FORCE-VELOCITY-POWER PROFILES OF ELITE SPRINTERS: INTER-AND INTRA-INDIVIDUAL DETERMINANTS OF PERFORMANCE

Helen Bayne[1]

Sport, Exercise Medicine and Lifestyle Institute, University of Pretoria, Pretoria, South Africa[1]

Elite athletes are underrepresented in scientific research and evidence from group-based studies may not be applicable to individual elite athletes. The purpose of this study was to investigate mechanical determinants of sprint performance in elite sprinters using inter- and intra-individual approaches. Six elite and six sub-elite sprinters performed maximal effort sprint acceleration trials and their force-velocity-power profiles were computed. Theoretical maximum velocity, power and the ratio of force were greater in the elite than the sub-elite athletes. Within the elite group, individuals achieved their fastest times through greater theoretical maximum horizontal force with only small differences in theoretical maximum velocity between the best and worst trials. Practitioners should consider these intra-individual data when coaching and programming for elite athletes.

KEYWORDS: acceleration, athletics, biomechanics, speed, sprinting

INTRODUCTION: To excel in sprint running, an athlete must produce large horizontal force and power from a stationary start and continue to accelerate for as long as possible in order to achieve a high maximum velocity. The force-velocity-power profile is used to describe an athlete’s capability to produce external forces during sprint acceleration and the mechanical effectiveness of the force application, based on the inverse linear force-velocity and parabolic power-velocity relationships that occur during maximal effort multi-joint activities (Samozino et al., 2016).

Mechanical horizontal power output, theoretical maximum velocity, horizontal ground reaction force, and the ratio of horizontal to total force have been found to be differentiating factors when comparing elite sprinters to lower level athletes (Morin et al., 2012; Rabita et al., 2015). These studies provide valuable information on the characteristics of elite sprinters. However, an intra-individual approach is needed to understand performance variation within individual athletes, which may be useful knowledge for the training and preparation of elite sprinters. However, intra-individual changes in force-velocity-power variables and their relationship to changes in performance have yet to be investigated.

Therefore, the aim of this study was to investigate inter-individual differences between the force-velocity-power profiles of elite and sub-elite sprinters, as well as intra-individual differences between more and less successful trials in elite sprinters.

METHODS: Twelve male sprinters performed 3-5 maximal effort 30 m sprint trials from a block start, with at least 5 minutes rest between each trial. Velocity was measured using a radar device (Stalker ATS II) with a sampling rate of 47 Hz. Data was processed using previously published methods to calculate theoretical maximum horizontal force (F0), velocity (V0), power (Pmax), the force-velocity profile (Sfv), the ratio of horizontal to total force maximum value (RFmax), the mean ratio of force over the first 2 s (RFmean) and the RF-V slope (Drf) (Samozino et al., 2016).

The athletes were classified as Elite if their personal best (PB) 100m time was less than 10.2 s (n = 6, 100 m PB = 10.04 s ± 0.12) and Sub-elite if their 100 m PB was between 10.2 s and 10.8 s (n = 6, 100 m PB = 10.59 s ± 0.16). Each athlete’s best trial was determined based on their fastest 30 m time, and these trials used for the comparison between elite and sub-elite athletes. Within the elite group, the best and worst trials were compared in order to investigate intra-individual differences between trials.

Standardised differences between the means (effect sizes, ES ± 90% confidence intervals, CI) were calculated for the respective comparisons. The magnitude of the effect sizes was described using the following thresholds: 0-0.2 is trivial, 0.2-0.6 is small, 0.6-1.2 is moderate, 1.2-2.0 is large, and >2.0 is very large (Hopkins, Marshall, Batterham, & Hanin, 2009). The likelihood that these differences were at least small (ES >0.2) was also calculated and these likelihoods were used to make a qualitative probabilistic inference about the true differences: if the likelihood of the effect being substantially greater and smaller than 0.2 were both greater than 5%, the effect was reported as unclear. Otherwise the effect was clear and reported as the magnitude of the observed value, which was described qualitatively using the following thresholds: 25-75%, possibly; >75%; likely; >95%, very likely; >99% almost certainly (Hopkins et al., 2009). Magnitude-based inference analysis was completed using a specifically designed, freely available spreadsheet (Hopkins, 2000).

RESULTS: Large effect sizes (ES) were found between sub-elite and elite sprinters for 30m time (ES = 1.6), V0 (ES = -1.4), Pmax (ES = -1.2), and RFmean (ES = -1.3), a moderate effect size for RFpeak (ES = -0.8) and small effect sizes for F0 (ES = -0.4) and Drf (ES = -0.6). There were large to very large intra-individual effect sizes between the elite athletes' best and worst trials for 30m time (ES = 2.3), F0 (ES = -1.6), Pmax (ES = -2.1), and RFpeak (ES = -1.8), a moderate effect size for Drf (ES = 0.9), and small effect sizes for V0 (ES = -0.3) and RFmean (ES = -0.4).

Table 1: Mechanical variables during maximal sprint acceleration of Elite (Best and Worst trial) and Sub-elite (Best trial) sprinters

				Standardised Differences	
	Elite Best	Sub-elite Best	Elite Worst	Sub-Elite vs Elite	Elite Worst vs Best
		Mean (SD)		ES (90% CI)	
30m (s)	3.87 (0.06)	4.08 (0.13)	4.05 (0.05)	1.6 (0.9)	2.3 (0.9)
V0 (m/s)	10.7 (0.4)	9.9 (0.4)	10.6 (0.2)	-1.4 (0.9)	-0.3 (0.4)
F0 (N/kg)	10.2 (0.5)	9.9 (0.7)	9.1 (0.5)	-0.4 (0.9)	-1.6 (0.7)
Pmax (W/kg)	27.4 (1.1)	24.6 (2.1)	24.1 (1.2)	-1.2 (0.9)	-2.1 (0.7)
Sfv	-72.9 (13.3)	-72.1 (17.2)	-65.7 (11.5)	0.0 (1.1)	0.4 (0.3)
RFpeak (%)	60.2 (1.1)	58.4 (2)	56.9 (1.5)	-0.8 (0.9)	-1.8 (0.8)
RFmean (%)	31.5 (0.9)	29.6 (1.2)	31.2 (0.5)	-1.3 (0.7)	-0.4 (0.5)
Drf (%)	-8.0 (0.6)	-8.5 (0.7)	-7.4 (0.4)	-0.6 (0.9)	0.9 (0.7)

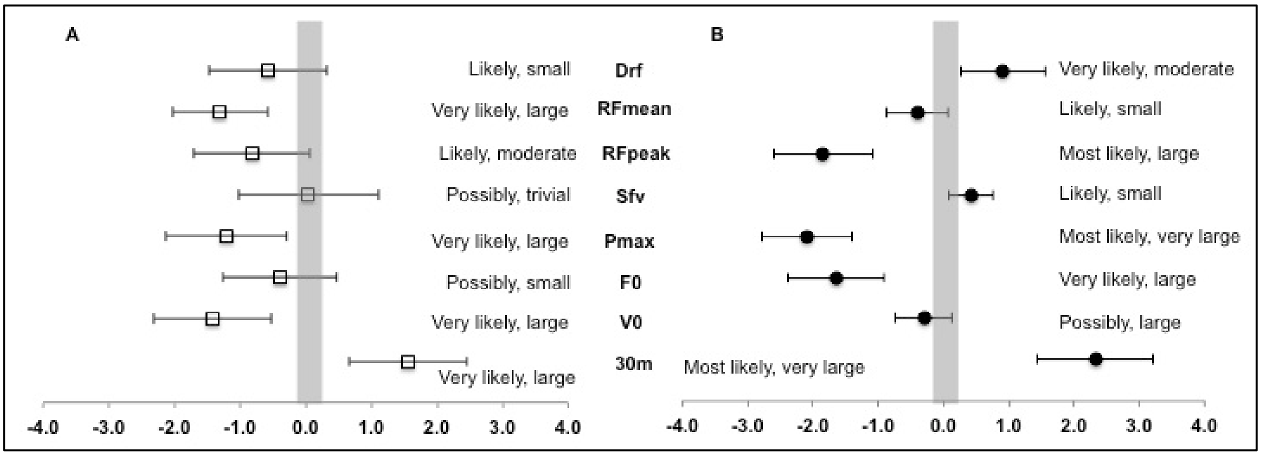

Figure 1: Standardised differences (ES ± 90% CI) between Elite and Sub-elite sprinters (A) and Best and Worst trials of Elite sprinters (B), with qualitative descriptors of effect size magnitude and likelihood that the true difference is at least small. Shaded area represents a trivial difference (ES <0.2).

DISCUSSION: Elite sprinters achieved faster 30 m times than their sub-elite counterparts, with greater maximum horizontal power and theoretical maximum velocity but only a small difference in theoretical maximum horizontal force. This suggests that the ability to generate horizontal forces at high running speed is a more important differentiator between these performance levels than horizontal force production at the start of the sprint. The elite sprinters were found to have a higher mean ratio of force over the first two seconds of the trial. The peak ratio of force at the start and the rate of decrease in the ratio of force with increasing velocity (Drf) were also better in the elite sprinters but to a lesser extent (moderate and small effect sizes, respectively). As the mean ratio of force is influenced by its peak and rate of decrease, this finding indicates that both components must be well executed to achieve a higher mean ratio of force throughout the sprint. Elite sprinters are therefore able to produce larger horizontal force that decreases at a lower rate with increasing velocity. These findings are in agreement with previous studies (Morin et al., 2012; Rabita et al., 2015).

Understanding intra-individual determinants of performance is important for athletes at the elite level who are trying to further improve their own performance. In contrast to the group-based analysis, it was found that theoretical maximum horizontal force was the major differentiator between the elite athletes' best and worst performances, as it was much lower in the worst trial, while the theoretical maximum horizontal velocity was only slightly decreased. A likely small decrement in mean ratio of force was observed in the worst trial, with a lower peak ratio of force but an improved Drf (less negative value). This reemphasises the importance of both factors in order to achieve high overall ratio of force.

Nagahara and colleagues (2017) applied an intra-individual approach to the analysis of step-to-step spatiotemporal variables and ground reaction forces. They reported that athletes achieved faster 60m sprint times through a higher step frequency and greater propulsive force, particularly during initial acceleration. The results of the current study appear to support these findings, as a greater propulsive force with each step, applied at a high step frequency during initial acceleration, would increase the horizontal force at the high force-low velocity region of the force-velocity relationship.

Empirical research involving elite athletes is rare, which presents challenges for practitioners working in elite sport as the existing evidence is overwhelmingly derived from non-elite athletes and may not necessarily be applicable. The current study involved world-class sprinters and provides some insights into the determinants of performance in individuals within this category. These data may be used to further investigate the mechanisms through which the key mechanical variables can be enhanced, such as kinematic factors, coaching cues, and neuromuscular function.

CONCLUSION: This study supports previous reports that theoretical maximum velocity, power, and the ratio of horizontal to total force are important differentiators between elite and sub-elite sprinters. However, intra-individual differences in acceleration performance of elite sprinters were more strongly related to changes in theoretical maximum horizontal force than velocity. Therefore, when utilising force-velocity-power profiles to assess elite sprinters who are capable of high theoretical maximum velocity, it is important to emphasise training methods to enhance horizontal force during initial acceleration.

REFERENCES

Hopkins, W. (2000). A new view of statistics. Retrieved from http://www.sportsci.org/resource/stats.

Hopkins, W., Marshall, S., Batterham, A., Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, 41(1), 3-12.

Morin, J.-B., Bourdin, M., Edouard, E., Peyrot, N., Samozino, P., Lacour, J.-R. (2012). Mechanical determinants of 100-m sprint running performance. *European Journal of Applied Physiology,* 112, 3921-30.

Nagahara, R., Mizutani, M., Matsuo, A., Kanehisa, H., Fukunga, T. (2017). Step-to-step spatiotemporal variables and ground reaction forces of intra-individual fastest sprinting in a single session. *Journal of Sports Sciences*, 36(12), 1392-401.

Rabita, G., Dorel, S., Slawinski, J., Saez de Villareal, E., Couturier, A., Samozino, P., Morin, J.-B. (2015). Sprint mechanics in world-class athletes: a new insight into the limits of human locomotion. *Scandinavian Journal of Medicine and Science in Sports,* 25(5), 583-94.

Samozino, P., Rabita, G., Dorel, S., Slawinski, J., Peyrot., Saez de Villareal, E., Morin, J.-B. (2016). A simple method for measuring power, force, velocity properties and mechanical effectiveness in sprint running. *Scandinavian Journal of Medicine and Science in Sports,* 26(6), 648-58.

ACKNOWLEDGEMENTS: The authors wish to thank all of the athletes and coaches who were involved in this study.