KINETIC FACTORS DIFFERENTIATING MID-TO-LATE SPRINT ACCELERATION PERFORMANCE IN SPRINTERS AND SOCCER PLAYERS

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High-speed running in soccer is an important skill, however, the underlying kinetic factors are not fully understood. Ground reaction forces from steps 8 to 24 of maximal-effort sprints were captured for 24 soccer players and 28 track and field athletes using 54 force plates. Correlations between discrete force variables and horizontal acceleration were assessed, and statistical parametric mapping revealed performance associations across entire waveforms. Track and field athletes produced higher forces (mean anteroposterior: 1.56 $N \cdot kg^{-1}$) across shorter contacts (0.101 s) than soccer players (1.27 $N \cdot kg^{-1}$, 0.110 s). Interestingly, the technical ability to apply force and the performance-differentiating parts of stance were similar across groups. Thus, practitioners should perhaps target physical (force production) rather than technical factors to improve soccer players' sprint abilities.

KEY WORDS: forces, regression, running, waveform analysis

INTRODUCTION: The perceived importance of high-speed running for successful participation in soccer is high (Haugen, Tonnessen, & Seiler, 2013) and consequently the mechanical determinants of soccer players' sprint performances are of great interest. Sprint acceleration performance is primarily determined by the ability to generate high net anteroposterior force and maintain a horizontally-orientated force vector (Rabita et al., 2015). However, the importance to generate large vertical force across progressively shorter ground contacts is high during maximum velocity treadmill running (Weyand, Sternlight, Bellizzi, & Wright, 2000) and also becomes increasingly more important as individuals approach maximum velocity during overground sprints (Nagahara et al., 2017). Furthermore, the minimisation of braking forces becomes progressively more important as higher running velocities are attained compared with early acceleration, where concentric force development appears to be more crucial (Colyer, Nagahara, & Salo, 2018; Nagahara et al., 2017). However, it is yet to be fully established whether these kinetic factors differentiating performance are directly comparable across sprinters and soccer players. Thus, this study aimed to understand the differences in kinetic determinants of mid-to-late acceleration amongst sprint specialists and soccer players.

METHODS: Twenty-eight male track and field athletes (mean ± SD age, mass and height were 20 ± 1 yr, 66.5 ± 3.6 kg and 1.73 ± 0.04 m, respectively) and 24 soccer players (20 ± 1 yr, 69.1 ± 5.7 kg and 1.73 ± 0.06 m, respectively) volunteered to participate in this study. Track and field athletes were sprint specialists who had 100-m personal best times ranging from 10.88 to 11.96 s. A research ethics committee provided ethical approval for this study to be conducted and all athletes provided written consent prior to participating. Track and field athletes performed between two and five maximal-effort 60-m sprints on an indoor running track from their normal crouched block start position, whereas soccer players performed three maximal-effort sprints from a standing start. Fifty-four force platforms (1000 Hz; TF-90100, TF-3055, TF-32120; Tec Gihan, Uji, Japan) connected to a single computer measured ground reaction forces during sprinting through 52 m from 1.5 m behind the start line to 50.5 m. At the start of certain trials, some soccer players were clearly moving and thus, these trials were excluded from further analyses. Photocells provided 60-m time, which was used to identify each athlete's fastest trial for inclusion in subsequent analyses.
Force data were filtered using a fourth-order low-pass Butterworth filter with a 70-Hz cut-off frequency derived through residual analysis. Resultant force was computed using the

anteroposterior and vertical forces, and ratio of forces was calculated as the ratio of anteroposterior to resultant force, in line with Morin, Edouard, and Samozino (2011). A threshold of 20-N vertical force was used to detect touchdown and take-off. In order to account for the influence of air resistance on calculated horizontal velocity, which would accumulate considerable errors over such a long distance, aerodynamic drag for each athlete was estimated using the approach of Samozino et al. (2016). Horizontal velocity calculations were verified by comparing the mean step velocities with the horizontal step velocity calculated from spatiotemporal data (centre of pressure and ground contact timings). Root mean square differences of <0.15 m/s suggested good agreement between methods.

Horizontal velocities at touchdown and take-off (calculated using anteroposterior ground reaction force and estimated aerodynamic drag) were combined with contact duration to provide average horizontal external power, which was the performance criteria for each contact based on Bezodis, Salo, and Trewartha (2010). Forces and power were calculated relative to body mass. The gradient of the trend line between step averaged velocity and ratio of forces provided the index of force application technique (D_{RF}), which reflects the ability to maintain a horizontally-orientated force vector as velocity increases (Morin et al., 2011). The maximal horizontal velocity attained across the entire 50 m was also reported.

As starting positions differed between the groups, comparisons across the initial steps were deemed inappropriate. However, it has previously been shown that differences due to starting style disappear by the 10-m mark (Salo & Bezodis, 2004). Moreover, the minimum number of steps taken by any athlete was 24 steps. Thus, force data were analysed from steps 8 (mean distance 10.5 ± 0.8 m) to 24. Mean vertical, anteroposterior, resultant and ratio of forces were calculated across each contact period, with mean values also calculated across all steps. Additionally, mean contact times and mean velocity changes during the propulsive and braking phases were calculated. Overall performance across this phase was evaluated using mean horizontal acceleration across all analysed steps (from 8^{th} to 24^{th}).

Standardised differences between groups were computed as the mean difference divided by the pooled standard deviation. Pearson correlations were used to assess whether the kinetic variables were associated with average horizontal acceleration. Standardised differences and correlation coefficients were evaluated based on smallest worthwhile effects of ±0.2 and ±0.1, respectively, through which clear (positive or negative) and unclear relationships were defined using 90% confidence intervals (CI). Open-source statistical parametric mapping (SPM) software (Pataky, 2012) was then used to assess the relationship between the anteroposterior force waveform and the average horizontal external power produced across each analysed contact, for the track and field athletes and soccer players separately. Force traces were temporally normalised from 0 to 100% of stance before linear regression models were applied to each of the 101 nodes resulting in a SPM{t} curve. Using random field theory, which describes probabilistic behaviour of random curves and accounts for the smoothness of the data, a critical threshold was set (α = 0.05). If the SPM{t} curve exceeded this critical threshold, force was deemed to be significantly related at these specific nodes to the average horizontal external power produced across that step.

RESULTS AND DISCUSSION: Track and field athletes exhibited higher mean horizontal acceleration (0.45 ± 0.05 $m \cdot s^{-2}$) and attained substantially higher maximum velocity (9.39 ± 0.35 $m \cdot s^{-1}$) compared with the soccer players (0.42 ± 0.05 $m \cdot s^{-2}$ and 8.72 ± 0.31 $m \cdot s^{-1}$) with effect sizes (±90% CI) of 0.54 ± 0.45 and 1.41 ± 0.33, respectively. The distance of maximum velocity attainment was 38.8 ± 3.9 m and 36.6 ± 3.9 m for sprinters and soccer players, respectively. This difference in accelerative capacity appears likely due to higher force production capabilities (both anteroposterior and vertical), particularly across shorter time frames, of the track and field athletes compared to soccer players (Table 1). Interestingly, the ratio of the forces produced by the soccer players as well as their ability to maintain a horizontally-orientated force vector (D_{RF}) were found to be similar to the track and field athletes. Thus, it seems that the variation in sprint ability predominantly stems from differences in physical (force production) capabilities rather than the way in which that force is applied to the ground (ratio of forces and index of force application).

In line with previous research on treadmill (Morin et al., 2011) and overground sprinting (Rabita et al., 2015), being able to generate high anteroposterior force and a high ratio of forces was related to higher accelerative performance in both athlete groups. However, in contrast to these aforementioned studies, vertical force was also found to be associated with average horizontal acceleration (Table 1). This may be due to the fact that athletes were running at a higher average velocity relative to their maximum due to data being analysed from mid-acceleration onwards. In fact, the ability to generate high effective vertical force is a key determinant of maximum speed during treadmill (Weyand et al., 2000) and overground (Nagahara et al., 2017) running. Interestingly, in both groups, braking (but not propulsive) velocity change was positively related to performance. This opposes previous findings where propulsive impulses were found to explain more of the variance in accelerative capacity than braking impulses (Hunter, Marshall, & McNair, 2005; Morin et al., 2015). This could, again, be attributed to the mid-to-late acceleration phase being studied here compared with earlier acceleration in previous studies. In fact, Nagahara et al. (2017) found that as the acceleration phase progressed, braking force became more strongly associated with sprint performance.

Table 1. Discrete kinetic variables and associations (Pearson's *r*) with mean horizontal acceleration across steps 8 to 24

	Track and field athletes		Soccer players	
	Mean ± SD	*r* ± 90% CI	Mean ± SD	*r* ± 90% CI
Mean anteroposterior force ($N{\cdot}kg^{-1}$)	1.56 ± 0.20*	**0.61 ± 0.20**	1.27 ± 0.10	**0.71 ± 0.18**
Mean vertical force ($N{\cdot}kg^{-1}$)	21.2 ± 1.2*	**0.38 ± 0.28**	18.5 ± 1.1	**0.30 ± 0.32**
Ratio of forces (%)	10.5 ± 0.8	**0.30 ± 0.29**	10.7 ± 0.8	**0.31 ± 0.32**
Index of force application (D_{RF})	-5.7 ± 0.8	**0.68 ± 0.18**	-5.8 ± 0.9	**0.35 ± 0.31**
Mean contact time (s)	0.101 ± 0.005^	**-0.37 ± 0.28**	0.110 ± 0.006	**-0.35 ± 0.31**
Mean braking velocity change ($m{\cdot}s^{-1}$)	-0.16 ± 0.02	**0.50 ± 0.24**	-0.15 ± 0.01	**0.56 ± 0.25**
Mean propulsion velocity change ($m{\cdot}s^{-1}$)	0.28 ± 0.02*	-0.14 ± 0.31	0.26 ± 0.02	-0.04 ± 0.34

CI = confidence intervals. * and ^ denote clear differences (higher or lower, respectively) between track and field athletes and soccer players. Bold denotes a clear association with mean horizontal acceleration. Correlations are statistically significant ($p < 0.05$) if the 90% CI of r do not cross zero.

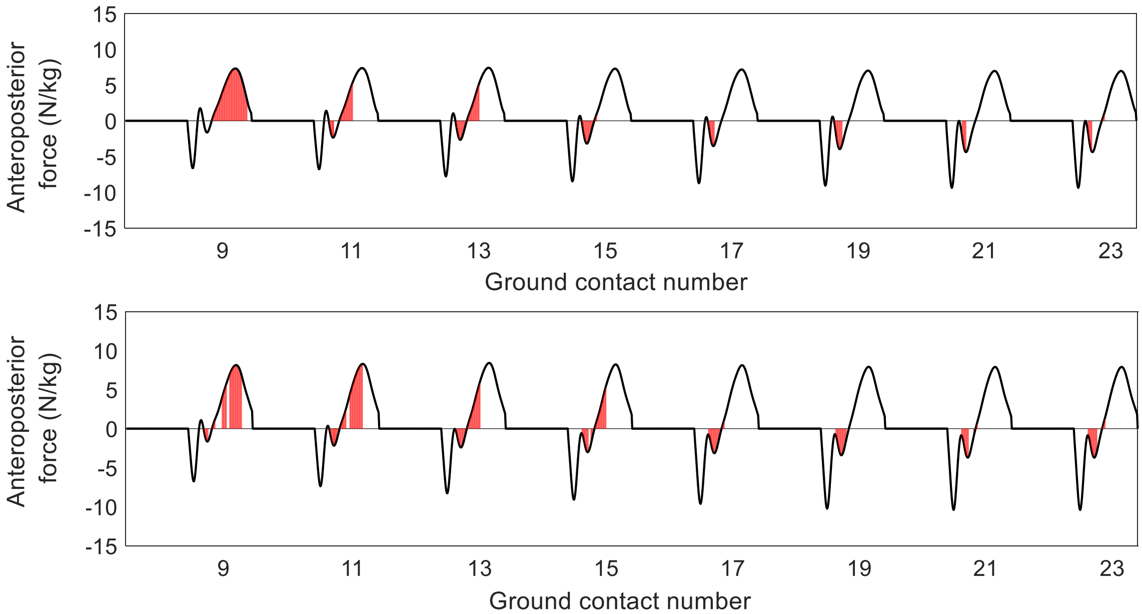

Figure 1. Mean anteroposterior force waveforms for sprint specialists (top) and soccer players (bottom), and the relationship with normalised average horizontal external power across each contact period. Red areas indicate phases of stance across which positive associations were observed for more than 5 nodes. Only odd steps are shown for presentation purposes.

The SPM analysis revealed similar patterns in the phases of stance where anteroposterior force was related to horizontal external power produced across that step for both athlete groups (Figure 1). Specifically, there was an evident shift in these associations toward earlier phases of stance as acceleration progressed. Thus, better athletes were those able to maximise propulsive forces in the earlier steps and minimise braking forces as higher velocities were attained. This highlights the varying kinetic requirements across a sprint, which should be carefully considered when prescribing training to improve acceleration.
As soccer players typically sprint on grass pitches and not on indoor tracks, it is noteworthy that these kinetic determinants may differ somewhat across different surfaces. Moreover, whilst this study revealed novel similarities and differences between sprint kinetics in soccer players and sprint specialists, we were only able to include data from step 8 onwards in our analysis due to between-group differences in starting style. As acceleration bursts in soccer are often short, the initial steps are presumably also crucial to success. Future research should incorporate the early steps in analyses, when starting styles are kept consistent.

CONCLUSION: Track and field athletes performed superior mid-to-late acceleration phases than the soccer players, primarily because they were able to generate greater anteroposterior and vertical forces across shorter contact periods. The technical ability to direct force (to produce a more horizontal force vector) and the shift in the phases of stance where anteroposterior forces differentiated performance (from increasing propulsion to limiting braking as velocity increased) appeared similar. These results indicate that in order to improve soccer players' acceleration, practitioners and coaches should perhaps place more emphasis on physical development (force generation) than technical training.

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