CONTRIBUTION OF THE ARMS IN THE SPRINT START AND THEIR INFLUENCE ON FORCE AND VELOCITY CHARACTERISTICS

Philip Graham-Smith[1], Alex Natera[1], Scott Saunders[1]

Aspire Academy for Sporting Excellence, Doha, Qatar[1]

The purpose of this case study was to quantify the contribution of the arms in the sprint start and compare the difference in force and velocity characteristics when arm forces are not accounted for. One elite student athlete performed 6 starts with the same block position whilst forces were measured independently for front and rear legs and left and right hands. The arms were found to apply force for 0.14s, initiated a peak force of 593N (0.83 BW) and accounted for 18% of the total vertical impulse generated. Inclusion of the arm forces increased the first vertical peak force by 118N, movement time by 0.03s, vertical toe-off velocity by 0.6m/s and projection angle by 10 degrees. Differences in vertical velocity and projection angle were halved by modifying the vertical system load to BW at the onset of movement. Peak horizontal forces and velocities were similar.

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). These parameters can be attained through video analysis (Coh et al., 2006) and through the double integration of directly measured force (acceleration) data (Fortier et al., 2005). 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 one cannot disregard the vertical impulse and its effect on the projection angle of the centre of mass and consequently on timing and foot placement characteristics in the first few steps. Kinematic studies report that the vertical velocity of the centre of mass at toe-off is in the region of 0.6 to 0.9 m/s, leading to projection angles of around 8 to 15 degrees (Coh et al., 1998; Coh et al., 2006).

In high performance training centres it is not uncommon to have embedded force platforms and these can be used to provide instantaneous feedback on toe-off velocity and timing of force application. However, the cost of force platforms (and/or instrumented blocks) sometimes restricts the optimal set up for data acquisition and may compromise the quality of the data and feedback generated. The sprint start is an example whereby compromise is often made. The typical dimensions of commercially available force platforms (60 x 90cm or 60 x 40cm) mean that two or more force measuring devices are required to fully account for system load in the set position prior to the onset of movement, and more importantly the force and impulse generated through all points of contact with the ground, (front and rear leg forces and forces generated through the hands).

It is not clear what contribution the arm forces have in the early phase of the start, and indeed what affect they have on movement time, force, impulse and velocity characteristics.

The aim of this study was to quantify the contribution of the arm/hand forces to horizontal and vertical impulse and to examine the effect of measuring (or not) the arm forces in the sprint start on key performance variables such as movement time, horizontal and vertical velocity at toe-off and the projection angle.

METHODS: One elite student athlete with a personal best performance of 10.51s in the 100m took part in the study (age = 18 years old, height = 1.68m, body mass = 72.8kg). Following his usual warm up he performed 6 maximal effort sprint starts, accelerating to 10m. Five minutes recovery was given between trials. Each trial was filmed in the sagittal view using a Casio Exilim ZR200 high speed video camera recording at 240 fps. Video footage

was digitised with an 18 point 14 segmental model using segmental data from de Leva (1996) to determine centre of mass. Data was smoothed using a 4th order Butterworth filter with a cut off frequency of 12 Hz. Horizontal and vertical velocities of the centre of mass at toe-off and the projection angle were used for comparison with the force derived data.
Force data was collected using four Kistler 9287CA force platforms sampling at 720 Hz with a 5 point moving average applied to the acquisition. The blocks were positioned on two separate rails to isolate the front and rear leg forces and independent forces from the hands were obtained, as shown in figure 1.

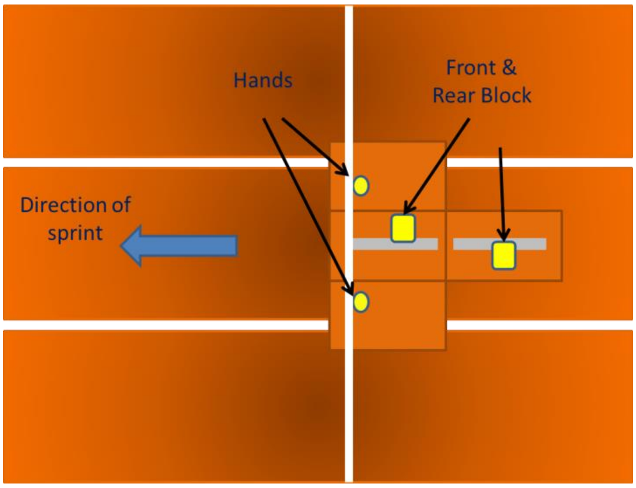

Figure 1: Experimental set up with four force platforms

The total ground reaction forces (GRF) in the vertical and anterior-posterior directions were attained by summing forces from the four platforms (see figures 2 and 3). The onset of movement was taken from the instant the total vertical force increased above an arbitrary 20N threshold from the steady baseline force in the set position.
Horizontal and vertical arm forces were removed for the legs-only analysis. This meant that the initial measurement of system load was significantly less than body weight. This data was processed in two ways, firstly using the underestimated system load, and secondly by artificially raising the baseline vertical force prior to the onset of movement, such that the summed leg force data initially started at body weight.
For each measurement scenario a number of variables pertinent to the sprint start were determined and these can be seen in table 1. Differences between analysis methods were examined using paired t-tests with a significance level set at $p<0.05$.

RESULTS & DISCUSSION: Analysis of the digitised video footage revealed that the average horizontal and vertical velocities and projection angle of the six trials were 3.63 ± 0.11 m/s, 0.68 ± 0.16, and 10.2 ± 2.2 degrees. These parameters compared favourably with the data generated from the force analysis (including arm forces) with values of 3.45 ± 0.04 m/s, 0.61 ± 0.07, and 10.0 ± 1.2 degrees respectively. The arms initially took 67% of the athlete's body weight prior to the onset of movement and provided a horizontal force of 78N to balance the pre tension force in the legs. The hands were in contact with the force platforms for 0.14s from the onset of movement and in this time they developed a peak vertical force of 593N, and 58Ns of vertical impulse (accounting for 18% of the total vertical impulse). The inclusion of arms forces increased the movement time by an average of 0.03s ($p<0.005$), and raised the first vertical peak force by an average of 118N ($p<0.005$). The first vertical peak force is generally acknowledged as the force generated from the rear leg. The results clearly demonstrate that around 10% of this peak force is generated by the arms. The arms have a negative effect on the horizontal impulse (-2.4%) as they push backwards to counteract the pre tension forces generated by the legs. This has a minimal effect on the peak horizontal forces and a moderate overestimation of horizontal velocity at toe-off (by 0.05m/s). However, this raises questions as to an optimal level of pre tension force and whether this percentage can be reduced to make the start more efficient. The most significant effects of not including the arm forces were on vertical impulse and consequently on the vertical velocity and projection angle at toe-off with differences of 43Ns, 0.61m/s and 9.3 degrees respectively (all significantly lower without arm forces, $p<0.001$).

It was possible to reduce the differences in vertical velocity (to 0.30 ± 0.09 m/s) and projection angle at toe-off (to 4.8 ±1.4 degrees) by modifying the initial system load to reflect body weight. However, these were still significantly lower than the values attained following the direct measurement of arm forces (both $p<0.001$).

Table 1
Comparison of data output with and without arm forces (and corrected for BW)

	Arms & Legs		Legs-only		Legs-only (corrected for BW)	
	mean	**sd**	**mean**	**sd**	**mean**	**sd**
Movement Time (s)	0.385	0.01	0.355	0.02	no change	
<u>Arm Forces</u>						
Baseline Arm Force (N)	476	16				
Peak Vertical Force Arms (N)	593	35				
Peak Horizontal Force Arms (N)	78	8				
Arm contact time (s)	0.140	0.012				
<u>Total Force</u>						
Peak Vertical Force 1 (N)	1134	37	1016	60	no change	
Peak Vertical Force 2 (N)	1196	37	no change		no change	
Net Vertical Impulse (Ns)	44	5	1	10	22	6
Vertical Velocity at toe-off (m/s)	0.61	0.07	0.02	0.13	0.30	0.09
Peak Propulsive Force 1 (N)	1407	67	no change		no change	
Peak Propulsive Force 2 (N)	945	28	no change		no change	
Net Horizontal Impulse (Ns)	251	3	255	3	no change	
Horizontal Velocity at toe-off (m/s)	3.45	0.04	3.50	0.05	no change	
Angle of projection out of blocks (deg)	10.0	1.2	0.3	2.1	4.8	1.4
<u>Contribution to Vertical Impulse (%)</u>						
Front Leg	56.1	1.8	69.2	2.3	no change	
Rear Leg	25.8	2.0	30.8	2.3	no change	
Arms	18.0	2.2				
<u>Contribution to Horizontal Impulse (%)</u>						
Front Leg	68.3	1.7	66.5	1.6	no change	
Rear Leg	34.1	1.8	33.5	1.6	no change	
Arms	-2.4	0.7				

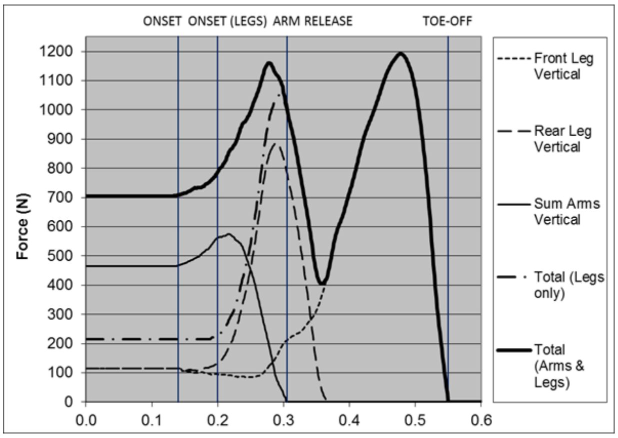

Figure 2: Vertical ground reaction forces

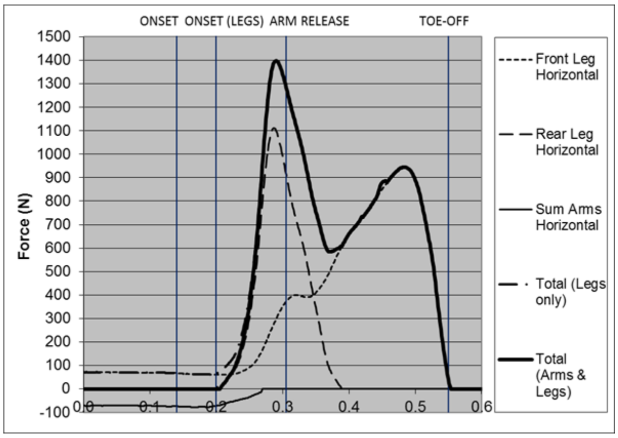

Figure 3: Horizontal ground reaction forces

CONCLUSION: The results revealed that the arm forces in the sprint starts account for around 18% of the total vertical impulse and therefore their contribution should not be ignored. Assessments made without the inclusion of arm forces are likely to underestimate movement time by 8% and the first vertical peak force by around 10%. When evaluating the sprint start and the effectiveness of block positions both vertical velocity and the projection angle at toe-off are meaningful parameters as these are likely to influence the acceleration and contacts over the first few strides. It is recommended that practitioners acknowledge the discrepancy in data output when arm forces are not accounted for, particularly around movement time, the first vertical peak, vertical velocity and the projection angle. Further investigations should be conducted across a larger population to examine the interactions between block positions and arm contributions. The practical implications of future studies will be to address the upper body strength and power requirements for sprinters and to examine more closely the effect of pre tension leg forces on the percentage of negative horizontal impulse created by the arms and ultimately horizontal velocity at toe-off.

REFERENCES:

Coh, M., Tomazin, K. and Stuhec, S. (2006). The biomechanical model of the sprint start and block acceleration. Physical Education and Sport, 4(2), 103-114.

Coh, M., Jost, B. Skof, B., Toma, K. and Dolenec, A. (1998). Kinematic and kinetic parameters of the sprint start and start acceleration model of top sprinters, *Gymnica*, 28, 33-42.

De Leva, P. (1996). Adjustments to Zatsiorsky-Suluyanov's segment inertia parameters. Journal of Biomechanics, 29(9), 1223-30.

Fortier, S., Basset, F.A., Mbourou, G.A. Faverial, J. and Teasdale, N. (2005). Starting block performance in sprinters: a statistical method for identifying discriminative parameters of the performance and an analysis of the effect of providing feedback over a 6-week period. *Journal of Sport Science and Medicine*, 4,134-143.