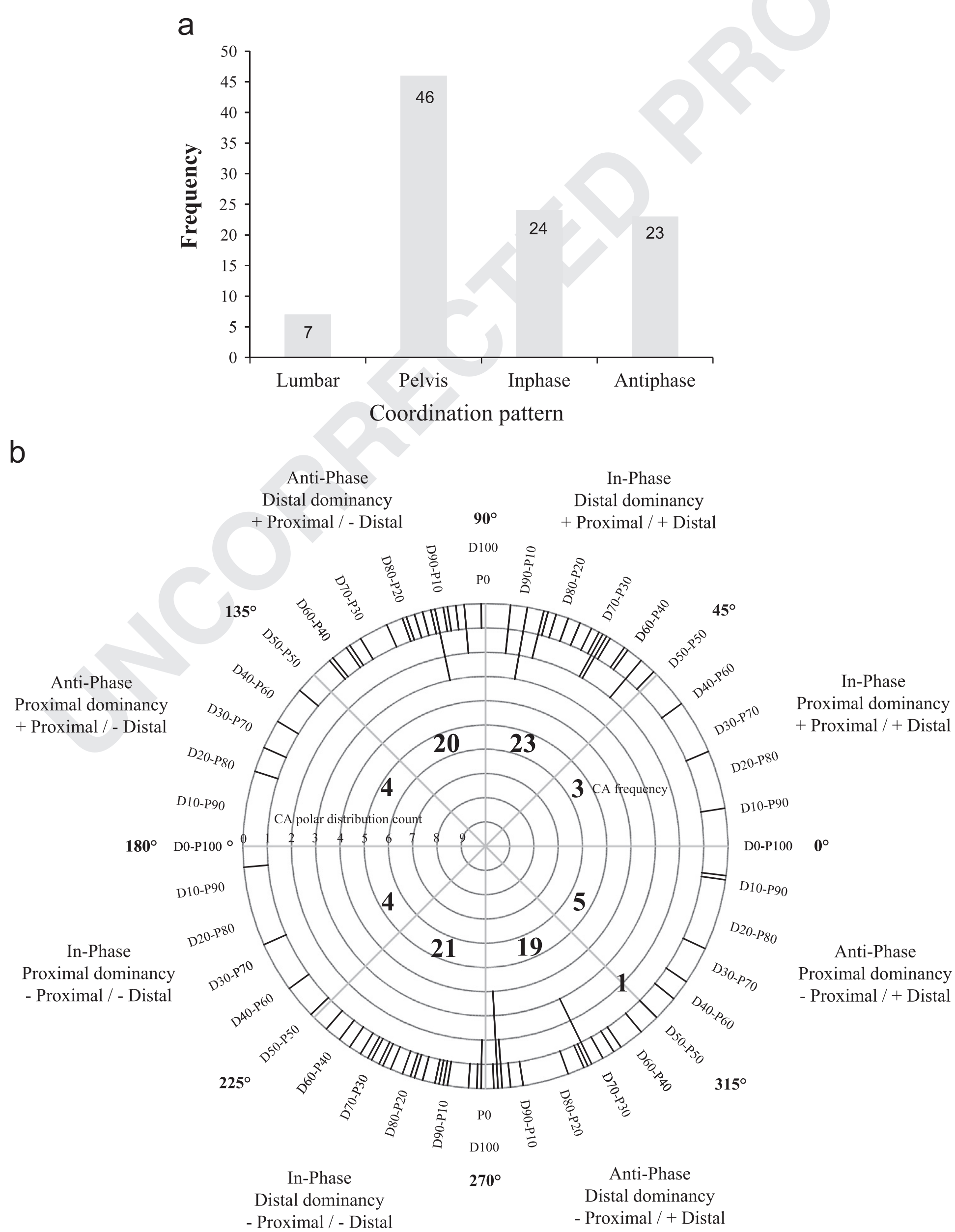

Fig. 5. Coordination pattern frequency data for lumbar–pelvis coordination in the frontal plane using a sum total approach (a) versus a new polar plot illustration subdividing the CA frequency within each coordination pattern (b). For each coordination pattern, the CA polar distribution count relates to the number of times each CA is calculated and is shown within the polar plot using the inner circles (1–9) (b). Segmental dominancy is shown around the circumference of the polar plot.

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in a positive direction which supports this claim. At approximately halfway through MS an in-phase coordination pattern is noted in Fig. 3. In Fig. 4 the new classification also revealed a pelvis dominant coordination pattern during this in-phase movement. The angle of the black arrow (70°) in comparison to the grey arrow (47°) within *T*1 demonstrates this pelvis dominancy during this period of the gait cycle.

4. CA polar distribution, coordination pattern frequency and segmental dominancy

Fig. 5a provides frequency data for lumbar–pelvic coordination in the frontal plane and highlights pelvis dominancy as the principle factor, with a similar contribution of in-phase and anti-phase coordination. The frequency data in Fig. 5b shows further information, by revealing an equal influence of anti- and in-phase coordination during this pelvis dominancy for both positive and negative segmental rotations.

For in-phase pelvis dominancy with both segments rotating in a negative direction, the resultant CA's were evenly distributed across the entire 45° bin (predominant polar distribution count of 1). However, in a positive direction, a similar distribution was shown although a polar distribution count above 1 was noted on some occasions. In addition, the polar plot also illustrates the dominancy measure to highlight which segment contributes the most to that relative movement in question. For example, if one looks at the upper right quadrant in Fig. 5b and follow the measurement in an anti-clockwise direction (from 45° to 90°), while there is clear pelvis dominancy there is no clear indication of the percentage contribution between the proximal and distal segment towards relative movement. A CA count of one was noted at 315° highlighting that the proximal and distal segments were rotating in an opposite direction at the same rate during that time window.

5. Discussion

5.1. Time 1 (T1)

Chang et al. (2008) noted similar coordination patterns when they reduced the 45° bins to 30°, suggesting that the CA did not lay near the bin margins for the majority of the time. This is in contrast to the current and a previous study where the CA regularly spanned across the coordination pattern bins and was often positioned near to the boundaries (Needham et al., 2014). For instance, in Fig. 3 an analysis of the CA during MS (green rectangle) initially suggests pelvis dominancy. However, at this particular point in time the CA lies close to an in-phase coordination pattern, and the analysis of the segmental angle data revealed this in-phase movement between the segments. In addition, following a transition to an in-phase coordination pattern (green rectangle) (Fig. 3), the CA subsequently lies near the boundary of pelvis dominancy. Again, an analysis of the global segmental data and the greater angle of the black arrow (70°) in comparison to the angle of the grey arrow (47°) within *T*1 demonstrated this pelvis dominancy during this in-phase movement (Fig. 4).

5.2. Time 2 (T2)

In the new illustration (Fig. 4) the inclusion of segmental dominancy and rotation information in each of the coordination patterns offers the opportunity to interpret the CA in relation to ROM. To demonstrate this, hypothetical data were included in Fig. 4. In this example, pelvis segmental ROM within *T*2 was increased in a negative direction (red dashed line). Subsequently, the CA (red dots) would remain in an in-phase pelvis coordination pattern as both segments are rotating in the same direction (negative) and the orientation of the red arrows implies the pelvis is still the dominant segment during relative movement.

6. CA polar distribution, coordination pattern frequency and segmental dominancy

In Figs. 3 and 4 the analysis of the global segmental kinematic waveforms (black and grey lines) revealed similar frontal plane segmental rotations in a positive and negative direction over the gait cycle. This information is presented clearly in Fig. 5b and shown by the equal distribution of the CA in each coordination patterns. For example, similar CA frequencies were noted for in-phase pelvis coordination when both segments were rotating in a positive and negative direction (23 and 21 respectively). Since this data is representative of healthy individuals, the presence of pathology could alter the symmetry of the CA frequency. However, the reporting of the CA frequency measure alone does not specify the degree of proximal or distal dominancy. For instance, if the CA were mostly distributed around 80° the distal segment (compared to the proximal segment) would contribute more to relative movement than if the CA were distributed around 50°. Therefore, an overall reporting of an in-phase distal dominancy coordination pattern would not provide for an accurate account of the dynamic interaction between segments. Fig. 5b offers a visual illustration of the polar distribution of the CA within each coordination pattern with the use of a percentage scale around the circumference of the polar plot providing information on segmental dominancy. In addition, the inner circles of Fig. 5b allow the frequency for each CA to be quantified. The new illustration (Fig. 4) and approach of interpreting the CA (Fig. 5b) could have implications in the study of pathology on gait kinematics. For instance, Seay et al. (2011) investigated the effect of low back pain (LBP) on pelvis–trunk coordination during walking and running. For the walking trials, the LBP group exhibited greater in-phase coordination in the frontal plane during the gait cycle which was attributed to a decrease in trunk dominancy and an increase in pelvis dominancy.

7. Conclusion

This paper has expanded on the utilisation of the VC technique by introducing a new coordination pattern classification which interprets the CA with phase dominancy (in-phase or anti-phase) and segmental dominancy information. The combination of such knowledge along with an understanding of segmental rotation direction offers the opportunity to highlight differences in ROM at each time point during the gait cycle which is particularly useful in the study of gait pathologies. The proposed illustration technique can have substantial implications in demonstrating gait coordination patterns in an understandable and easily comprehendible fashion by clinicians and scientists alike.

Conflict of interest statement

None.

Uncited reference

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Winter et al. (1974).

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