ANALYSIS OF SPRINT START TRANSITION PHASES AND THEIR ASSOCIATIONS WITH PERFORMANCE

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The sprint start consists of three transitions defined by the instants the hands, rear leg and front leg leave the ground, which delimit three phases. Ground reaction forces produced by 57 sprinters during the block phase were analysed to investigate the performance (average horizontal external power) implications of transition timing and the force production and centre of mass (CM) displacements between them. Better sprint starters exhibited higher horizontal (r = 0.47 for phase two), but lower vertical (r = -0.40), CM displacement across shorter time periods. Additionally, more horizontally-orientated force vectors to reduce CM projection angle at each transition were favourable (r range = -0.62 to -0.45). Coaches should encourage high anteroposterior bilateral force production even though this may compromise (r = -0.41) subsequent front block force production.

KEY WORDS: forces, correlation, power, track & field

INTRODUCTION: The ability to rapidly generate high anteroposterior force against the blocks across a short period of time underpins performance of the sprint start (Willwacher et al., 2016). Executing a powerful block start is, however, a multifactorial skill requiring high force production under different conditions: when all four limbs are in contact with the ground or blocks, when pushing bilaterally with the lower limbs against the blocks and unilaterally against the front block only. Thus, the start can be divided into three specific phases, the end-points of which correspond to the instants when the hands leave the ground and when the rear and front leg exit the respective block.

Better sprint starters have been shown to spend less total time in the blocks, yet generate considerably higher impulses (Willwacher et al., 2016). Although the relative durations of rear and front block pushing have not been extensively studied, Slawinski et al. (2010) found that elite sprinters spent a longer proportion of total block time pushing against the rear block (43.5%, 0.154 s) compared with their well-trained (39.8%, 0.140 s) counterparts. Coupled with higher anteroposterior force production, this was linked to greater rear hip extension (Slawinski et al., 2010), which has elsewhere been associated with higher performance levels (Bezodis et al., 2015). Conceivably, this would also result in a more anterior centre of mass (CM) position (relative to the front foot) at rear block exit. Conversely, the duration that the hands are in contact with the ground tends to be shorter in senior compared to junior sprinters (Graham-Smith et al., 2018). This is likely related to the set position adopted by the athlete and/or their physical ability (e.g. strength and stability) but this also has the potential to affect performance across the latter block push phases.

Little research to date has specifically focussed on these transition phases and to our knowledge no studies have investigated their potential relationship with overall sprint start performance. Thus, the aim of this study was to investigate the timings of these transitions, as well as the CM displacements and force production between them, and their associations with overall sprint start performance (average horizontal external power).

METHODS: Fifty-seven male athletes (mass = 70.9 ± 10.1 kg and height = 1.74 ± 0.25 m) ranging from junior academy athletes to sub-10 second sprinters provided informed consent. Following a self- or coach-led warm-up, athletes performed between one and eight maximal-effort block starts with at least four minutes recovery between efforts. Ground reaction force data were collected during 20-40 m accelerations for thirty-seven athletes in an indoor track

setting. The remaining athletes performed ~5 m accelerations from the blocks in a laboratory setting. The block phase protocol was, however, exactly the same across testing locations.
Four force platforms (two 9287CA and two 9281E on the indoor track and four 9287BA in the laboratory; Kistler Instruments Ltd, Switzerland; sampling at 1000 Hz) covered by synthetic matting were used to collect ground reaction forces under each of the legs and arms separately. A 7-point moving average was used to smooth all the data, as this was irreversibly applied to the data collected on the indoor track due to the nature of these sessions and the requirements for quick feedback. Pilot testing revealed very minor differences (<0.3%) in output variables when compared to those calculated from data smoothed using a conventional low-pass Butterworth filter.
Anteroposterior and vertical forces from all four force plates were summed to provide total forces in the respective directions, from which resultant force (sagittal plane) was calculated. Weight distribution (%) across the rear and front legs, and the arms (combined) was then computed when the athlete was in the stable set position. The first instant where vertical force exceeded 20 N above the steady body weight force (and stayed above for 30 ms) was defined as movement onset. Three phases were defined (Figure 1) which ended at the instants the hand forces and the rear and front block forces fell below 20 N, respectively.

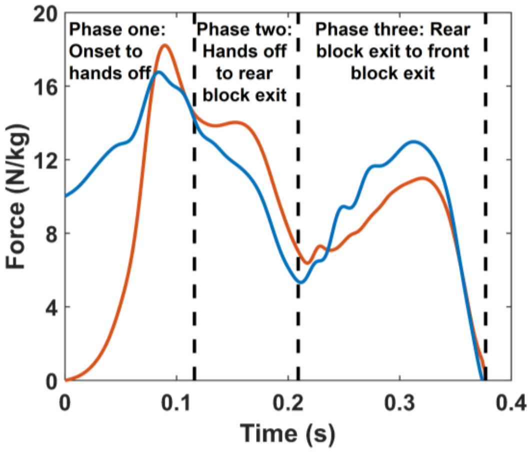

Figure 1. Example of the ground reaction forces (red = anteroposterior; blue = vertical) produced across each phase of the sprint start. Dashed lines represent transition points (i.e. when hands leave the ground (left), rear block exit (middle) and front block exit (right).

Mean resultant, vertical and anteroposterior (body-mass normalised) forces along with mean ratio of forces were then calculated across each phase. The impulse-momentum relationship was used to compute vertical and horizontal velocity from which CM projection angles were calculated at each transition. Front block exit velocity was combined with the total push duration to provide average horizontal external power as the criterion measure (Bezodis et al., 2010), normalised for body mass. To compute the CM displacements across each phase, the impulse-momentum relationship was applied to the velocity data.
Statistical analyses were conducted in IBM SPSS (v.25). Associations between the output variables and average horizontal external power were assessed using Pearson correlations. Additionally, partial correlations controlling for body height were also computed to assess the relationships between CM displacements and performance taking into account differences in height. A 0.1 threshold was set for the smallest practically important correlation through which clear (positive or negative) and unclear relationships were defined using 90% confidence intervals (CI) in line with Hopkins et al. (2009). The magnitudes of the correlation coefficients were interpreted on the following scale: < 0.1, trivial; 0.1 to 0.3, small; 0.3 to 0.5, moderate; 0.5 to 0.7, large; and > 0.7, very large.

RESULTS AND DISCUSSION: Mean average horizontal external power exhibited by the group was 14.3 ± 2.3 W/kg with a total block push duration of 0.390 ± 0.039 s and block exit velocity of 3.30 ± 0.20 m/s. Athletes who had a higher distribution of weight on their hands in the set position, also achieved higher average horizontal external power on the blocks (Table 1) in line with previous findings comparing elite and well-trained sprinters (Slawinski et al., 2010). Interestingly, this appears to allow more effective force application during the subsequent bilateral push (phase two) with higher anteroposterior force production (r ± 90% CI = 0.38 ± 0.19) and higher ratio of forces (0.66 ± 0.13) observed in athletes with higher proportions of weight distributed on their hands. Alternatively, it could simply be that those athletes who are able to produce higher forces on rear block also have the physical capacity (e.g. strength and/or stability) to adopt a more anteriorly-distributed set position. The observed importance of a high mean anteroposterior component of force and high mean ratio of forces across the block phase supports previous studies (Rabita et al., 2015; Willwacher et al., 2016), however, this appears to be particularly important in the initial parts to the push (onset to hands off, phase one; r = 0.67 ± 0.12; Table 2).

Table 1. Mean values for selected output variables and their association with average horizontal external power.

Output variable	Mean ± SD	r ± 90% CI
Duration of hands contact (s)	0.132 ± 0.045	**-0.62 ± 0.14**
Duration of rear block push (s)	0.197 ± 0.040	**-0.52 ± 0.16**
Duration of total block push (s)	0.390 ± 0.039	**-0.62 ± 0.14**
Weight distributed on hands in set position (%)	70.4 ± 7.4	**0.25 ± 0.21**
Weight distributed on rear block in set position (%)	15.7 ± 5.1	**-0.19 ± 0.21**
Weight distributed on front block in set position (%)	13.9 ± 7.0	**-0.13 ± 0.22**
Horizontal CM displacement – onset to hands off (m)	0.032 ± 0.017	**-0.18 ± 0.21**
Horizontal CM displacement - bilateral pushing (m)	0.122 ± 0.039	**0.47 ± 0.17**
Horizontal CM displacement - unilateral pushing (m)	0.606 ± 0.070	**0.36 ± 0.19**
Vertical CM displacement – onset to hands off (m)	0.027 ± 0.020	**-0.61 ± 0.14**
Vertical CM displacement - bilateral pushing (m)	0.064 ± 0.027	**-0.40 ± 0.19**
Vertical CM displacement - unilateral pushing (m)	0.181 ± 0.048	**-0.39 ± 0.19**
CM projection angle at hands off (°)	26.6 ± 9.3	**-0.56 ± 0.15**
CM projection angle at rear block exit (°)	18.7 ± 5.2	**-0.62 ± 0.14**
CM projection angle at front block exit (°)	10.5 ± 2.1	**-0.45 ± 0.18**

Bold denotes clear associations. Magnitudes should be interpreted according to the scale outlined in the methods. CI = confidence intervals; CM = centre of mass.

From this more anteriorily-distributed initial set position, better athletes spent less time in each phase and displaced their CM further in the horizontal direction before both rear and front block exits (Table 1). Partial correlations revealed similar associations for the CM displacement variables when height was controlled for. Specifically, horizontal CM displacements at rear and front block exits were positively associated (r ± 90% CI = 0.44 ± 0.18 and 0.27 ± 0.20, respectively) with average horizontal external power. This could be linked to greater extension of both hips at respective block exits, as positive associations with average horizontal external power have previously been reported (Bezodis et al., 2015). Conversely, the corresponding vertical CM displacements were negatively associated with performance, even during unilateral pushing (r ± 90% CI = -0.39 ± 0.19) when there is conceivably an inherent need to achieve a sufficient flight time and prepare for the first stance phase. In fact, lower projection angles at the end of each phase were associated with better performance (r ranged from -0.45 to -0.62) and should therefore be encouraged.

Interestingly, greater horizontal CM displacement at rear block exit was found to be negatively associated with the anteroposterior, resultant and ratio of forces produced during the subsequent unilateral pushing against the front block (phase three; r ± 90% CI = -0.41 ± 0.18, -0.32 ± 0.20 and -0.35 ± 0.19, respectively). Indeed, force production in this later phase was not as strongly associated with performance as the earlier phases (Table 2). This may suggest that to enhance sprint start performance, the priority should be to maximise force production during the bilateral rather than the unilateral phase (phase two vs. three), despite the relatively longer time spent pushing against the front block compared with the rear and the associated higher horizontal impulses typically produced (Graham-Smith et al., 2018).

Table 2. Mean (± SD) forces and their association with average horizontal external power.

		Onset to hands off (phase one)	Hands off to rear block exit (phase two)	Rear block exit to front block exit (phase three)
Anteroposterior force (N/kg)	Mean ± SD	7.7 ± 2.3	11.4 ± 2.1	8.3 ± 0.9
	r ± 90% CI	**0.60 ± 0.14**	**0.66 ± 0.13**	**0.27 ± 0.20**
Vertical force (N/kg)	Mean ± SD	13.6 ± 0.9	10.4 ± 1.8	9.7 ± 0.8
	r ± 90% CI	0.01 ± 0.22	**0.46 ± 0.18**	**0.20 ± 0.21**
Resultant force (N/kg)	Mean ± SD	16.6 ± 1.6	15.5 ± 2.6	12.8 ± 1.1
	r ± 90% CI	**0.41 ± 0.18**	**0.61 ± 0.14**	**0.25 ± 0.21**
Ratio of forces (%)	Mean ± SD	40.0 ± 11.2	77.6 ± 10.4	60.4 ± 4.5
	r ± 90% CI	**0.67 ± 0.12**	**0.39 ± 0.19**	**0.16 ± 0.21**

CI = confidence intervals. Bold denotes clear associations. Magnitudes should be interpreted according to the scale outlined in the methods.

CONCLUSION: Better sprint starters distributed more weight on their hands in the set position, which was related to greater anteroposterior force production. Additionally, higher average horizontal external power was observed when athletes spent less time in each phase and displaced their CM further during both the bilateral and unilateral pushing phases. Conversely, coaches should discourage vertical displacement across all phases and athletes should endeavour to achieve a lower CM projection angle at each transition by orientating the force vector more horizontally, particularly in the early parts of the push. Athletes should strive to maximise force production and horizontal CM displacement during the middle phase of the sprint start (bilateral push once hands leave), even though this could compromise force production in the subsequent front block pushing phase. Thus, training focussed on improving bilateral anteroposterior force production is likely to be beneficial to performance.

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