IMPACT OF FOREFOOT CUSHIONING STIFFNESS ON BLOCK START PERFORMANCE IN SPRINTING

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This study aimed to identify the impact of different forefoot cushioning properties in “advanced spiked footwear” on sprinting performance during the block start. Kinetic parameters were collected for twenty-three competitive sprinters during a block sprint start in two advanced spike conditions with only a difference in forefoot cushioning stiffness. An instrumented start block was used to measure the ground reaction forces applied in the front and rear leg. The stiffer shoe condition showed significantly better performance for most parameters, suggesting a softer midsole in forefoot cushioning is not related to better block start performance. This study has demonstrated that differences in midsole materials can alter sprinting block performance and should be considered when analysing advanced spikes features, especially across different shoe brands and their cushioning technologies.

KEYWORDS: running biomechanics, super spikes, AFT, athletics, locomotion

INTRODUCTION: Rapid advances in track spike innovation, characterised by lightweight, resilient, and compliant midsole foams in the forefoot (Frederick, 2022), has led to a surge in record-breaking performances, which might be attributed to the impact of advanced spike footwear on athletic performance (Mason et al., 2023; Robbin et al., 2023). Changes in the properties of spikes have already been shown to improve sports performance. Stiffening the longitudinal midsole with embedded carbon fibre plates can improve acceleration and sprinting performance (Stefanyshyn & Fusco, 2004; Willwacher et al., 2016). In distance running, evidence exists supporting that not only bending stiffness but also altered midsole cushioning stiffness can influence performance (Worobets et al., 2014). However, with regard to sprinting, a comprehensive biomechanical examination of forefoot cushioning has not been conducted to date. Studies addressing the effects of recently introduced advanced spike technologies have focused mostly on the high-speed phases of sprinting (Prajapati et al., 2023). Nonetheless, sprint mechanics differ between the start, acceleration, maximum speed, and speed endurance phases (Mero et al., 1992). To quantify block start performance in sprinting, current research recommends the following parameters (Bezodis et al., 2019): the normalized average horizontal block power (NAHBP), the ratio of anterior-posterior force to resultant impulse (RHRI) (Morin et al., 2011) and the horizontal centre of mass velocity at block exit (V_{Hor}) (Bezodis et al., 2010; Willwacher et al., 2013). Since no study has focused specifically on the effects of forefoot cushioning stiffness, the purpose of this study was to determine the main differences in performance-related biomechanical variables when systematically changing the stiffness of the forefoot cushioning foam in sprinting spikes.

METHODS: Twenty-three sprinters volunteered to participate in this study which were classified as competitive sprinters (14 males, nine females, age: 18.2 ± 5.6 years, height: 1.77 ± 0.06 m, body mass: 65.5 ± 8.7 kg). All participants were free of lower extremity musculoskeletal injuries in the previous six months before data collection. Personal records in 100 m races averaged 11.46 ± 0.30 s for men and 12.68 ± 0.30 s for women. The study had ethical approval from the local Research Ethics Committee, and all participants signed informed consent forms before participating in the study.
Kinetic parameters were captured using an instrumented starting block with a 3D force plate in each block (1000 Hz, Contemplas, Kempten, Germany). The following parameters were extracted for analysis: Reaction time (T_{react}), block time (T_{block}, time from first reaction to block release), normalised average horizontal block power (NAHBP), resultant maximum forces, and

resultant force impulse for both legs ($F_{maxfront}$, $F_{maxrear}$, and I_{res}, respectively). Additionally, the velocity at block release (V_{Hor}) was calculated by integrating horizontal force curves, wherein local horizontal forces were accurately transformed into global horizontal forces, accounting for the inclination of both starting blocks.
Prototype shoe conditions were provided by adidas (adidas AG, Herzogenaurach, Germany) in two different sizes for men UK9.5 and women UK6.5. Each pair was provided three times to avoid material fatigue. Forefoot cushioning was tested by applying a standardised force and measuring the forefoot deformation. The softer prototype (P_{soft}) was 11% more deformed than the harder condition (P_{hard}). All prototypes (UK9.5 and UK6.5) were normalised to the same weight, excluding potential shoe mass effects.
After an individual warm-up, participants completed three starts in each shoe condition in randomized order, with a self-selected rest period between each trial to avoid fatigue. After an auditory start cue, the instruction was to accelerate as fast as possible for 5 m.
Statistical analyses were conducted in MATLAB (The Mathworks Inc., Natick, MA, USA) and consisted of paired sample t-tests to compare the two conditions within the same participants. Only the best start per condition indicating a higher NAHBP value,) was considered for the analysis for each participant. The level of significance was set to 0.05.

RESULTS: There was a significant decrease in NAHBP from 0.260 for P_{hard} to 0.251 (-3.5%) for P_{soft} (p =.008) (Figure 1). RHRI was significantly lower (i.e., a more vertical push-off, -1.5%) in P_{soft} (0.596) compared to P_{hard} (0.605; p =.007).

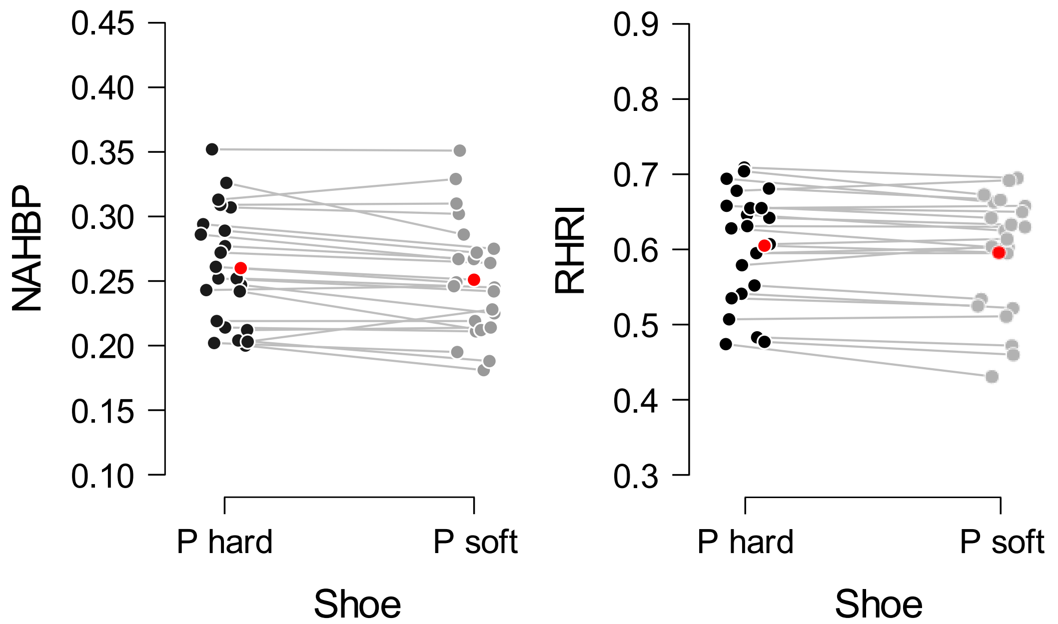

Figure 1: Mean values (red) of normalized average horizontal block power (left) and ratio of anterior-posterior force to resultant impulse (right). A higher value on the y axis suggests a larger push-off power and a horizontal push-off.

A significantly higher V_{Hor} (+2%) was observed in the harder spikes compared to the softer spikes (p=.004). No significant differences were found in $F_{maxfront}$, $F_{maxrear}$, I_{res}, T_{react}, T_{block} (see table 1 for all parameters).

Table 1: Results of start block performance parameters (mean ± SD).

Parameters	$Prototype_{hard}$	$Prototype_{soft}$
$F_{maxfront}$ (N/kg)	16.36 ± 1.92	16.25 ± 1.72
$F_{maxrear}$ (N/kg	10.67 ± 2.69	10.78 ± 2.69
I_{res} (N/kg)	4.80 ± 0.49	4.79 ± 0.11
T_{block} (s)	0.39 ± 0.03	0.39 ± 0.03
T_{react} (s)	0.21 ± 0.05	0.22 ± 0.05
V_{Hor} (m/s) $^{p<0.01}$	2.873 ± 0.184	2.817 ± 0.189
RHRI$^{p<0.01}$	0.605 ± 0.075	0.596 ± 0.077
NAHBP $^{p<0.01}$	0.260 ± 0.045	0.251 ± 0.045

DISCUSSION: The purpose of the present study was to analyse the block start performance in different forefoot cushioned sprint spikes. Our findings demonstrate that spikes with a firmer forefoot cushioning foam exhibited superior performance without discernible alterations in time-related parameters (T_{react} and T_{block}). Notably, the stiffer foam condition demonstrated an enhanced anterior-posterior force orientation, resulting in a more favourable horizontal force distribution (RHRI) - an indicative marker of improved performance. The alignment of horizontal velocity results with other parameters further supports the superiority of the firmer condition in block start execution. According to Bezodis et al. (2010), a higher NAHBP value in the P_{hard} condition suggests better athlete performance. However, current research suggests that individual responses and athlete variability need to be considered when applying footwear findings to practice (Knopp et al., 2023). As the first study to focus only on foam stiffness characteristics of advanced spikes while keeping the other components the same, it is essential for future research to explore variations in midsole properties to make technical optimizations as well as to understand the biomechanical adaptations. This could be addressed by measuring the kinematics and kinetics with a 3D motion capture system and characterise how block start execution is influenced. Future research should also take other phases of sprinting into account, such as acceleration and maximal sprint, where individual responses are likely to play a prominent role as well as energy storage and return are expected to be superior in softer shoes. Furthermore, a traditional spike footwear condition as a controlled baseline could benefit the understanding of forefoot cushioning developments and for systematic comparisons of advanced spiked footwear.

CONCLUSION: This study identified that forefoot cushioning can alter performance-related parameters during sprint block starts, notably influencing horizontal velocity and block power. Specifically, these parameters exhibited inferior outcomes when utilizing a softer midsole system compared to a denser material.

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ACKNOWLEDGEMENTS: This study was funded, co-ideated, and shoes were provided by adidas (adidas AG, Herzogenaurach, Germany).