DETERMINANTS OF ACCELERATION PERFORMANCE IN ELITE FEMALE SPRINTERS

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The purpose of this study was to explore the determinants of performance in the early acceleration phase (first four meters) in nine elite female sprinters. Acceleration performance was quantified using a modified version of the normalized average horizontal block power. Ground reaction forces were collected using an instrumented starting block and three force plates. In addition, full body kinematics were captured using an optoelectronic motion capture system. The results indicate that a starting technique facilitating a horizontal push-off direction and force application with short contact times is beneficial for starting performance. This might be achieved through a greater forward lean of the body. Previously proposed beneficial effects of an active touchdown of the foot could not be confirmed in the present study.

KEY WORDS: sprint running, force application, sprint technique, running, running mechanics

INTRODUCTION: The major goal in short distance sprint races over distances of 100 m (outdoors) or 60 m (indoors) is to increase centre of mass (CoM) velocity as fast as possible up to the maximal achievable value and to keep that velocity as high as possible until reaching the finish line. Successful acceleration is related to the ability to create high average ground reaction forces (GRFs) in the running direction and to orientate the resulting GRF vector horizontally (Morin, Edouard & Samozino, 2011; Morin, Slawinski, Dorel, de Villareal, Couturier, Samozino & Rabita, 2015) in male athletes. Nonetheless, a confirmation of these results is partly missing for female elite athletes in the literature. Even though it is well known that females are characterised by slower 100 m race times than males (e.g. Tatem, Guerra, Atkinson & Hay, 2004), detailed descriptions on sex differences in sprinting and acceleration mechanics are missing in the literature.

Several features of the sprint technique in the acceleration phase have been emphasized to improve performance. Kugler & Janshen (2010) demonstrated a relationship between the forward lean of the body and the magnitude of propulsive force impulses in sport students. Whether or not a similar relationship exists in elite athletes has not been demonstrated in the published literature, yet. It has been further stated that an active touchdown motion of the foot (i.e. minimal positive or even negative velocity of the foot immediately prior to foot strike, e.g. Mann & Sprague, 1983) and positioning the CoM anterior to the point of force application (PFA) (Mero, Komi & Gregor, 1992) could improve acceleration performance (AccP), partly by reducing the GRF braking impulse. Still, a recently performed study failed to identify a relationship between GRF braking impulse magnitude and AccP (Morin et al., 2015). The identification of determinants of successful AccP can help coaches to improve their instructions to athletes and might further benefit the development of specific training drills for improving AccP. As differences might exist between male and female athletes and between sub-elite and elite athletes, the purpose of the present study was to explore the determinants of performance in the early acceleration phase (first four meters) in elite female sprinters.

METHODS: Nine female sprinters (age: 20.8 ± 3.2 years; body mass: 60.0 ± 4.4 kg; standing height: 1.71 ± 0.04 m) who were members of the German short sprint or hurdle sprint

national team or junior national team participated in the study (100 m personal records (PR): 11.02 s – 12.21 s).
A custom–made starting block consisting of a very stiff, steel centre rail and separate block base and force sensing units for the front and rear foot was used for force data collection. Different base units were used for each block inclination angle, which were screwed to the centre rail in order to provide a highly stiff system for force measurements. Small custom made force platforms including four Kistler piezo type 3D force transducers each, were screwed on top of the block bases for force measurements. Further, details of the instrumented starting block are provided in Willwacher, Küsel-Feldker, Zohren, Herrmann & Brüggemann (2013). GRFs of the first three steps after block clearance were captured using three force platforms (0.9 x 0.6 m, 1250 Hz, Kistler Instrumente AG, Winterthur, Switzerland) covered with the same Tartan surface as the runway. All force signals were filtered using a recursive 4th order digital Butterworth filter (100 Hz cut – off frequency).

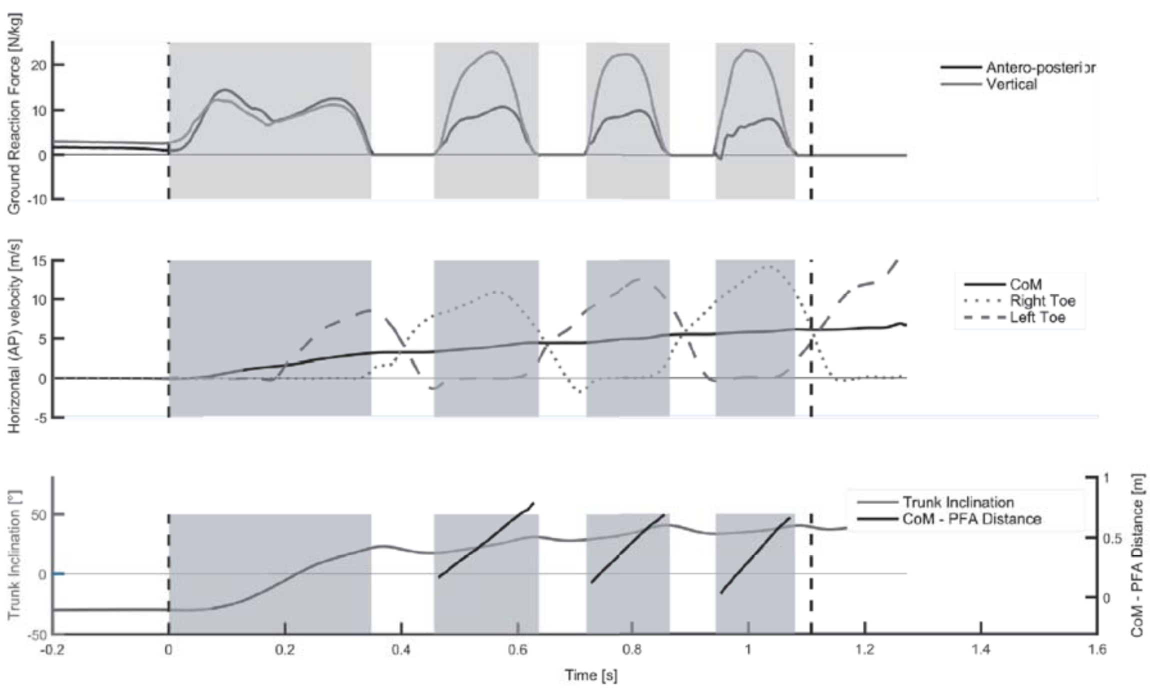

Figure 1: Example curves of variables of interest in the present study. Top: GRFs in the antero-posterior (AP) and vertical direction. Middle: Horizontal (AP) velocity of CoM, left and right toe. Bottom: Trunk inclination and CoM-PFA distance. Grey areas indicate contact with the ground. Centre of mass to point of force application (CoM-PFA) distance was calculated for the stance phase only, omitting the first and last 5% due to known inaccuracies in PFA determination at low force levels.

Further, full body kinematics (including CoM position) were measured using a 21 segment rigid body model (Alaska Dynamicus, Institute of Mechatronics, Chemnitz, Germany), requiring 54 reflecting markers to be tracked using a 16 camera optoelectronic motion capture system (Vicon MX 40, Vicon Motion Systems, Oxford, UK). CoM motion and velocity were analysed for the first four meters of maximum effort starts over a distance of 12 m. The following parameters were extracted for this interval:
Total time (to 4 m mark), contact time, flight time, impulses and average force development in the braking, propulsion, vertical and mediolateral direction, trunk inclination, CoM to PFA distance (positive value, if CoM is in front of PFA), ratio of horizontal to resultant impulse and horizontal toe velocity immediately prior to touchdown. Trunk inclination was defined as the angle of a vector pointing from the midpoint of the pelvis to the midpoint between C7 and

sternoclavicular joint and the horizontal plane. Figure 1 visualizes some of the variables captured for a typical trial. GRF related parameters were summed up (impulses) or averaged (average forces, CoM-PFA distance) over the total ground contact time. Medio-lateral forces were calculated as absolute values in order to analyse the absolute amount of force produced orthogonal to the running direction.
To describe AccP, an extended version of the normalized average horizontal block power (Bezodis, Salo & Trewartha, 2010) was used. Here, the observation interval was extended to the point when the CoM reached the 4 m mark and normalisation was performed using body height instead of leg length.
Correlation analyses using Spearman's rho were used to identify relationships between parameters of interest. Due to the low sample size and corresponding statistical power, the level of significance was set to 0.1 and a significant trend was considered to be present for p – values between 0.1 and 0.2.

Table 1:
Descriptive statistics and correlation coefficients (Spearman's rho) for the relationship to acceleration performance for parameters of interest.

	Mean ± sd	Bivariate correlation with acceleration performance	
Acceleration performance	0.35 ± 0.03	Spearman's rho	p-value
CoM velocity at 4 m mark (m/s)	5.88 ± 0.16	0.97	<0.001
4 m time (s)	1.14 ± 0.03	-0.92	0.001
Contact time (s)	0.90 ± 0.04	-0.85	0.006
Flight time (s)	0.24 ± 0.04	-0.13	0.744
Total braking impulse (m/s)	-0.06 ± 0.05	0.03	0.948
Total propulsive impulse (m/s)	6.06 ± 0.29	0.30	0.437
Total medio-lateral impulse (m/s)	1.10 ± 0.28	0.22	0.581
Total vertical impulse (m/s)	10.43 ± 0.41	-0.57	0.121
Avg. braking force (N/kg)	-0.06 ± 0.04	0.03	0.948
Avg. propulsive force (N/kg)	5.32 ± 0.36	0.67	0.059
Avg. medio-lateral force (N/kg)	0.96 ± 0.24	0.48	0.194
Avg. vertical force (N/kg)	9.14 ± 0.33	0.02	0.982
Avg. trunk inclination (°)	18.73 ± 4.49	-0.52	0.162
Avg. CoM - PFA distance (m)	0.39 ± 0.02	0.57	0.121
Avg. ratio prop. / res. impulse	0.48 ± 0.02	0.70	0.043
Avg. toe velocity prior to TD (m/s)	-0.13 ± 0.53	-0.15	0.708

RESULTS: A significant trend was observed between AccP and the 100 m season best time in the outdoor season following data collection (rho: -0.52, p: 0.16). Besides those parameters that are directly used in the determination of AccP (4 m time and CoM velocity at 4 m), a strong correlation was found between AccP and overall contact time (-), average propulsive force (+) and the ratio of propulsive and resultant GRF impulse (+) (table 1). Further trends were observed for the relationships between AccP and total vertical impulse (-), average medio-lateral force (+), average trunk inclination (-) and average CoM-PFA distance (+) (table 1).

DISCUSSION: The purpose of this study was to explore the determinants of performance in the early acceleration phase in elite female sprinters. A correlation of -0.52 highlights the importance of AccP for the overall 100 m race performance. The calculated rho value is underestimating the real strength of the relationship between AccP and 100 m race performance as the data collection took place in January. During the approx. five months to the start of the summer season the actual AccP of the athletes might have changed. In addition with other sources of error (measurement error, environmental conditions, etc.) this might have reduced the effect size of the observed relationship. The results of the present study further emphasize the previously found (for male athletes) relationships between AccP and the direction of force application and highlights the importance of propulsive force application (Morin et al., 2011, Morin et al., 2015). These forces need to be applied in a short contact time, which is reflected both in the high correlation between AccP and overall contact time as well as the fact that a stronger relationship was found for average propulsive GRF compared to overall horizontal GRF impulse. Acceleration performance was further positive related to a sprinting technique that features a more pronounced forward lean of the body. Interestingly, a significant trend was also observed for the positive correlation between average absolute forces in the mediolateral direction and AccP. This might be explained by a mechanism where muscles which are working predominantly but not exclusively outside the sagittal plane might contribute to propulsive force generation. Further, athletes might use a technique where the feet are not positioned directly underneath their body, but are placed more laterally (e.g. speed skating technique) which might be associated with greater mediolateral force application.

CONCLUSION: The results of the present study confirm some of the determinants of AccP, which were previously identified in sub-elite and elite male subjects. Improved AccP might be achieved by increasing the forward lean of the body and by directing the GRF vector more to the running direction. GRFs further need to be applied during a short period of time. An active touchdown of the foot and braking force application were not related to AccP. The relationship between mediolateral and propulsive force application in different starting / acceleration techniques needs to be investigated in greater detail in the future.

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