SIMILARITY OF COORDINATION PATTERNS IN A GROUP OF HIGHLY TRAINED SPRINTERS: A NOVEL APPROACH

Byron Donaldson[1], Neil Bezodis[2], Helen Bayne[1]

[1]Department of Physiology and Sport Exercise Medicine and Lifestyle Institute (SEMLI), Faculty of Health Sciences, University of Pretoria, South Africa
[2]A-STEM Research Centre, Swansea University, UK

Understanding coordination patterns aids technical understanding and potential grouping of athletes that exhibit similar movement patterns. This study assessed between-individual similarity in initial sprint acceleration coordination in highly trained to world class sprinters using a novel pairwise approach. Similarity between participants was higher for thigh-thigh coordination compared to shank-foot and trunk-shank coordination. Mean similarity increased from step 1 to step 4 in shank-foot (0.74 to 0.83) and trunk-shank (0.68 to 0.79) couplings but remained consistent in the thigh-thigh coupling (0.89 to 0.91). Researchers and practitioners should consider that coordination between sprinters converges over initial acceleration, but between any two individuals coordination similarity might increase or decrease across steps.

KEYWORDS: lower-limb coordination, coupling angle difference, sprint.

INTRODUCTION: In many biomechanics contexts, researchers are interested in assessing similarity in movement patterns across groups or individuals, in order to identify features of movement patterns which may be associated with particular performance outcomes, injury risks or pathologies. Coordination analysis is a useful technique to understand movement organisation as a component of technique in a given task. In popular coordination analysis techniques like modified vector coding (Chang et al. 2008), differences between groups are typically assessed using broad measures like the proportion of time spent in a particular coordination pattern (i.e. bin frequency) over the entire course of a movement or a relevant sub-phase. However, bin frequencies provide only a high level view of similarity in coordinative approach and it is logically plausible for different coordination strategies to yield similar bin frequencies over an entire phase or movement. Such bin frequencies reveal neither similarity in the sequence of bins over time nor easily quantify the degree of similarity between two profiles, considering that the difference between different bins is not uniform. A one-to-one comparison for each time point taking into account the structure of the underlying data may help solve this problem. Further, while groups can often be clearly defined based on a priori criteria (e.g. pathology, experience, skill or physical capacities), sometimes group classifications may be arbitrary or of little use and it would be more suited to particular research questions to categorise individuals with similar movement strategies, an approach common in many unsupervised machine learning algorithms. This may facilitate grouping athletes with similar movement strategies to understand the particular constraints around the way they move for training purposes and injury risk profiles.

While initial sprint acceleration may generally be considered a cyclic movement, step-to-step kinematic changes do occur (Nagahara et al., 2014; von Lieres und Wilkau et al., 2018). This may result in differences in coordination similarity between individuals over the course of initial sprint acceleration. Understanding this may be useful in trying to identify athletes with common technical approaches to the sprint start, where it may be of value to know whether strategies are consistent at the level of the individual step or the whole phase, or if coordination strategies diverge or converge between certain individuals. However, to date this has not yet been studied. Therefore, the purpose of this study was to evaluate coordination similarity between individuals in three segment couples (thigh-thigh, trunk-shank, shank-foot) during the first four steps of sprint acceleration and assess whether similarity between individuals changes between steps.

METHODS: Twenty-one highly trained to world-class male and female sprinters (100 m PB: M = 10.47 ± 0.42 s; F = 11.79 ± 0.24 s) gave written consent to participate in this study, approved by the institutional research ethics committee. On an outdoor track, following their habitual warm up, sprinters performed three maximal effort sprint trials of at least 20 m from starting blocks, from which their fastest trial was included for analysis. Trials were performed in participants' own spikes with at least 5 minutes rest between efforts. Sagittal plane kinematics were obtained from tri-axial inertial measurement units (IMU; 200 Hz, Myomotion, Noraxon, USA) fitted prior to performing sprint trials. Sensors were attached to the upper spine (T1), lower spine (T12), sacrum, lateral aspect of both thighs, medial aspect of both shanks and the dorsal surface of both feet using double-sided tape and secured with custom velcro straps or self-adhesive bandages. A static calibration procedure in an upright standing posture was performed, establishing the 0° reference angle (Berner et al., 2020). A synchronised sagittal plane video camera (100 Hz, Ninox-250, Noraxon, USA) recorded the first four steps of each trial and was used to identify touchdown and toe off. Video and IMU data were recorded and processed using MyoResearch 3.14 (Noraxon, USA). A step was defined from toe off to the next toe off of the contralateral foot. Sagittal plane kinematic variables for each of the first four steps were time normalised to 101 data points, with block clearance representing 0% time in step 1.

Coupling angles (CA) for thigh-thigh, trunk-shank and shank-foot segment couplings were obtained from angle-angle plots using modified vector coding techniques (Chang et al., 2008; Needham et al., 2020). Coordination similarity was assessed pairwise for all combinations of participants for each of the four steps and each segment coupling. Coordination similarity was defined using a modified version of the CA difference score used by Bezodis et al. (Bezodis et al., 2019), applied to the raw CA. For each pairwise participant combination, the angular distance between corresponding CA vectors for participants A and B was calculated using equation 1 for each point in time.

$$\theta = \begin{cases} 360 - |A - B|, & \text{if } |A - B| > 180° \\ |A - B|, & \text{otherwise} \end{cases} \qquad (1)$$

Therefore, the maximum possible distance between any two vectors was 180°. The sum of angular distances over the entire step was divided by the maximum possible difference score and subtracted from 1, resulting in a CA similarity score between 0 and 1. A score of 0 indicated direct opposite CA vectors at every time point and 1 indicated identical CA vectors at every time point. Similarity scores were computed between every possible pair of participants and represented in a similarity matrix for each step. Between-step differences in coordination similarity were assessed using one-way repeated measures ANOVAs and pairwise t-tests with Bonferroni corrections.

RESULTS: Pairwise similarity was typically higher for thigh-thigh coordination (mean[range]: step (S) 1 = 0.89[0.74 - 0.97], S2 = 0.92[0.75 – 0.98], S3 = 0.91[0.78 – 0.97], S4 = 0.91[0.80 – 0.98]) compared to shank-foot (mean[range]: S1 = 0.74[0.44 - 0.95], S2 = 0.76[0.47 - 0.91], S3 = 0.79[0.60 – 0.96], S4 = 0.83[0.60 – 0.96]) and trunk-shank (mean[range]: S1 = 0.68[0.39 - 0.86], S2 = 0.72[0.47 – 0.88], S3 = 0.76[0.59 – 0.92], S4 = 0.79[0.57 – 0.95]) (Figure 1, Figure 2). There was a significant effect of step on coordination similarity for the shank-foot ($F_{(2.6,535)}$ = 44.49, $p < 0.001$, $\eta^2 = 0.176$), trunk-shank ($F_{(2.4,502)}$ = 98.80, $p < 0.001$, $\eta^2 = 0.321$) and thigh-thigh ($F_{(2.4,508)}$ = 38.64, $p < 0.001$, $\eta^2 = 0.156$) couplings. For shank-foot and trunk shank couplings, all step combinations, except step 1 – step 2 ($p = 0.44$) in shank-foot, were significantly different ($p < 0.001$). Step 1 was significantly different to all other steps for thigh-thigh ($p < 0.0001$), as was step 2 – step 3 ($p = 0.021$). While mean similarity increased across the whole group between steps, for any given pair of participants, whether similarity increased or decreased was variable (Figure 1, Figure 2).
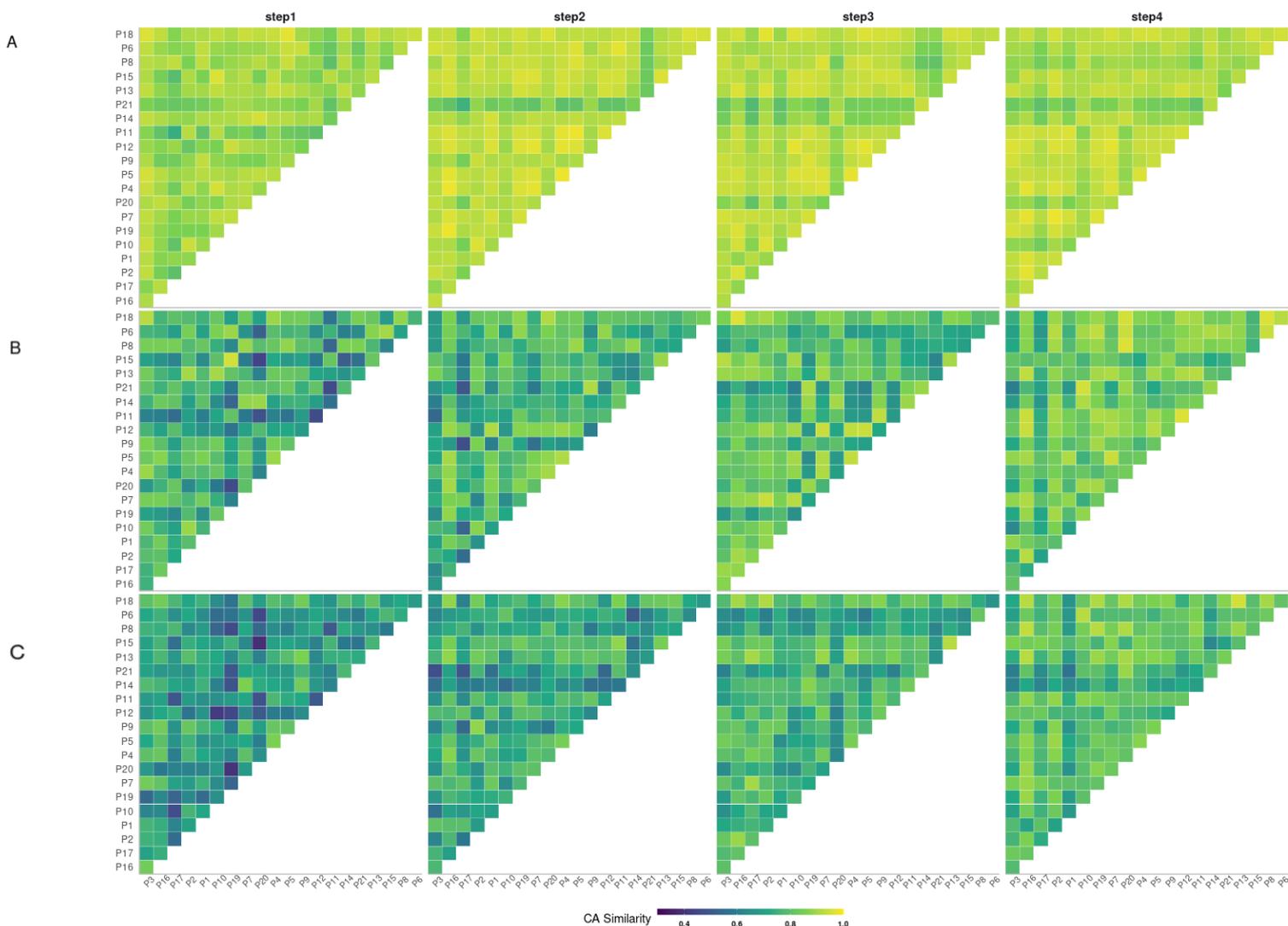
Figure 1: Coupling angle (CA) similarity matrices of all pairwise combinations of participants for shank-foot (A), thigh-thigh (B) and trunk-shank (C) segment couplings
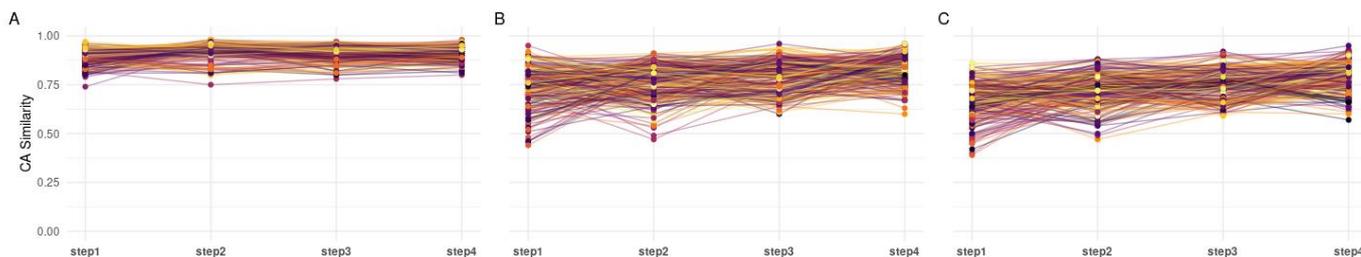
Figure 2: Progression of coordination similarity over the first four steps in all pairwise participant combinations for shank-foot (A), thigh-thigh (B) and trunk-shank (C) segment couplings

DISCUSSION:

The purpose of this study was to evaluate pairwise coordination during sprint acceleration and assess whether similarity changed between steps. Pairwise coordination similarity across a group of sprinters was typically higher in the thigh-thigh coupling compared to the shank-foot and trunk-shank couplings over the first four steps of acceleration. Pairwise similarity increased over the four steps with significant differences between steps, suggesting a convergence of

coordination patterns. The high level of similarity in thigh-thigh coordination suggests strong constraints on thigh motion. Indeed, the general increase in similarity over the four steps implies the spectrum of available coordination strategies gets narrower throughout initial acceleration. The presence of both high and relatively low similarity scores in step 1 and 2 suggest potential sub-groups with greater differences in coordination strategies than later steps. Despite the group-wide trends towards increased similarity across the four steps, for any given pair of sprinters the tendency to exhibit increased or decreased similarity between steps was variable (Figure 1, Figure 2). Indeed, in some cases there were changes of up to 0.5, or 50%, in similarity scores between steps. These results suggest that in complex movements such as acceleration, similarity between individuals and therefore potential sub-groups may change as the movement progresses. Unlike more cyclic tasks where coordination between steps may be more consistent, in acceleration one athlete might have similar coordination to another in one step but not the next.

In a range of contexts, researchers and practitioners may be interested in identifying sub-groups of athletes with similar coordination patterns in order to make sense of individual profiling and understand the constraints that guide the movement patterns of their athletes. This study applies a simple approach for assessing coordination similarity between individuals from the modified vector coding derived coordination profiles which facilitate intuitive visual profiling via colour coding of coordination bins. The simple similarity score can be further used to compute the distance matrix required by clustering algorithms to objectively identify sub-groups of coordination patterns.

Thus, researchers might consider whether they are interested in coordination similarities in specific phases of an action or over whole events when comparing athletes, and carefully consider their desired outcome when using machine learning tools like cluster analysis based on coordination data as inputs. From a practical perspective, sprinters generally appear to converge on similar coordination strategies as initial acceleration progresses, possibly suggesting emphasis be placed on the first two steps when categorising athletes for coaching purposes.

CONCLUSION: This study presented a novel approach to assessing similarity between coordination profiles. At a whole group level, similarity in coordination patterns between sprinters increases over the course of initial acceleration, however for any two individuals similar patterns in one step may not reflect similarity in another. Future research is needed to determine the implications of such changes..

REFERENCES:
Berner, K., Cockcroft, J., Morris, L. D., & Louw, Q. (2020). Concurrent validity and within-session reliability of gait kinematics measured using an inertial motion capture system with repeated calibration. *Journal of Bodywork and Movement Therapies*, *24*(4), 251-260.

Bezodis, I. N., Brazil, A., von Lieres und Wilkau, H. C., Wood, M. A., Paradisis, G. P., Hanley, B., Tucker, C. B., Pollitt, L., Merlino, S., Vazel, P.-J., Walker, J., & Bissas, A. (2019). World-Class male sprinters and high hurdlers have similar start and initial acceleration techniques. *Frontiers in Sports and Active Living*, *1*, 23. https://doi.org/10.3389/fspor.2019.00023

Chang, R., Van Emmerik, R., & Hamill, J. (2008). Quantifying rearfoot–forefoot coordination in human walking. *Journal of Biomechanics*, *41*(14), 3101–3105. https://doi.org/10.1016/j.jbiomech.2008.07.024

Hafer, J. F., Peacock, J., Zernicke, R. F., & Agresta, C. E. (2019). Segment coordination variability differs by years of running experience: *Medicine & Science in Sports & Exercise*, *51*(7), 1438–1443. https://doi.org/10.1249/MSS.0000000000001913

Nagahara, R., Matsubayashi, T., Matsuo, A., & Zushi, K. (2014). Kinematics of transition during human accelerated sprinting. *Biology Open*, *3*(8), 689–699. https://doi.org/10.1242/bio.20148284

Needham, R. A., Naemi, R., Hamill, J., & Chockalingam, N. (2020). Analysing patterns of coordination and patterns of control using novel data visualisation techniques in vector coding. *The Foot*, 101678. https://doi.org/10.1016/j.foot.2020.101678

von Lieres und Wilkau, H. C., Irwin, G., Bezodis, N. E., Simpson, S., & Bezodis, I. N. (2018). Phase analysis in maximal sprinting: An investigation of step-to-step technical changes between the initial acceleration, transition and maximal velocity phases. *Sports Biomechanics*, 1–16. https://doi.org/10.1080/14763141.2018.1473479