MAGNITUDE AND TECHNICAL CHARACTERISTICS OF EXTERNAL FORCE PRODUCTION IN THE STARTING BLOCKS: RELATIONSHIP WITH PERFORMANCE.

Adam Brazil[1], Gareth Irwin[1], Timothy Exell[1], Ian Bezodis[1], Cassie Wilson[2], Steffen Willwacher[3]

School of Sport, Cardiff Metropolitan University, Cardiff, Wales[1]
Department for Health, University of Bath, Bath, England[2]
Institute of Biomechanics and Orthopaedics, German Sport University, Cologne, Germany[3]

The aim of this study was to investigate magnitude and technical characteristics of external force production in the block phase of the sprint start. Nine male sprinters (100 m PB 10.48 ± 0.28 s) performed five to six maximal effort block starts. External force applied to the front and rear blocks were measured using customised instrumented blocks. Average horizontal, vertical and resultant force, and the angle of the resultant force vector underwent correlational analyses with block performance (normalised average horizontal power). Results revealed that front block average horizontal, vertical and resultant force, and rear block angle of the resultant force vector possessed significant relationships with performance, and highlighted that both magnitude and technical characteristics were related to block performance.

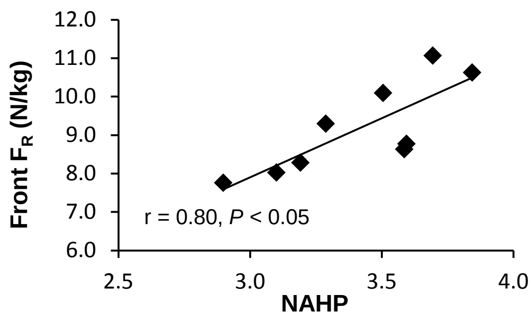
KEY WORDS: Sprint start, running, force application

INTRODUCTION: In the short sprint events performance of the starting block phase can greatly influence the outcome of the race. Success in the block phase is characterised by achieving high horizontal velocity of the sprinters centre of mass at the instant of block exit, in the shortest time possible. This acceleration is influenced by the nature of external force application in the starting blocks.
Numerous studies have observed differences in external force production during the block phase between varying levels of sprinters (Slawinski et al., 2010; Willwacher et al., 2013; Otsuka et al., 2014), although findings have not always been consistent. This inconsistency could be a result of differences in the level of sprinters used or whether group analyses have categorised athletes based on 100 m time or explicitly block performance. Recently Bezodis et al. (2010) recommended normalised average horizontal external power as the best measure of block performance, as it reflects the rate at which work is performed, influencing the acceleration achieved in the block phase, whilst accounting for morphological differences. Thus it is pertinent to investigate how characteristics of external force production influence this criterion measure of performance.
In the block phase (Otsuka et al., 2014) and other phases in sprinting (Morin et al., 2012) it has been highlighted that a superior technical ability to orientate the resultant ground reaction force vector horizontally may be of greater importance than the magnitude of the resultant force. Given these findings, the relationship between performance and the magnitude and technical characteristics of external force production in the block phase warrants further investigation due to its potential impact on coaching and training.
Therefore, the first aim of this study was to investigate how performance in the block phase is associated with magnitude and technical characteristics of external force production. A further aim was to compare external force characteristics between the front and rear block. The purpose of this research was to help inform biomechanical understanding of the block phase and provide useful information to benefit coaching practice.

METHODS: Nine male sprinters (23.7 ± 4.4 years, 1.77 ± 0.03 m, 76.5 ± 2.8 kg) participated in this study following ethical approval. Mean 100 m PB was 10.48 ± 0.28 s (range 10.10 to 10.96 s). Each sprinter performed five to six maximal starts from a set of custom made force instrumented starting blocks. The blocks consisted of a small force platform utilising four Kistler piezoelectric 3D force transducers mounted to each block base and measured external forces from both the front and rear block. Force data were sampled at 10 000 Hz.

A 2nd order digital Butterworth filter with a 120 Hz cut-off was applied to the force signals prior to analysis. Horizontal power was calculated from the product of the total horizontal force- and velocity-time signals. The total force-time signal was the sum of front and rear block forces for the duration of the block phase (i.e. when the rear foot left the block, the total signal only comprised front block forces). The velocity-time signal was obtained through dividing impulse (obtained through integrating the force-time signal) by mass. Horizontal power was averaged over the duration of the block phase and then normalised in the same way as Bezodis et al. (2010) to obtain a dimensionless value of normalised average horizontal power (NAHP). NAHP served as the performance measure in the current study.
To understand the relationship between performance and external force characteristics, rear block, front block, and total block forces were analysed. Average horizontal (F_Y), vertical (F_Z) and resultant (F_R) force were calculated to represent force magnitude characteristics. The angle of the average resultant force vector relative to the horizontal (FA) was calculated to represent the technical application of external force production. Push time (excluding reaction time), horizontal velocity at block exit and average horizontal acceleration were also reported to allow comparison with other studies.
Data are presented as mean ± SD unless otherwise noted. Aside from front and rear FA for which Spearman rank correlations were calculated due to violating the assumption of normality (Shaprio-Wilk $P < 0.05$), Pearson's product-moment correlations were calculated to determine the relationship between block performance and external force characteristics. Paired samples T-tests were used to assess differences between the front and rear block. The level of significance was set at 0.05. Effect sizes (Cohen's *d*) were also calculated with 0.2, 0.5, and 0.8 defined as thresholds for small, moderate and large effects.

RESULTS: On average the sprinters in this study achieved a horizontal velocity at exit of 3.27 ± 0.11 $m.s^{-1}$ with a push time of 0.35 ± 0.02 s, resulting in average acceleration of 9.34 ± 0.58 $m.s^{-2}$. Average horizontal power was 1167 ± 97 W and 0.51 ± 0.05 following normalisation (Table 1). The strongest correlations with performance were found for total horizontal and resultant force (r = 0.98 and 0.97, respectively, $P < 0.05$). When considering each block independently, significant correlations ($P < 0.05$) with performance for horizontal (r = 0.78), vertical (r = 0.80) and resultant (r = 0.80, Figure 1) force were found only for the front block (Table 1). Conversely FA for the rear block only was significantly correlated with block performance (r = -0.80, $P < 0.05$) (Table 1, Figure 1). Although F_Y, F_Z and F_R tended to be greater in the front block, none of these between block comparisons were statistically significant ($P > 0.05$) even though moderate ($d = 0.52$) and large ($d = 0.84$ and 1.22) effect sizes were found for F_Y, F_Z and F_R, respectively (Table 2). A statistically significant difference between the front and rear block was found for FA, in which rear FA was significantly ($P < 0.05$) lower than front FA with a large effect size observed ($d = 1.44$).



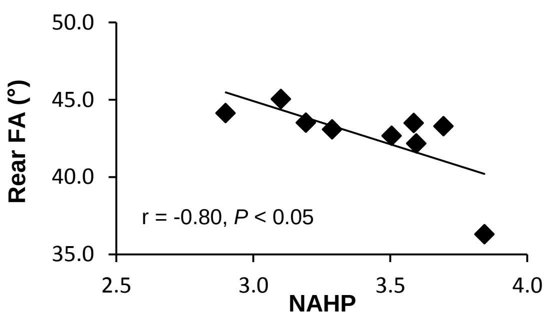


Figure 1: Correlations between front resultant force (left) and rear angle of the resultant force vector (right) and block performance (NAHP)

Table 1: Group block variables and correlations (r values) with performance (NAHP).

Variable	Mean	SD	r-value	
NAHP	0.51	0.05		
Push Time (s)	0.35	0.02	-0.79	*
Velocity at Block Exit ($m.s^{-1}$)	3.27	0.11	0.86	*
Average Acceleration ($m.s^{-2}$)	9.34	0.58	0.97	*
Average Horizontal Power (W)	1167	97	0.87	*
Rear F_Y (N/kg)	5.96	0.79	0.16	
Rear F_Z (N/kg)	5.49	0.76	-0.33	
Rear F_R (N/kg)	8.23	1.03	-0.12	
Front F_Y (N/kg)	6.36	0.73	0.78	*
Front F_Z (N/kg)	6.54	0.96	0.80	*
Front F_R (N/kg)	9.17	1.18	0.80	*
Total F_Y (N/kg)	9.32	0.55	0.98	*
Total F_Z (N/kg)	9.25	0.62	0.88	*
Total F_R (N/kg)	13.20	0.79	0.97	*
Total FA (°)	44.77	1.07	0.07	
	Median	IQR[a]		
Rear FA (°)	43.27	2.51	-0.80	*
Front FA (°)	46.26	1.66	0.42	

**Denotes a significant correlation with NAHP ($P < 0.05$)*
[a]IQR = Interquartile Range

Table 2: Comparison of external force variables between the front and rear block.

Variable	Front-Rear	*P*	Effect Size (*d*)
F_Y (N/kg)	0.40	> 0.05	0.52
F_Z (N/kg)	1.05	> 0.05	1.22
F_R (N/kg)	0.93	> 0.05	0.84
FA (°)	3.07	< 0.05	1.44

DISCUSSION: The aims of this study were to understand how magnitude and technical characteristics of external force production related to block performance in a cross section of sprinters, and whether differences in these characteristics existed between the front and rear block. The present analyses indicated that differences in external force production were apparent between the front and rear block, and that superior performance was significantly correlated with different external force characteristics for each block.

Average horizontal and resultant force for the total block phase held the strongest relationship with NAHP (Table 1), whilst the angle of the resultant force vector for the total phase was not associated with superior performance (r = -0.13, $P > 0.05$). Thus when considering the total block phase only it would appear that maximising average force production is a key strategy for success. These findings partially agree with those of Otsuka et al. (2014) who found significant differences in average horizontal force and the angle of the resultant force vector between different levels of block performers.

Considering the front and rear block independently highlights potentially differing contributions of each to block phase success. For the front block significant relationships with performance for average horizontal, vertical and resultant force were observed (r = 0.78-0.80, $P < 0.05$). However, for the rear block the magnitudes of external forces were not significantly correlated with performance (r = -0.33-0.16, $P > 0.05$) and thus indicated that superior block performers were associated with a greater ability to generate and maintain high forces in the front block. When considering the angle of the resultant force vector (FA) which was selected to measure a sprinters technical ability to orientate the resultant force vector horizontally, differences in correlations between the front and rear block were again observed. For the rear block achieving a smaller FA possessed a significant relationship with

block performance (r = -0.80, $P < 0.05$), indicating that a superior ability to ensure the rear block resultant force vector was orientated horizontally appeared to be a discriminating factor between different levels of block performance. Conversely, the non-significant correlation between front block FA and performance indicated that magnitude as opposed to technical characteristics were potentially more important for maximising block performance. The correlational evidence both supports and builds upon previous work (Morin et al., 2012; Ostuka et al., 2014) by showing that magnitude and technical characteristics of external force production are both significantly related to performance but appear block dependant. Whilst this was acknowledged by Otsuka et al. (2014), their analysis suggested that FA in the front and not the rear block significantly differed between groups of different performance levels. The different styles of analysis between studies may explain the conflicting findings.
Although statistical significance was not reached, effect sizes showed moderate (F_Y) and large (F_Z and F_R) differences between the front and rear block indicating that a greater magnitude of force is typically produced in the front block. With respect to technical characteristics, the angle of the resultant force vector was found to be significantly lower in the rear block (Table 2). The observed differences between the front and rear block matched the external force characteristics of each block that were significantly associated to performance and reinforced the potentially different role of each leg in the block start.
Future work should investigate whether the highlighted characteristics of external force production also discriminate between trials on a within individual basis, whilst also considering joint kinematic and kinetic variables to further understand block technique and performance.

CONCLUSION: Results indicate that superior performance in the block phase is associated with both magnitude and technical aspects of external force production but are block dependant. It appears that maximising force production in the front block and applying resultant force more horizontally in the rear block are key characteristics discriminating between sprinters based explicitly on their block performance. The findings contribute to further understanding the starting block phase in sprinting and may help guide coaching and training practice for this skill.

REFERENCES:
Bezodis, N. E., Salo, A. I. & Trewartha, G. (2010). Choice of sprint start performance measure affects the performance-based ranking within a group of sprinters: which is the most appropriate measure? *Sports Biomechanics,* 9, 258-269.
Morin, J. B., Bourdin, M., Edouard, P., Peyrot, N., Samozino, P. & Lacour, J. (2012). Mechanical determinants of 100-m sprint running performance. *European Journal of Applied Physiology,* 112, 3921-3930.
Otsuka, M., Shim, J.K., Kurihara, T., Yoshioka, S., Nokata, M. & Isaka, T. (2014). Effect of expertise on 3D force application during the starting block phase and subsequent steps in sprint running. *Journal of Applied Biomechanics,* 30, 390-400.
Slawinski, J., Bonnefoy, A., Leveque, J.M., Ontanon, G., Riquet, A., Dumas, R. & Chèze, L. (2010). Kinematic and kinetic comparisons of elite and well-trained sprinters during sprint start. *Journal of Strength and Conditioning Research,* 24, 896-905.
Willwacher, S., Herrmann, V., Heinrich, K. & Brüggerman, G. P. (2013). Start block kinetics: what the best do different than the rest. In T. Y. Shiang, W. H. Ho, P. C. Huang, and C. L. Tsai (Eds.), *Proceedings of XXXI International Conference on Biomechanics n Sports*, Taipei, Taiwan.

Acknowledgement
This study was funded by the Sport Council for Wales. The authors would like to thank the Institute of Biomechanics and Orthopaedics at the German Sport University, Cologne for use of their instrumented start blocks.