

ANALYSING PATTERNS OF COORDINATION AND PATTERNS OF CONTROL DURING A MAXIMAL INSTEP KICK IN ASSOCIATION FOOTBALL USING NOVEL DATA VISUALISATION TECHNIQUES IN VECTOR CODING

Robert A. Needham¹, Jamie A. Gosling¹, Roozbeh Naemi¹, Joseph Hamill^{1,2}, Nachiappan Chockalingam¹

**Sport & Exercise, Staffordshire University, Stoke-on-Trent, UK¹
University of Massachusetts Amherst, USA²**

The purpose of this study was to use novel data visualisations for profiling the coordination pattern, segmental dominancy and inter-data point range of motion (IDP-ROM) when utilising a modified vector coding technique. On group data, coupling angle mapping and segmental dominancy profiling noted similar coordination patterns between the thorax and pelvis during the maximal instep kick on the dominant (D) and non-dominant limbs (ND). However, time-series profiling of IDP-ROM of the dominant segment visually highlighted greater pelvis range of motion during the forward swing phase of the kicking leg for the D limb in comparison to the ND limb.

KEYWORDS: Coupling angle mapping, segmental dominancy profiling, range of motion

INTRODUCTION: An angle-angle diagram provides a qualitative view on the coordination pattern between segments during movement. For a quantitative assessment, a modified vector coding technique can be used to calculate the vector orientation between adjacent data points on an angle-angle diagram relative to the right horizontal (Needham, Chockalingam, & Naemi, 2014). The outcome measure is referred as the coupling angle (Fig. 1a) and based on the vector orientation, each coupling angle over a movement cycle can be assigned to a coordination pattern classification (Needham, Naemi, & Chockalingam, 2015) (Fig. 1b). Coupling angle data is typically reported using a time-series figure that describes the unit measure on the left vertical axis and the coordination pattern classification on the right vertical axis. However, this traditional reporting approach is limited when comparing multiple trials on the same figure (Needham, Naemi, Hamill, & Chockalingam, 2020). Developments in vector coding provide novel data visualisations that support single-subject research designs and allow for a comparison of several time-series data with no data overlay. For instance, the introduction of coupling angle mapping, which denotes a colour-scale method to display the coordination pattern (Fig. 1b), permits for the vertical stacking of coupling angle maps that provides a simple and intuitive view of an entire dataset at specific time points (Needham et al., 2020). In addition, combining coupling angle mapping with data bars can provide a qualitative view on segmental dominancy profiling, which not only provides a quantitative measure of dominancy as a percentage, but can detail changes in the distribution of the coupling angle within a coordination pattern classification over time (Needham et al., 2020). Coupling angle mapping has been used previously to examine thorax-pelvis coordination during the maximal instep kick in Association Football (Needham et al., 2018). The authors found that the thorax and pelvis rotated in the same direction (in-phase coordination) during the back swing of the kicking leg, which was followed by rotation in opposite directions (anti-phase coordination) during the forward swing of the kicking leg. This coordination strategy represents the formation and release phase of a concept known as the 'tension arc' (Shan & Westerhoff, 2005), which is considered an expression of the stretch-shortening cycle (Lees, Asai, Andersen, Nunome & Sterzing, 2010) and is a key contributor to foot velocity during a maximal instep kick. Needham et al. (2018) also observed similar coordination patterns between the thorax and pelvis segments during the maximal instep kick with the dominant (D) and non-dominant (ND) limbs. However, single-subject analysis revealed several participants produced greater thorax and pelvis range of motion (ROM) while kicking with the D limb in comparison to the ND limb. Detailing trunk kinematics is important since greater trunk axial rotation ROM is strongly linked

to greater post-strike ball velocity in skilled footballers (Fullenkamp, Campbell, Laurent, & Lane, 2015). However, vector coding can characterise the shape of an angle-angle plot and detail the coordination between segments at each instant in time but is unable to provide a measure of control (i.e. range of motion). To fully understand performance outcomes, it is necessary to examine patterns of coordination and patterns of control (Glazier, 2017). From a qualitative perspective, an accurate comparison of coupling angle and segment angle data at specific time points on a traditional time-series figure is not possible due to the measurement scale of the parameters, and when multiple trials are overlaid (Fig. 1c/d). Quantifying “inter-data point range of motion” (IDP-ROM) of the dominant segment on an angle-angle plot is an alternative approach, which complements segmental dominancy profiling and can be superimposed over coupling angle mapping (Needham et al. 2020).

Therefore, the aim of this study was to showcase data visualisation techniques that profiles time-series data on the coordination pattern, segmental dominancy, and IDP-ROM (Needham et al., 2020). The dataset in this study compares thorax-pelvis coordination in the transverse plane during the maximal instep kick with the D and ND limbs.

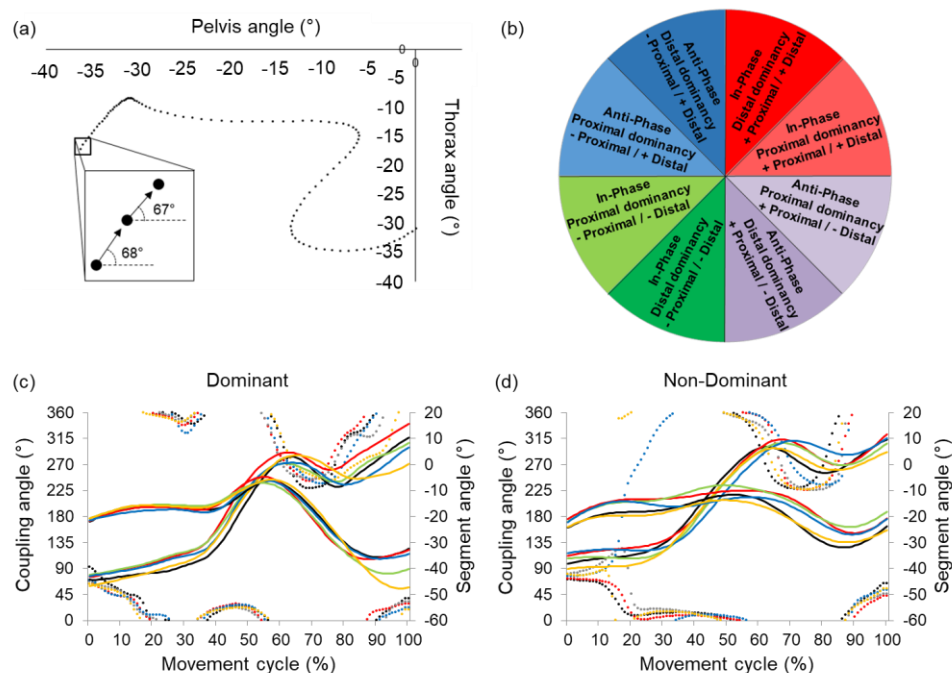


Figure 1: (a) angle–angle plot representing axial rotation of the thorax and pelvis segment during a maximal instep kick. The inset provides an expanded view of two coupling angles; (b) Coordination pattern classification adapted from Needham et al. (2020) illustrating colour-scale for each classification; (c/d) angle-time series figure describing coupling angle data (dotted lines) on the left vertical axis and segment angle (solid lines) data on the right vertical axis. Each colour represents the same trial.

METHODS: The data collection procedures and experimental data were from a previous study from which ethical approval was sought and received from the University Research Ethics Committee (Needham et al., 2018). In summary, ten male university football players participated in this study (mean \pm SD age: 22.1 \pm 5years, height: 183.47 \pm 24.1cm, mass: 75.88 \pm 18.14kg). An 18-camera motion capture system (VICON, Oxford, UK) collected thorax and pelvis segment angle data at 200Hz. Five trials were collected on the D and ND sides. Data was normalised for time (0-100%) from kicking leg toe off (KLTO) to maximum hip flexion (MHF) of the kicking leg. Additional events during the maximal instep kick included maximal hip extension (MHE) and ball contact (BC). Readers are directed elsewhere for further information on vector coding calculations (Needham et al., 2020), coordination pattern classification (Fig. 1b) (Needham et al., 2015), coupling angle mapping, segmental dominancy and IDP-ROM profiling (Needham et al., 2020).

RESULTS & DISCUSSION:

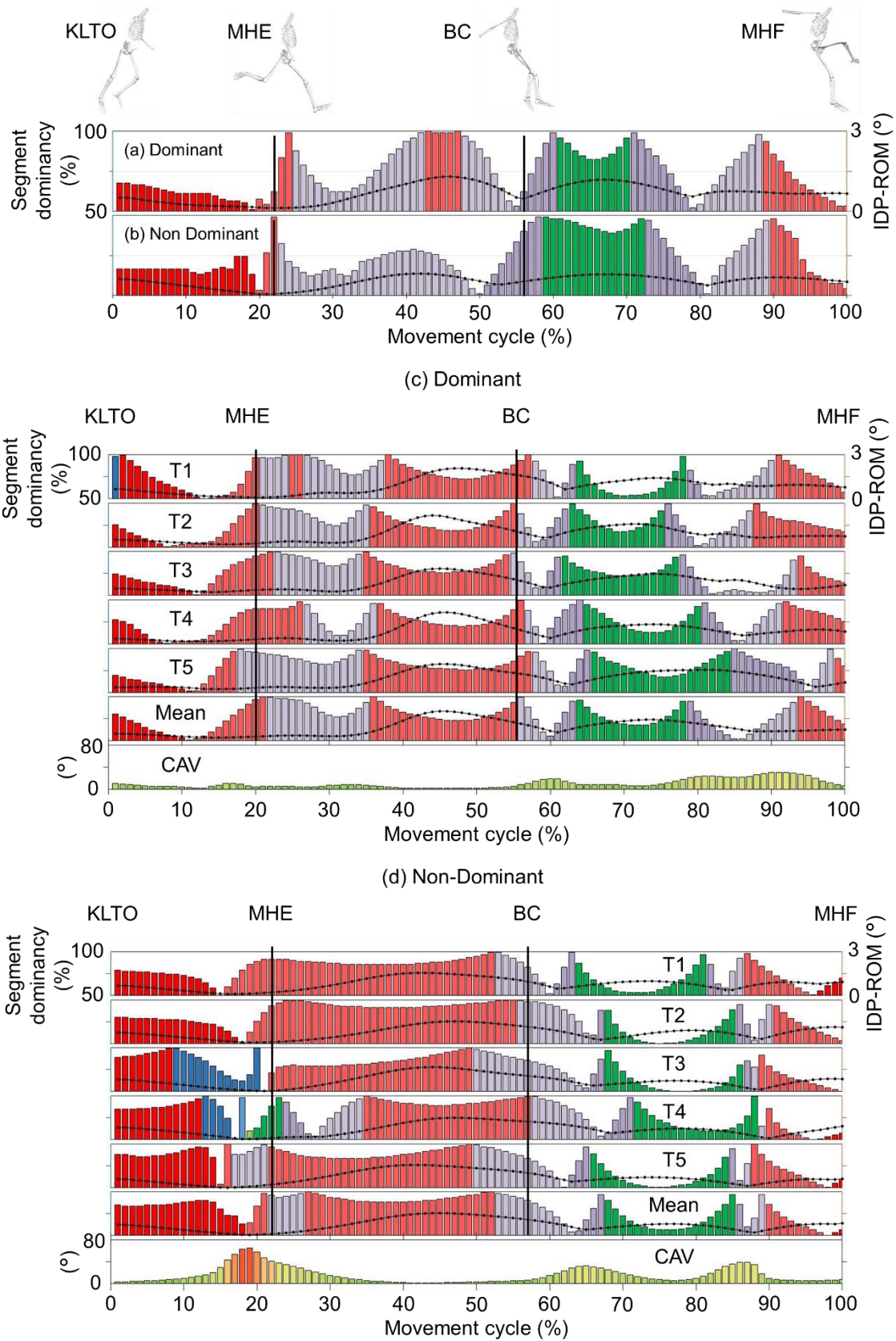


Figure 2: (a/b) Coupling angle mapping (color), segmental dominance (data bars) and IDP-ROM (black dots) profiling representing the group mean and (c/d) for a single participant across five trials (T1-T5) for the D and ND limb. CAV illustrates coordination variability profiling.

Table 1: Peak foot velocity (m/s) for the group and for a single participant

<i>Group</i>	Dominant	Non-dominant
Mean (\pm)	17.31 (0.94)	14.48 (1.20)
<i>Participant</i>		
Trial 1	17.41	14.17
Trial 2	17.39	14.13
Trial 3	17.94	13.97
Trial 4	18.20	14.04
Trial 5	18.01	13.95
Mean (\pm)	17.79 (0.37)	14.05 (0.10)

Thorax-pelvis coordination in the transverse plane during the maximal instep kick revealed in-phase coordination with thorax dominance between KLTO and MHE, and predominantly anti-phase coordination with pelvis dominance between MHE to BC (Fig. 2a/b). These coordination strategies are consistent with the tension arc theory (Shan & Westerhoff, 2005). However, in the release phase, the pelvis is more dominant and rotates through a greater ROM with the D limb compared to the ND limb. In addition, peak pelvis dominance and peak IDP-ROM occur closer to BC for the D limb. These observations for the D limb, along with the transition from thorax dominance to pelvis dominance, may have increased the amount of energy and momentum transferred to the lower limbs that would explain the higher foot velocity compared with the ND limb (Table 1) (Fullenkamp et al., 2015; Naito, Fukui, Maruyama, 2012).

Foot velocity for the kicking leg was greater for the D limb compared to the ND limb for both group and single participant data. While similar velocities were noted between the group and the single participant for either the D or ND limb (Table 1), the coordination pattern on the D and ND limb for the single participant did not match the group observation during the release phase (Fig. 2). Also, compared to the group, the single participant demonstrated a rapid increase in IDP-ROM profile for the D limb following the transition from anti-phase to in-phase pelvis dominance. With this example, the proposed data visualisations may provide insight into the relationship between coordination and control and should be applied in single-subject research designs based on the uniqueness of individual coordination pattern development.

CONCLUSION: The data visualisations and profiling techniques presented in this study offer practitioners a detailed view on patterns of coordination and patterns of control that will have benefits by informing coaching and clinical management strategies.

REFERENCES

- Fullenkamp, A. M., Campbell, B. M., Laurent, C. M., & Lane, A. P. (2015). The contribution of trunk axial kinematics to poststrike ball velocity during maximal instep soccer kicking. *Journal of applied biomechanics*, 31, 370-376.
- Glazier, P. S. (2017). Towards a grand unified theory of sports performance. *Human movement science*, 56, 139-156.
- Lees, A., Asai, T., Andersen, T. B., Nunome, H., & Sterzing, T. (2010). The biomechanics of kicking in soccer: A review. *Journal of sports sciences*, 28, 805-817.
- Naito K, Fukui Y, Maruyama T (2012). Energy redistribution analysis of dynamic mechanisms of multi-body, multi-joint kinetic chain movement during soccer instep kicks. *Human Movement Science*, 31, 161–181.
- Needham, R.A., Naemi, R., & Chockalingam, N. (2014). Quantifying lumbar–pelvis coordination during gait using a modified vector coding technique. *Journal of Biomechanics*, 47, 1020–1026.
- Needham, R.A., Naemi, R., & Chockalingam, N. (2015). A new coordination pattern classification to assess gait kinematics when utilising a modified vector coding technique. *Journal of Biomechanics*, 48, 3506–3511.
- Needham, R.A., Gosling, J.A., Naemi, R., Hamill, J., & Chockalingam, N. (2018). Coupling angle mapping to assess pelvis-thorax coordination and coordination variability during the maximal instep kick in association football. 36th Conf. International Society of Biomechanics in Sport., Auckland University of Technology, New Zealand: 2018.
- Needham, R.A., Naemi, R., Hamill, J., & Chockalingam, N. (2020). Novel data visualisation techniques in vector coding: Using colour and data bars to profile time series data for assessing segment coordination and coordination variability. *The Foot (in-press)*.
- Shan, G., & Westerhoff, P. (2005). Full-Body Kinematic Characteristics of the Maximal Instep Soccer Kick by Male Soccer Players and Parameters Related to Kick Quality. *Sports Biomechanics*, 4, 59-72.