SPRINT START KINETICS: COMPARISON OF AMPUTEE AND NON-AMPUTEE SPRINTERS

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The purpose of this study was to observe relationships between reaction forces measured with an instrumented force starting block, start performance (normalized average horizontal block power) and 100 m personal record times in 142 male and female able-bodied sprinters. Further, start kinetics of 7 amputee sprinters and able-bodied sprinters of similar 100 m performance level were compared. Amputee sprinters showed a reduced starting performance, which seems to be related to their lower capacity of creating high peak forces with their rear (affected) legs. In able-bodied athletes, starting performance was related to peak force production in the front and rear blocks, but also to the ability to apply these forces in a horizontal direction. The obtained dataset offers a strong potential for the use in performance diagnostics and feedback training.

KEY WORDS: push-off forces, amputee sprinting, sprint start.

INTRODUCTION: Optimal performance in the starting phase is of critical importance in short sprint running events. Successful starting performances are characterized by short reaction times, short push-off durations and a high horizontal centre of mass (CoM) velocity at block clearance. From a mechanical point of view, a high positive horizontal acceleration of the CoM generated in a very short time maximizes performance. This is equivalent to creating the highest possible average horizontal CoM block power (AHBP), which has been shown to be the potentially best descriptor of starting performance (Bezodis, Salo & Trewartha, 2010).
From a biomechanical point of view, high AHBP is the result of high rates of energy flow from leg extending muscle tendon units to the skeletal system (Braunstein et al., 2013). Therefore, AHBP must be related to the explosive force capacities of athletes. Further, AHBP might be related to the technical ability of directing the external GRF vector in a horizontal direction (Morin et al., 2012). Nonetheless, studies examining the relationship between external force production characteristics and AHBP over a wide range of 100 m sprint performance levels is currently missing in the literature.
In amputee sprinting, the start phase has the same importance to short sprint running success as in non-amputee sprinting. Contrary to abled-bodied sprinters, amputee sprinters are missing considerable amounts of energy generators (muscles), depending upon their amputation level. Currently, investigations on amputee sprint start kinetics are limited to unilateral transtibial amputees (Taboga, Grabowski, di Prampero & Kram, 2014).
Therefore, the purpose of the present study was to analyse the relationship between overall 100 m race performance, starting performance (AHBP) and selected external force application parameters in able-bodied sprinters and to compare sprint start kinetics between amputee and non-amputee sprinters.

METHODS: 142 male and female able-bodied sprinters (ABS, age: 20.2 ± 3.5 years; body mass: 69.8 ± 9.7 kg; standing height: 1.78 ± 0.08 m) of a wide range of performance levels (100 m personal records (PR): 9.58 s – 14.00 s) participated in the study. Further, seven

male amputee sprinters (AMS) participated (Table 1). Informed consent was obtained by all participants and the experimental procedures were strictly in line with the guidelines stated in the declaration of Helsinki. 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, Herrmann, Heinrich & Brüggemann (2013).
Force signals were filtered using a recursive 4th order digital Butterworth filter (100 Hz cut – off frequency). The following parameters were extracted for analysis: Block time (T_{block}, time from first reaction to block clearance), centre of mass velocity at block clearance (V_{CoM}, determined by integration of mass normalized horizontal force curves), normalized average horizontal block power (NAHBP, see Bezodis et al. (2010) for calculation; instead of leg length, total body height was chosen for normalization since leg length was not available for all subjects), maximum resultant forces of the front and rear leg ($F_{maxfront}$ and $F_{maxrear}$, respectively) and the ratio of horizontal to resultant GRF impulse of both legs (RHRI, Morin, Bourdin, Edouard, Peyrot, Samozino, & Lacour, 2012).
Each athlete performed at least 3 full effort sprint starts over a distance of 20 m. The best start (based on NAHBP) was selected for further analysis. Pearson's product moment correlations were calculated to determine linear relationships between parameters and 100 m PR as well as starting performance (NAHBP). All AMS were compared to ABS of similar level of performance, based on their 100 m PR using two sided Wilcoxon rank sum tests. The level of significance was set to 0.05. If significant differences were observed, effect sizes (Cohen's d) were calculated. Due to the low sample sizes no significance testing was performed for the differences between ABS and AMS subgroups.

Table 1:
Amputee sprinter characteristics.

		Amputation level	Affected leg	Height (m)	Mass (kg)	Age (years)	100 m PR (s)
AMS01	UL	TF	right	1.89	73.8	32	12.70
AMS02	UL	TT	right	2.00	85.7	33	12.40
AMS03	UL	TF	left	1.78	71.0	31	12.26
AMS04	UL	TF	left	1.81	80.2	30	12.40
AMS05	UL	TT	right	1.91	74.7	25	11.92
AMS06	UL	TT	right	1.97	89.1	24	11.70
AMS07	BI	TT	both	1.87	69.7	27	12.27

UL = unilateral amputation; BI = bilateral amputation

TF = transfemoral amputation; TT = transtibial amputation

RESULTS: Significant correlations between NAHBP and $F_{maxfront}$ ($r = 0.58$, $p < 0.001$), $F_{maxrear}$ ($r = 0.61$, $p < 0.001$) and RHRI ($r = 0.48$, $p < 0.001$) were observed. NAHBP shared more variance with V_{CoM} ($r = 0.91$, $p < 0.001$) than with T_{block} ($r = -0.46$, $p < 0.001$). A significant linear relationship was obtained between NAHBP and 100 m PR ($r = -0.61$, $p < 0.001$), while 100 m PR was also significantly correlating with $F_{maxfront}$ ($r = -0.18$, $p < 0.05$), $F_{maxrear}$ ($r = -0.52$, $p < 0.001$, see fig. 1), RHRI ($r = -0.58$, $p < 0.001$), V_{CoM} ($r = -0.47$, $p < 0.001$) and T_{block} ($r = 0.61$, $p < 0.001$).
AMS were characterized by significantly longer T_{block} ($p = 0.007$, $d = 1.28$) and lower $F_{maxrear}$ ($p = 0.001$, $d = 1.92$). NAHBP showed a tendency towards lower values for AMS compared

to matching ABS (p = 0.08, d = 0.78). Table 2 summarizes the comparison of AMS and matching ABS.

Table 2:
Summary of the comparison between AMS and ABS (mean ± std).

	Matching ABS	All (n=7) AMS	UL TT AMS (n=3)	UL TF AMS (n=3)	BL TT AMS (n=1)
100 m PR (s)	12.09 ± 0.29	12.24 ± 0.33	12.01 ± 0.36	12.45 ± 0.22	12.27
NAHBP	0.28 ± 0.06	0.23 ± 0.05	0.24 ± 0.06	0.25 ± 0.05	0.19
T_{block} (s)	0.39 ± 0.03	0.44 ± 0.03 **	0.41 ± 0.03	0.45 ± 0.02	0.47
V_{CoM} (m/s)	2.99 ± 0.35	2.92 ± 0.30	2.90 ± 0.41	3.01 ± 0.27	2.72
$F_{maxfront}$ (N/kg)	15.59 ± 2.27	15.36 ± 2.18	14.49 ± 2.92	16.77 ± 0.57	13.70
$F_{maxrear}$ (N/kg)	11.71 ± 2.62	6.23 ± 3.92 **	9.56 ± 1.81	2.44 ± 1.92	7.60

* = significant difference (p < 0.05) between AMS (n = 7) and performance matching ABS (n = 34)
** = significant difference (p < 0.01) between AMS (n = 7) and performance matching ABS (n = 34)

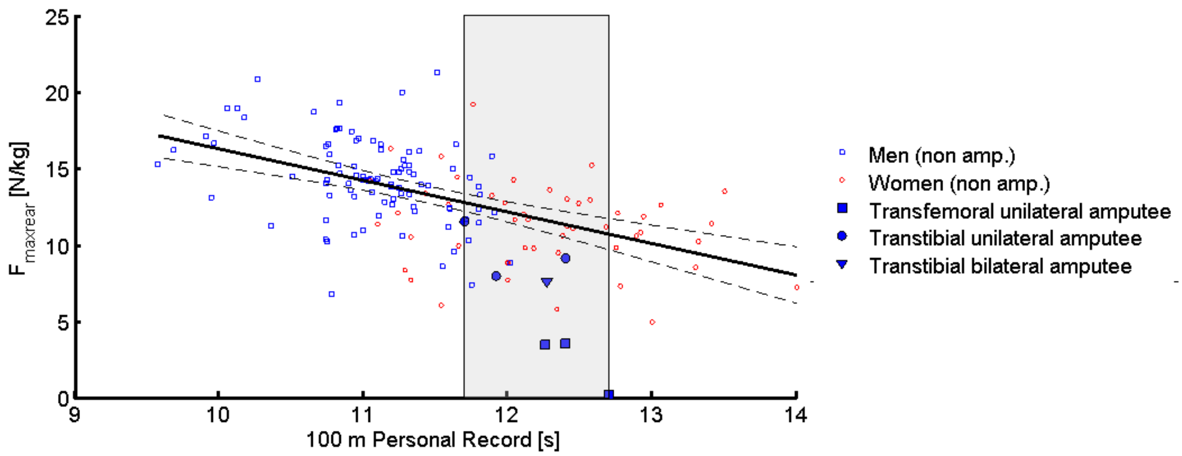

Figure 1: Relationship between 100 m PR time and $F_{maxrear}$. The shaded area indicates the range of athletes with matching performance level compared to amputee athletes.

DISCUSSION: The purpose of this study was to analyse selected sprint start reaction force characteristics of ABS and AMS and to explore their relationship to 100 m race and starting performance. The results emphasize the importance of explosive force capacities for a successful sprint start performance. Better start performance in this study was related both to short block times and high peak force production in the front and the rear leg. High extension moments and positive power output is required by lower extremity joints in the start and early acceleration phase, particular at the hip and ankle joint (Braunstein et al., 2013, Mero, Kuitunen, Harland, Kyröläinen & Komi, 2006, Bezodis, Salo & Trewartha, 2015). Sprint start specific strength training regimes should incorporate exercises which include high rates of positive work at these joints, with time characteristics similar to block times during the sprint start. Better sprinters were able to orientate the GRF vector more to a horizontal direction, showing that start performance is not solely related to explosive leg extension force potential, but also to starting technique.

The dataset of 142 ABS from all performance levels obtained for this study has a strong potential to serve as norm data base for performance diagnostics. In those parameters that show a significant linear relationship with performance, the vertical distance from the linear regression line can be interpreted to relate the start characteristics of an individual to the average performance of athletes of similar overall 100 m performance level. In Figure 1 for

example, AMS values are all located below the regression line, indicating inferior force production in the rear blocks compared to athletes of similar performance levels. Corresponding modifications of starting technique, or specific strength training exercises might help athletes to improve their performance in this parameter and to produce values closer to or even above the regression line.
Amputee athletes in this study showed a lower sprint start performance than their matching ABS counterparts. This seems to be related to their limited force producing capacities in the rear leg, as all athletes placed their affected leg in the rear block. Since start (and potentially early acceleration) performance was reduced, but 100 m PR time was similar between ABS and AMS, it might be concluded that the sprint specific prosthesis used by AMS replicate the functionality of the missing biological limbs better during the constant speed part of the 100 m race than during the start phase.

CONCLUSION: The relationships between force characteristics and performance obtained in the large dataset of able-bodied athletes has a great potential to be used in performance diagnostics and feedback training. Sprinters using sprint specific prosthesis are limited with respect to performance during the push-off phase of the sprint start. This limitation relates mostly to their inability to produce high peak forces with their affected leg, which is related to their missing muscular capacities to perform positive work.

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