A NOVEL METHOD FOR COMPARING VECTOR CODING PROFILES

Adam Brazil[1], Laurie Needham[1], Tim Exell[2], Cassie Wilson[1] and Gareth Irwin[3]

Department for Health, University of Bath, Bath, UK[1]
School of Sport, Health & Exercise Science, University of Portsmouth, Portsmouth, UK[2]
School of Sport & Health Sciences, Cardiff Metropolitan University, Cardiff, UK[3]

The aim of this study was to present a new method for comparing intra-limb coordination profiles utilising vector coding and coordination binning approaches. Three-dimensional kinematic data (250 Hz) were collected from six male sprinters performing bilateral and unilateral 30 cm drop jumps. Vector coding techniques were applied to sagittal plane angle-angle plots for the hip-knee, hip-ankle and knee-ankle joint couples and resulting coupling angles were binned into eight distinct coordination patterns. A 'difference score' was calculated to provide discrete and continuous comparison of coordination profiles between each task. The method presented offers a simple, practical way for researchers and practitioners to understand and compare movement coordination between tasks and could be applied to any inter- and intra- individual comparison.

KEYWORDS: coordination, exercise selection, training specificity.

INTRODUCTION: The analysis of intra-limb coordination provides information about the interaction between components of the biological system that can enhance understanding of how movement is organised beyond the analysis of individual joints (Freedman-Silvernail et al., 2018). Vector coding analysis quantifies the relative motion of two joints or segments, by calculating the vector orientation between adjacent points on an angle-angle plot relative to the right horizontal, referred to as the coupling angle (Hamill, Haddad, & McDermott, 2000). The coupling angle therefore describes the relationship between segments or joints, offering spatial information for researchers, clinicians and coaches to easily interpret movement coordination (Freedman-Silvernail et al., 2018). Further classification of the coupling angle into distinct 'bins' has emerged as a popular way to describe, quantify and compare movement coordination during particular tasks (Chang, Van Emmerik, & Hamill, 2008; Needham, Chockalingam, & Naemi, 2014). Whilst qualitative comparison of coordination patterns can be achieved through coupling angle profiles and novel colour mapping (Needham et al., 2018), quantitative comparisons remain limited to discrete phases within a movement by comparing the prevalence of coordination 'bins' (Chang et al., 2008; Needham et al., 2014), or the average coupling angle using circular statistics (Freedman-Silvernail et al., 2018). At present, there is a gap in the literature for a method of directly comparing coupling angle data across a movement cycle, that is interpretable for both scientists and practitioners.
In the context of sports training, similarity in movement patterns may facilitate the transfer of training to improved performance, based on the principle of specificity (Young, 2006). Taking a dynamical systems approach to movement specificity and understanding how different tasks influence intra-limb coordination patterns, may offer a fruitful avenue to objectively guide exercise selection for sports training and/or rehabilitation. The aim of this study was therefore to present a method that combines qualitative and quantitative approaches to compare intra-limb coordination profiles utilising vector coding and binning approaches. The study's purpose was to offer researchers and practitioners a simple way to compare and interpret coordination data when investigating differences between movement tasks that could be applied to any inter- or intra-individual comparison.

METHODS: Six male sprinters (mean ± SD: age, 23 ± 4 years; height, 1.82 ± 0.06 m; mass, 78.52 ± 6.91 kg) gave written consent to participate in this study following institutional ethical approval. Each participant completed three bilateral (DJ_{BL}) and three unilateral (DJ_{UL}) 30 cm drop jumps, with unilateral trials performed on each sprinters' corresponding lead leg in the starting blocks. External force data (9287BA, Kistler, Switzerland, 1000 Hz) were used to

define the ground contact phase (vertical force >10 N). Lower limb kinematic data (Brazil et al., 2017), were collected using a 15-camera motion capture system (Vicon, Oxford, UK, 250 Hz). Marker trajectories were low-pass filtered (4^{th} order Butterworth, 12 Hz cut-off) and flexion-extension joint angles computed using Visual 3D (v6, C-Motion Inc, Germantown, USA). For both tasks, sagittal plane ankle, knee and hip joint angles were analysed for the specified lead leg, and time normalised to 100% of the ground contact phase using a cubic spline.
To quantify intra-limb joint coordination, vector coding techniques (Chang et al., 2008; Needham et al., 2014) were applied to angle-angle plots for the hip-knee, hip-ankle and knee-ankle joint couples to obtain coupling angle (CA) profiles across the ground contact phase (Figure 1). Circular statistics were then applied to calculate individual average CA profiles across multiple trials, and ensemble group average CA profiles for each task. The CA at each instance of the ground contact phase was classified into one of eight coordination patterns (bins) and assigned a colour (Figure 1), to aid qualitative visualisation of coordination patterns throughout each task (Needham et al., 2018).
To provide further qualitative and quantitative comparison of coordination patterns between each task, a 'difference score' in coordination pattern, ranging from 0 (same bin) to 4 (opposite bin) was calculated at each instance across the ground contact phase, and assigned a specific grey-scale colour value (Figure 1). To quantify the global difference in coordination between the two tasks, a "Coupling Angle Difference" (CA_{DIF}) was calculated as the total difference score (sum of all difference scores at each instance of the ground contact phase) expressed as a percentage of the maximum possible value. Therefore, a lower value of CA_{DIF} indicated greater coordination similarity between the two tasks. CA_{DIF} between DJ_{BL} and DJ_{UL} was calculated on an individual (using each athlete's average CA profile) and group (using the ensemble group average CA profile) basis.

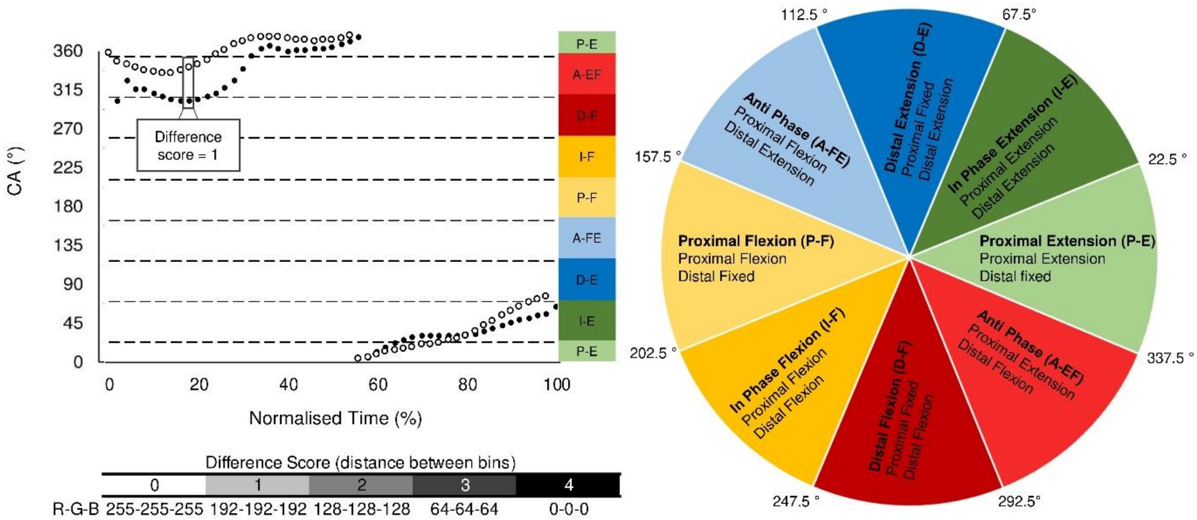

Figure 1: (left) example coupling angle profile with definition of the 'difference score', and (right) coordination pattern classification (bins).

RESULTS: Figure 2 presents the use of colour to profile coordination patterns and differences in coordination between DJ_{BL} and DJ_{UL} throughout ground contact. Results showed that DJ_{BL} and DJ_{UL} group ensemble coupling angle profiles were predominantly within one coordination bin across all joint couples. Knee-ankle coordination showed larger between-task differences around mid-contact, at the point where coordination transitioned between the two dominant patterns of in-phase flexion/ extension (Figure 2). Overall magnitudes of CA_{DIF} were found to be 6%, 11% and 13%, respectively for the hip-knee, hip-ankle and knee-ankle joint couples from the group ensemble coordination data (Figure 2), whilst individual magnitudes of CA_{DIF} ranged from 6-16%, 6-21% and 10-21% for each joint couple, respectively (Table 1).

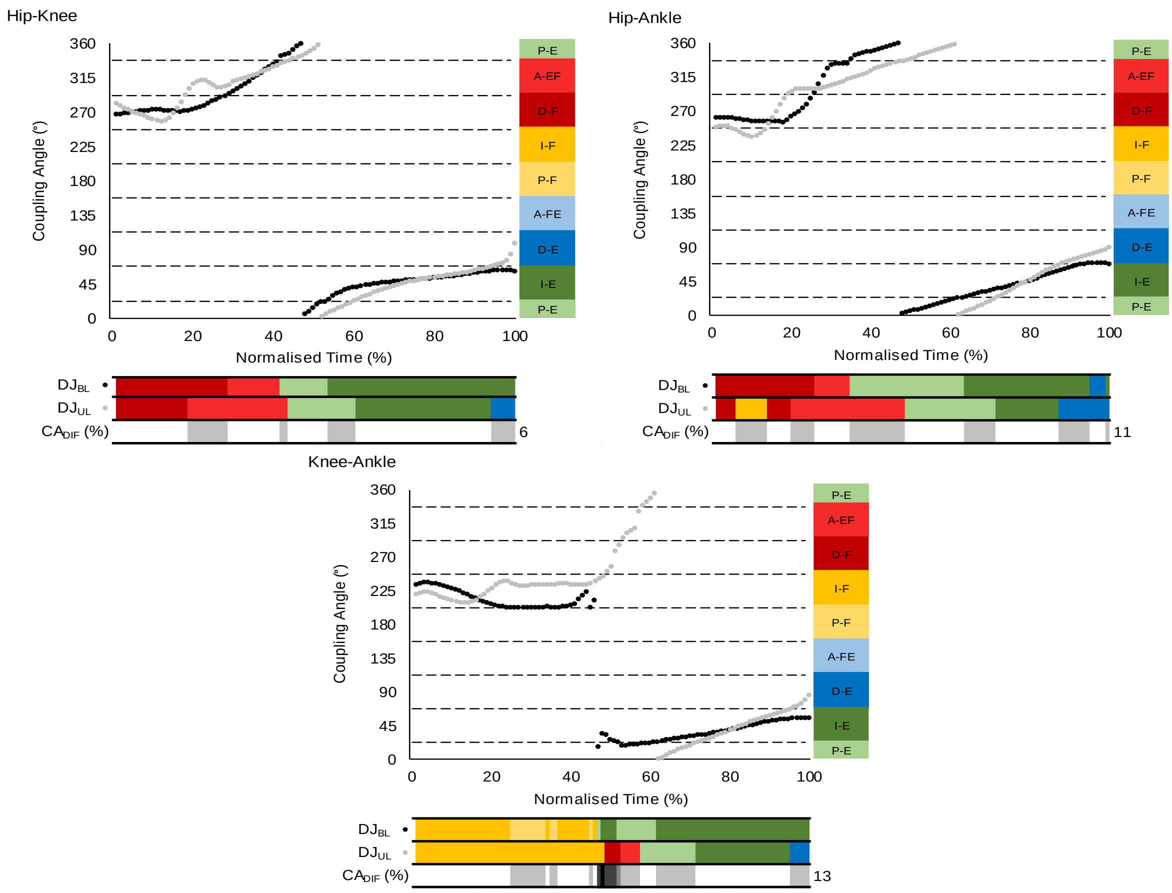

Figure 2: Group ensemble average hip-knee (top, left), hip-ankle (top right), knee-ankle (bottom) coupling angle profiles for bilateral (DJ_{BL}) and unilateral (DJ_{UL}) drop jumps. Colour maps for each coupling angle profile, and the difference in coordination bins are shown across the entire movement phase alongside the overall magnitude of CA_{DIF}.

Table 1: Individual coupling angle difference (CA_{DIF}) between bilateral and unilateral drop jumps for the hip-knee, hip-ankle, and knee-ankle joint couples.

Participant	CA_{DIF} (%)		
	Hip-Knee	Hip-Ankle	Knee-Ankle
1	13	10	21
2	14	8	18
3	6	6	10
4	8	11	12
5	16	21	20
6	10	14	16
Mean	11	12	16
SD	4	5	4

DISCUSSION: The aim of the current study was to present a new method for comparing intra-limb coordination profiles across an entire movement phase, combining qualitative and quantitative techniques applied to traditional vector coding and coordination binning approaches. By visualising the difference between coordination patterns, lower limb joint coordination was found to be largely similar between bilateral and unilateral drop jumps throughout the entire phase duration and observed local differences were mostly within one bin (Figure 2). The greatest local difference was shown for the knee-ankle joint couple around mid-contact (Figure 2). At this point, coordination was transitioning from in-phase flexion to in-phase extension (Figure 2) and the observed differences may be indicative of increased neuromuscular demand to tolerate eccentric forces during DJ_{UL}, changing the dynamics of coordination around knee and ankle joint reversal. Alternatively, greater individual variability at joint reversals or artefact when consecutive CA data points are in close proximity, may explain the observed differences (Heiderscheit, Hamill & Van Emmerik, 2002). CA_{DIF} provided additional quantification of global differences in coordination between DJ_{BL} and DJ_{UL} (Figure 2, Table 1), with knee-ankle coordination again eliciting the greatest differences. Magnitudes of CA_{DIF} were lower when applied to group average CA profiles (Figure 2, Table 1), highlighting that single-subject analysis can be an effective way of complementing group designs.

The current method offers a practical alternative over directional statistics applied to discrete phases within a movement (Freedman-Silvernail, 2018; Wilson, Simpson & Hamill, 2009), and greater insight over frequency analysis of coordination patterns (Chang et al., 2008; Needham et a., 2014). Qualitative and quantitative use of the ‘difference score’ could be applied to any inter- or intra- individual comparison in addition to modern techniques of ‘coupling angle mapping’ (Needham et al., 2018) as shown in Figure 2, and could be used in conjunction with other binning definitions (Beitter et al., 2020; Chang et al., 2008; Needham et al., 2018). The ‘difference score’ defines the largest difference when the same pattern of coordination emerges but with opposite direction in joint motion (Figure 1). Whilst this may conflict with previous interpretations of CA data (Chang et al., 2008), the presented method recognises the true movement pattern and, in principle, has the same interpretation as computing the CA circular difference (Freedman-Silvernail et al., 2018).

An important application of the current research for sports biomechanics is the comparison of coordination between tasks to help guide exercise selection (Irwin & Kerwin, 2007; Wilson et al., 2009). Understanding how different tasks influence emergent coordination patterns may provide novel insight to movement specificity and how similarities in movement pattern may mediate the transfer of training to sports performance, or patient specific rehabilitation.

CONCLUSION: This study implemented a new method for comparing coordination patterns, derived from vector coding and coordination binning techniques, that allows local and global differences in coordination to be qualitatively and quantitatively assessed across an entire movement cycle. The “Coupling Angle Difference” method provides an interpretable way for researchers and practitioners to understand the emergence of different patterns of coordination and could easily be applied to any within- or between- subjects design.

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