KINETIC ANALYSIS OF THE BLOCK START AND FIRST TWO CONTACTS IN SPRINTING

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The purpose of this study was to examine the force production characteristics of the arms and each leg in the block start and in the first two contacts of the acceleration phase in sprinting. The set-up consisted of six force platforms embedded in an indoor running track. A total of 61 starts from 19 male international level athletes were collected during maximal effort starts and accelerations between 10m and 40m. The average time over 10m was 1.648 ±0.048 seconds, measured using a Laveg speed gun. Results indicated that the arms accounted for 13.9% of the vertical impulse and -2% to horizontal impulse, the front leg 69% and 60% and the rear leg 25 and 33% respectively. Peak vertical and horizontal forces (relative to BW) in the front leg and their associated RFD's produced the strongest correlations with time over 10m (all $p<0.001$).

KEY WORDS: sprint start, forces, velocity, projection angle

INTRODUCTION: When assessing an athlete's sprint start or evaluating the effect of different block positions on an athlete's start mechanics it is important to evaluate the horizontal and vertical impulses, toe-off velocities and the projection angle of the centre of mass as these are associated with performance in the early acceleration phase (Coh et al., 1998; Coh et al., 2006).

Instrumented starting blocks and embedded force plates are becoming more popular in high performance centres and these have the ability to provide immediate feedback on force generation. Interestingly most studies investigating the force characteristics of the sprint start have neglected to quantify arm forces and tend to focus primarily on the anterior-posterior force component. Whilst horizontal acceleration is the ultimate objective for the sprinter, the vertical impulse and its effect on the projection angle of the centre of mass cannot be neglected as it has consequences on timing and foot placement characteristics in the first few steps. Neglecting the arm forces and its contribution to vertical impulse was shown by Graham-Smith et al. (2014) to reduce vertical impulse by 19%, underestimate the projection angle at take-off by 10 degrees and movement time by 0.03 seconds. The errors due to not accounting for full system load at the onset of movement in the block start has implications on previous research findings. Consequently, it is not clear what contribution the arms and the front and rear legs have in the early phase of the start and what affect they have on movement time, force, impulse and velocity characteristics. The cost of embedding multiple force platforms also limits the ability to collect the start and first and second foot contacts to examine acceleration out of the blocks.

The aims of this study were: to examine the force characteristics of the block start and the first two contacts in the acceleration phase and, to quantify the contribution of the arms and the front and rear legs to horizontal and vertical impulses in the block start and examine their relationship to horizontal velocity and sprint performance times.

METHODS: Nineteen international level male athletes with an average height and body mass were 178.8 ± 7.1 cm and 75.7 ± 7.7 kg respectively took part in the study. Data collection was carried out as part of their training session with their coach present to guide the warm up and progress the intensity. Following this a series of block starts and accelerations between 10m – 40m were performed at maximal effort. Speed was recorded using a Laveg LDM 300C laser gun and split times over 10m intervals were recorded using a 5 point moving average.

An array of six Kistler force platforms (four 9287CA and two 9281E) was used to collect horizontal and vertical ground reactions forces through the four points of contact in the starts (feet and hands separately) and the first and second contact (see figure 1). All sprints were recorded in the sagittal view using a Casio Exilim ZR200 high speed video camera recording at 240 fps to ensure the entire foot was placed on the force platforms. This configuration enabled us to measure the entire system load in the set position and therefore quantify movement time, impulses and velocities at toe-off more accurately than systems that do not factor in arm forces (Graham-Smith et al, 2014). Force platforms were zeroed immediately before the athlete entered the blocks and were set to record at 1000 Hz for 5 seconds, with a 7 point moving average applied on acquisition. Body weight was measured for 10s prior to the first trial.

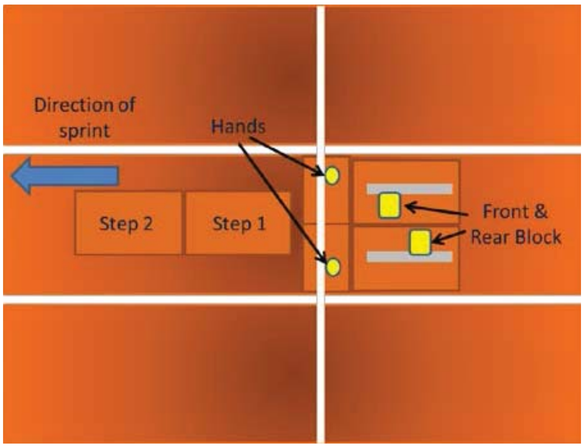


Figure 1: Experimental set up with the six force platform configuration

The total ground reaction forces (GRF) in the vertical and anterior-posterior directions were attained by summing forces from the six platforms. The onset of movement was taken from the instant the total vertical force increased above an arbitrary 40N threshold from the steady body weight force in the set position. The same threshold was used to identify flight and contact phases in the subsequent steps.

Impulses, accelerations, velocities and displacement characteristics of the centre of mass were derived from the total horizontal and vertical forces. The % contributions of front and rear legs and the arms to absolute horizontal and vertical impulses were also quantified.

The relationship between time over 10m and force parameters were examined using the Pearson Product Correlation Coefficient and the coefficient of determination R^2.

RESULTS & DISCUSSION: The results in tables 1 and 2 reveal that the mean movement time in the blocks was 0.371 s, of which the front leg was in contact the entire time, the arms 0.121 (33%) and rear leg 0.219 (59%). During the start the arms were found to contribute 13.9% and -2.9% to vertical and horizontal impulses, the rear leg 25.4% and 32.8% and the front leg 60.7% and 69.5% respectively. Figure 2 highlights that in terms of peak forces the rear leg produced the greatest horizontal force (919 ± 215N) and the front leg produced the greatest vertical force (1024 ± 156N). The ratio between vertical and horizontal impulses suggest an equal distribution in the rear leg but a slightly greater emphasis on vertical force in the front leg with ratios of 1.00 ± 0.13 and 1.11 ± 0.12.

In other scenarios it may only be possible to measure the combined force of all points of contact. Typically, the combined GRF profile shows a characteristic double peak in both the horizontal and vertical force profiles. Data in table 3 and figure 3 highlights that the first push tends to have a slightly greater horizontal emphasis whilst the second push (primarily from the front leg) has a slightly greater emphasis on vertical force generation.

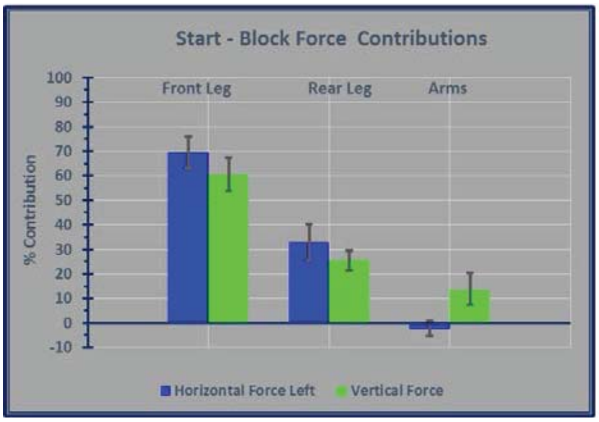
Strong correlations were found between horizontal velocities at toe-offs from the block, first step and second step with time to 10m (r = -0.475, -0.588, -0.576 respectively, all $p<0.001$). The peak vertical and horizontal forces relative to BW from the front leg produced strongest correlations with time to 10m (r = -0.574, -0.591, both $p<0.001$) which isn't surprising considering its major contribution to the vertical and horizontal impulses at toe-off from the blocks. The average rate of force development in the front leg also exhibited strong associations to lower times to 10m (r= -0.528, -0.437 in vertical and horizontal directions, both $p<0.001$). The ratio of the vertical and horizontal impulse produced by the front leg was found to elicit a strong association with the velocities at toe-off in the first and second contacts (r = -0.491, -0.553, both $p<0.001$). While the overall average indicates a tendency for greater vertical force application from the front leg (compared to horizontal), the faster athletes at toe-off in the first and second steps appear to have a slightly lower vertical to horizontal impulse ratio.

Table 1
Contributions of limbs to force production in the block start

	Front Leg		Rear Leg		Arms	
	Mean	SD	Mean	SD	Mean	SD
Peak Vertical Force (N)	1029	156	817	198	605	141
Peak Horizontal Force (N)	834	130	919	215	-103	38
Vertical Impulse (Ns)	191	24	81	20	46	28
Horizontal Impulse (Ns)	173	20	82	23	-6	7
time in contact (s)	0.372	0.044	0.219	0.087	0.121	0.049
contribution to Vertical Impulse (%)	60.7	6.7	25.4	4.0	13.9	6.5
contribution to Horizontal Impulse (%)	69.5	6.4	32.8	7.4	-2.3	3.0
Vertical : Horizontal Impulse ratio	1.11	0.12	1.00	0.13	10.80	6.55

Table 2
Kinematic descriptors of the start and first two steps

	Blocks		1st Contact		2nd Contact	
	Mean	SD	Mean	SD	Mean	SD
Movement / Contact time (s)	0.371	0.044	0.191	0.021	0.167	0.017
CM displacement (horizontal) (m)	0.577	0.048	0.734	0.092	0.828	0.094
CM displacement (vertical) (m)	0.178	0.032	0.041	0.022	0.042	0.023
Horizontal Velocity (m/s)	3.30	0.14	4.53	0.20	5.44	0.24
Vertical Velocity (m/s)	0.55	0.12	0.47	0.15	0.48	0.16
Projection Angle (deg)	9.4	2.0	5.9	1.9	5.0	1.6
Flight time (s)	0.065	0.019	0.050	0.017		
Flight distance of CM (m)	0.213	0.031	0.224	0.040		



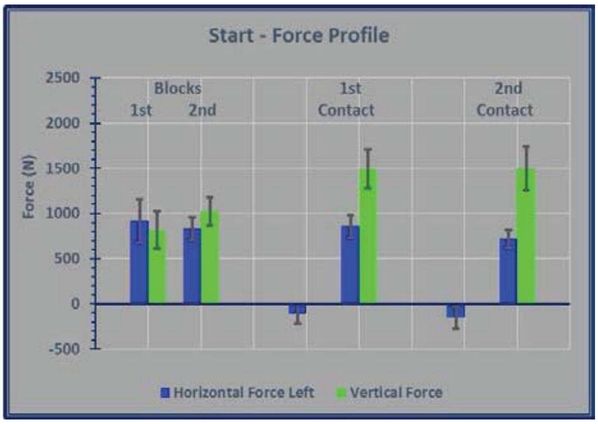


Figure 2: Contributions of Limbs in the start **Figure 3: Horizontal and Vertical GRF's**

Table 3
Kinetic descriptors of the start and first two steps

	Blocks		1st Contact		2nd Contact	
	Mean	SD	Mean	SD	Mean	SD
Vertical Force						
Peak Vertical Force 1 (N)	1293	208	1494	220	1501	242
Peak Vertical Force 2 (N)	1031	156				
Net Vertical Impulse (Ns)	41.7	10.3	36.9	12.8	39.1	16.1
Peak Vertical Acceleration (m/s^2)	7.3	1.5	9.9	1.5	10.0	2.2
Change in Vertical Velocity (m/s)	0.55	0.12	0.49	0.16	0.52	0.20
Vertical Velocity at Toe-off (m/s)	0.55	0.12	0.47	0.15	0.48	0.16
Average Vertical RFD 1 (kN/s)	17.2	7.4	15.2	4.7	19.8	8.6
Average Vertical RFD 2 (kN/s)	4.9	2.5				
Horizontal Force (Ant-Post)						
Peak Braking Force (N)			-113	105	-150	120
Peak Propulsive Force 1 (N)	1367	239	859	125	721	98
Minimum Horizontal Force	585	95				
Peak Propulsive Force 2 (s)	853	125				
Braking Impulse (Ns)			-1.4	1.4	-1.8	1.5
Propulsive Impulse (Ns)			94.6	14.2	70.5	9.1
Net Horizontal Impulse (Ns)	249.8	28.4	92.7	14.3	68.7	8.8
Peak Horizontal Acceleration (m/s^2)	18.2	2.1	11.3	0.9	9.5	0.7
Change in Horizontal Velocity (m/s)	3.30	0.14	1.23	0.15	0.91	0.06
Average Horizontal RFD 1 (kN/s)	15.3	6.1	6.8	1.8	6.4	1.5
Average Horizontal RFD 2 (kN/s)	3.0	1.4				

CONCLUSION: The results revealed that the arm forces in the sprint starts account for around 14% of the total vertical impulse and therefore their contribution should not be ignored. It is recommended that practitioners acknowledge the discrepancy in data output when arm forces are not accounted for. The quantification of individual forces and impulses generated from the arms and from front and rear legs has provided a greater insight into their role in the block start, and their effect on horizontal velocity at toe-off in the first two contacts of the acceleration phase. The role of the rear leg appears to be one in which overcomes inertia and generates equal amounts of vertical and horizontal impulse, facilitating the front leg to generate the greatest rates of force development such that it will generate approximately 10% more vertical impulse than horizontal.

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