WHOLE-BODY COORDINATIVE STRATEGIES CONTRIBUTE TO THE MINIMIZATION OF CENTRE OF MASS DISPLACEMENT IN MAXIMAL VELOCITY SPRINTING

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Sprinting is a dynamic skill that requires rapid and precise postural control. This study investigates the association between frontal plane centre of mass (CoM) displacement, whole-body coordination, and sprint velocity. Significant correlations with sprint velocity were found between stance phase frontal plane (cPL), superior inferior range of motion (SI ROM), and sprint velocity. Spatiotemporal coordinative coupling of the bilateral knees and thorax-pelvis axial twisting displayed significant partial correlations with the minimization of frontal plane cPL and SI CoM RoM. The findings of this work suggest that both the upper and lower body contribute to the control of the CoM within the frontal plane. Coaches and performance practitioners can leverage these findings to identify potential technical errors to enhance athlete sprint performance.

KEYWORDS: Sprint Biomechanics, Spine, Motor Control, Dynamical Systems Theory, Wearable Sensors

INTRODUCTION: For decades, biomechanists have been interested in understanding the biomechanical determinants leading to improved sprint velocity. Early studies on this topic date back to the early 1900s when the first biomechanical studies on sprint performance were completed. These studies aimed to understand the mechanical dynamics that could be used to model sprint velocity (Furusawa et al., 1927). Since then, the majority of research on sprinting has been done to understand the neuromuscular Mero & Komi, 2004), kinematic (Clark et al., 2020; Haugen et al., 2018), kinetic (Clark & Weyand, 2014; Morin et al., 2015) and step kinematics (Hunter et al., 2004), that underpin improved sprint performance. However, in doing so there has been a neglect of understanding the time-varying spatiotemporal multi-joint coordinative strategies that underpin improved sprint performance. Specifically, what remains neglected is the understanding that the coordination between segments of the upper-body and lower-body contributes to the control of the centre of mass during maximal velocity sprinting. The study of multi-segmental coordination during sprinting is limited, but previous work has demonstrated that differences in coordinative strategies can be used to differentiate between skill levels in sports such as race walking (Cazzola et al., 2016; Preatoni et al., 2013), and cross-country skiing (Vereijken et al., 1992), while differences can also be observed in individuals with a history of injury compared to healthy individuals in sub-maximal running (Hamill et al., 2012; Seay et al., 2011). The functional performance benefits and injury prevention benefits of different coordinative strategies are well represented in the biomechanics literature, however, an established biomechanical rationale for the improvement in health and performance has yet to be established. Therefore, the ***purpose*** of this project is to understand the association of measures of coordination of the upper and lower extremity, and trunk on frontal plane CoM displacement. We ***hypothesized***, that frontal plane CoM displacement will display negative correlations with faster sprint velocity and that contralateral upper and lower limbs, bilateral limbs and trunk mean absolute relative phase (MARP) profiles will be associated with the minimization of the displacement of the CoM in the frontal plane.

METHODS: 39 healthy university aged athletes (27 male; mean +/- standard deviation age: 21.8 +/- 3.2 years; height: 176.8 +/- 8.4 cm, peak sprint velocity: 7.94 +/- 0.69 m/s) were recruited for this study. Participants ran three maximal 60m sprints while wearing a 17-sensor IMU motion capture suit (XSens MTW Awinda, Netherlands). Five strides about the point of peak velocity, of the fastest sprint, were drift corrected, stride segmented, time-normalized and ensemble averaged before being used to calculate frontal plane CoM behaviour and multi-joint coordination. To quantify CoM behaviour, stance phase, and flight phase frontal plane cPL

(Equation 1), ML CoM RoM and SI CoM RoM were calculated. To quantify whole-body coordination, mean absolute relative phase (MARP) (Hamill et al., 2012; Seay et al., 2011) was calculated for the following couplings, Knee-Knee, Hip-Hip, Shoulder-Shoulder, Thorax-Pelvis (Flexion/Extension, Lateral Bending, and Axial Twisting), Right Shoulder-Left Hip, Left Shoulder-Right Hip, Left Shoulder-Right Knee, and Right Shoulder – Left Knee (Equation 2).

Equation 1: $PL = \sum_{i=1}^{n} \sqrt{(CoMy(i+1) - CoMy(i))^2 + (CoMz(i+1) - CoMz(i))^2}$

Equation 2: $N\big(y(t_i)\big) = 2\left(\frac{y(t_i) - \min(y(t))}{\max\big(y(t)\big) - \min(y(t))}\right) - 1$

To understand the relationship between the stance and flight phase frontal plane CoM cPL, SI CoM and ML CoM RoM bivariate linear regressions were completed. The CoM metrics, that displayed significant correlations with sprinting velocity, were used as independent variables to determine the association between bilateral, contralateral and 3D trunk spatiotemporal coordination and CoM frontal plane displacement. Following this, partial correlation coefficients were calculated to understand the contribution of each coordinative coupling on the independent CoM variable.

RESULTS: The results of this study suggest that frontal plane stance phase CoM displacement displayed statistically significant correlations with sprint velocity (**Figure 1**). Specifically, stance phase frontal plane cPL, ML CoM RoM, and SI CoM RoM demonstrated a moderate negative correlation with sprint velocity and were statistically significant ($r = -0.36$-0.59, $r^2=0.13$-$.34$, $p = 0.0001$-0.02) (**Table 1**). In addition to these stance phase CoM metrics, the flight phase SI CoM RoM also demonstrated a significant negative correlation with sprint velocity ($r = -0.35$, $r^2 = 0.125$, $p = 0.005$). The frontal plane cPL and ML CoM RoM were not correlated with sprint velocity ($r=0.01$-0.02, $r^2<0.01$, $p = 0.92$-0.95) (**Table 2**).

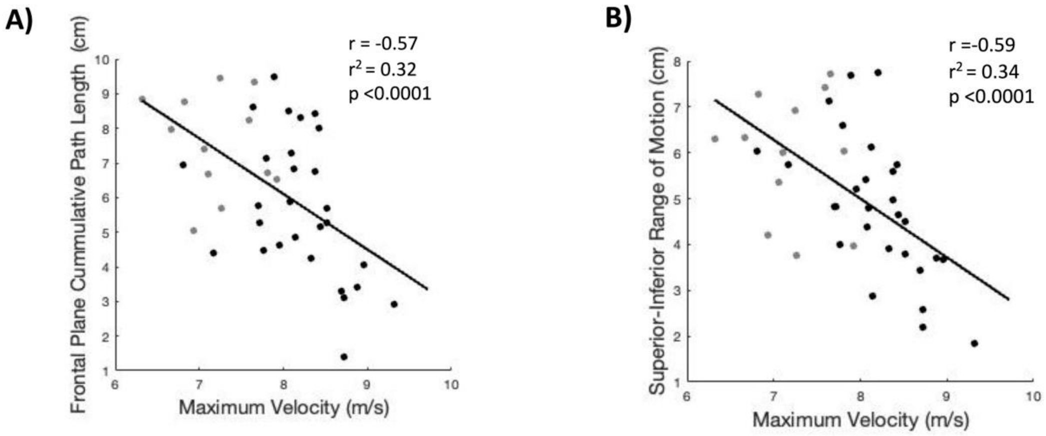

Figure 1. Significant bi-variate correlations between frontal plane CoM behaviour and sprint velocity. Grey represents female participants, black represents male participants.

Multivariate linear regression models were constructed to determine the association between bilateral, contralateral and 3D trunk spatiotemporal coordination and CoM frontal plane displacement. Significant regression models were created for the stance cPL, and stance phase SI CoM RoM. A summary of these models are presented in **Table 1**. Additionally, to understand the importance of each of the coordinative couplings on the control of the CoM for the statistically significant multivariate regression models, partial correlation coefficients were calculated for each coordinative coupling. A summary of these can be seen in **Figure 2**.

Table 1: The Relationship Between Mean Absolute Relative Phase (MARP) and Statistically Significant Frontal Plane CoM Behaviours (m/s).

	r^2	Adjusted r^2	RMSE	p-value

Stance				
Frontal Plane Cumulative Path Length	0.53	0.36	1.72	**0.007***
Medio-Lateral Range of Motion	0.3	0.06	0.83	0.316
Superior-Inferior Range of Motion	0.54	0.38	1.27	**0.005***
Flight				
Superior-Inferior Range of Motion	0.14	0.14	1.13	0.89

*Significant correlation: *p<.05.*

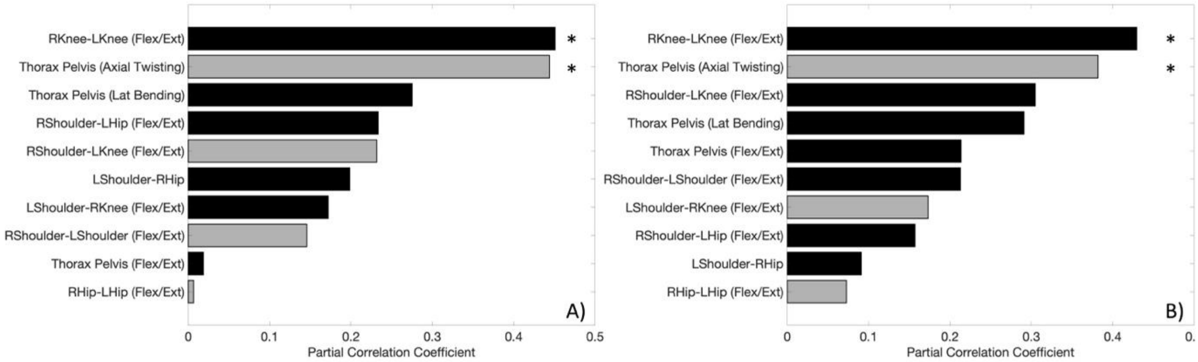

Figure 2. Partial correlation coefficients for MARP couplings in the multivariate models. **A)** Represents the stance frontal plane cumulative CoM path length and **B)** Represents the stance phase SI RoM. Black represents a positive partial correlation value, grey represents a negative. The asterisk (*) represents a statistically significant (p<.05) partial correlation coefficient.

DISCUSSION: The results from this study revealed that stance phase CoM frontal plane cPL, ML RoM and SI RoM displayed significant correlations with sprint velocity. During the flight phase, SI RoM was the only CoM metric that displayed a significant correlation with sprint velocity. Each of these CoM variables were used as inputs into multivariate linear regression models to understand the relationship between bilateral, contralateral and 3D trunk coordination were associated frontal plane CoM kinematics. Stance phase SI RoM and stance phase CoM cPL displayed significant correlations with ten bilateral coordinative couplings. These findings support our initial hypothesis that CoM frontal plane displacement (as calculated through frontal plane cPL, SI RoM and ML RoM) was associated with full-body spatiotemporal coordination.
The results of this study demonstrate the utility of analysing the entire body during complex whole-body movements such a sprinting. Much of the previous rhetoric in sprinting has aimed to looked to understand sprint performance by exclusively analysing the lower body. As a result, a plethora of previous research has demonstrated the utility of analysing the lower extremity in sprinting athletes, while many questions remain regarding the functional significance of the upper body and trunk during sprinting. The results of this study build on previous theoretical work and experimental work in submaximal running and walking, that suggest that the reciprocal action of the contralateral arm and leg swing and axial rotation of the trunk play an important role in the regulation of the frontal plane CoM behaviour. Specifically, the stance phase cPL in the frontal plane an SI CoM RoM demonstrated significant associations with peak velocity. These findings suggest that the coordination of the upper body during sprinting plays an active role in maintaining balance and aiding an athlete in maintaining a forward projection of the CoM. Further work can be completed to understand additional the role the upper body plays in key factors in sprinting, such as optimization of ground contact time and flight time, bioenergetic efficiency, and creation of optimal ground reaction force orientation.

CONCLUSION: Sprinting is a complex skill that requires the athlete to fine-tune their motor coordination strategy to optimize their velocity. The results of this study demonstrate the utility in approaching the study of whole-body movement patterns by considering both the trunk and lower body. By doing this we were able to find evidence that supports the notion that the trunk plays a functionally significant role in the generation of sprint velocity, which is likely mediate through the control of the stance CoM SI RoM and CoM frontal plane cPL. The information from this study can be used by coaches and athletes to better understand technique manipulations that may be required to improve maximal velocity running.

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