AMPUTATION SIDE AND SITE DETERMINE PERFORMANCE CAPACITY IN PARALYMPIC CURVE SPRINTING

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In the 2015 IPC world championships athletes with amputation at the inside leg were underrepresented in the finals of the 200 and 400 m sprinting events. Yet there is only very limited information on amputee curve sprinting and the influence of side and/or level of amputation on propulsion mechanisms. The aim of this study was to describe amputee curve sprinting kinetics and to it compare to able-bodied athletes. Three amputee athletes with different amputations of the lower limb and six able-bodied athletes performed curved runs. Results show differences between athletes in the ability to create high vertical and centripetal forces and suggest a dependence on site (above and below knee) and side (left or right) of amputation. Running specific prosthesis might benefit from design adaptation if used at the left limb in curve running.

KEYWORDS: GRF, athletics, velocity, kinetics, prosthetic design, amputee

INTRODUCTION: In competitive athletics sprint disciplines over more than 100 m, the quantity of curve running is more than 50%. At the 2015 IPC (International Paralympic Committee) world championships no male athletes with amputations of the left (inside) leg competed in the T42 (above knee) and T44 (below knee) 200 m finals and the T44 400 m final. In the T42-T47 4 x 100 male relay final of the same championship only one out of 14 curve running athletes was left sided amputated. This is not counter indicating the findings of Hobara et al. (2015) as their analysis was retrospective and therefore a preselection of subjects regarding performance level had taken place. In an experimental case study Funken et al. (2014) proposed a disadvantage in terms of propulsive mechanisms during maximal curve sprinting for a unilateral knee exarticular amputee athlete with the prosthesis at the inner leg. It was shown that his ability to create a high centripetal and vertical ground reaction force (GRF) was limited in normal (counterclockwise) curve sprinting. Furthermore, it was recently shown in athletes with two biological legs that the inside and outside leg in curve sprinting require different functionalities for sprinting performance (Alt, Heinrich, Funken & Potthast, 2015; Churchill, Salo & Trewartha, 2015). For example Alt et al. (2015) found higher ankle eversion and internal rotation at the knee for the inside leg compared to the outside leg in curve running of able-bodied (AB) athletes. Due to factors related to material and design of running specific prosthesis (RSP) it is likely that amputee athletes cannot fulfill those requirements and have to choose movement strategies different to AB athletes. Additionally their ability to deliberately alter lower limb joint kinematics depends on their individual level of amputation.
Without comprehensive understanding about the effect of side and site (level) of amputation on curve running performance the classification of amputee athletes in sprint distances over 100 m stays partly intuitive. Furthermore, knowledge on that topic might be relevant in terms of training purposes, relay line-up and prosthetic design. Related information however, is so far missing in scientific literature. Therefore the purpose of this study was to analyze and compare sprinting kinetics of amputee athletes with different levels and side of amputation as well as AB athletes.

METHODS: Three athletes of highest international level with lower limb amputations and six able-bodied athletes of national competitive level participated in this study on an indoor athletics track (Tab. 1). All athletes performed three curved runs with a run-up of 30 m at maximal (amputee athletes) or submaximal (AB athletes) speed. In accordance to the IAAF rule for the first lane of a standard track, the curvature of 36.3 m radius was marked on the ground. The kinematic data were recorded by a 3D motion capture system (VICON™, Oxford, UK) consisting of 16 infrared cameras (MX F40) operating at 250 Hz. Four force plates (90 x 60 cm, Kistler™, Winterthur, Switzerland) operating at 1000 Hz were used to determine kinetic data. Force plates were mounted flush to the floor in the vertex of the curve and covered with the same tartan topping as the run-up (Fig. 1).

Table 1: Subject details including anthropometrics and level/side of amputation for amputee athletes (P1, P2 and P3) and able-bodied reference group (AB).

Subject	Side of Amputation	Site of Amputation	Mass [kg]	Height [m]
P1	right	transtibial	89.0	1.96
P2	bilateral	transtibial	71.7	1.87
P3	left	knee exarticular	80.4	1.81
AB (n=6)	--	--	76.3 ± 8.2	1.86 ± 0.06

Retro-reflective markers were placed on anatomic reference points and the prosthesis of the athletes. Markers were used for inverse dynamic calculations. For the results presented in this paper, however, only the four pelvis markers were used for further calculations. All calculations on GRF were executed in MATLAB® (R2013b, The Mathworks, Natick, USA). Kinematic and kinetic data were filtered by a 4th order recursive butterworth filter with a cutoff frequency of 20 Hz (kinematics) or 50 Hz (GRF). All data were time normalized to the duration of the stance phase. Ground contact was determined using the unfiltered vertical ground reaction force and a threshold of 10 N. Running velocity was determined calculating the mean horizontal velocity of the COM (AB athletes) or the four pelvis markers collectively (amputee athletes) over stance phase. In addition to the peak values of the GRFs and impulses, also their left to right ratio and the sum of both legs was calculated. Due to a small sample size of the amputee athletes, peak values were assumed to be different when the difference between the means was greater than the sum of both standard deviations.

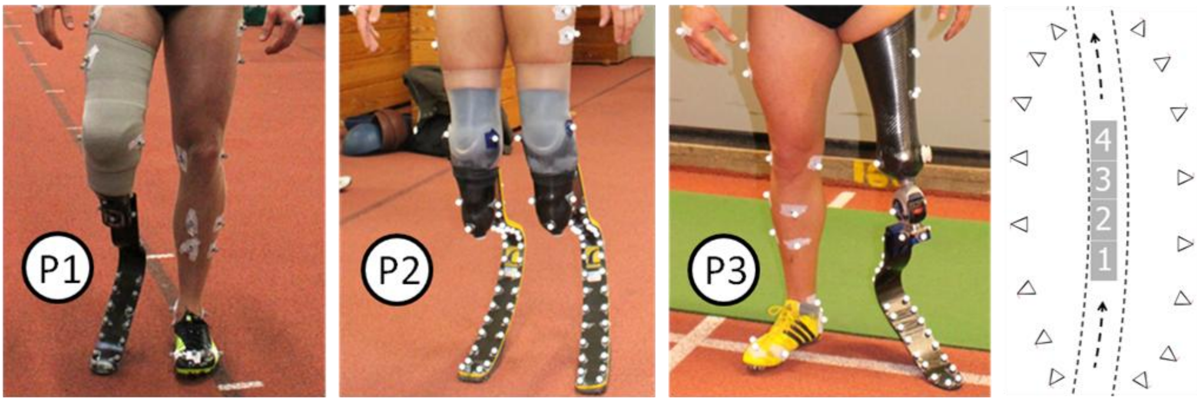

Figure 1: Lower limbs of the amputee athletes (left: P1 right side below knee; middle left: P2 bilateral below knee; middle right: P3 left side knee exarticular) and the technical set up (right) including cameras, force plates, ground marking and running direction is shown.

RESULTS AND DISCUSSION: In both unilateral amputee athletes (P1 and P3) stance time was longer for the prosthetic compared to the sound leg. In all athletes except for P1 (right side unilateral amputee) stance time for the inner leg was longer than for the outside leg (Tab. 2). This difference was most pronounced for P3 (left side unilateral amputee).

Peak posterior (braking) force was higher for the sound compared to the prosthetic limb in unilateral amputee athletes. Regarding shape and amplitude amputee sprinters produced with their sound side similar GRF as their AB counterparts – regardless if left or right side was affected (Fig. 2). Similar to the AB athletes there was no difference between peak braking force in P2 (bilateral) when comparing outside to inside leg. Breaking impulse only differed in P1 between right and left side being more than twice as high for the sound limb. Anterior (propulsive) impulse of P1 and P3 was higher for the outside limb. For P2 and the AB athletes there was no difference in the propulsive impulse between left and right.

Table 2: Mean peak GRF and impulse including standard deviation (SD) are presented for the left (Le) and right (Ri) limb for all three amputee (P1, P2, P3) and the group of able-bodied athletes (AB). Sound and prosthetic limb are indicated with S and P respectively.

	P01		P02		P03		AB	
	Le(S)	Ri(P)	Le(P)	Ri(P)	Le(P)	Ri(S)	Le	Ri
Force [N/kg]								
anterior	6.96 (0.36)	6.08 (0.01)	7.04 (0.31)	6.28 (0.64)	4.41 (0.38)	8.04 (0.46)	7.66 (0.61)	7.95 (0.44)
posterior	12.28 (1.08)	3.47 (0.59)	3.89 (1.25)	3.72 (0.91)	3.97 (0.53)	9.99 (1.57)	10.42 (2.51)	12.04 (1.16)
vertical	34.13 (0.64)	35.42 (2.24)	30.54 (1.15)	31.38 (2.48)	25.64 (1.78)	32.29 (1.97)	36.40 (1.68)	38.52 (4.90)
inward	9.72 (0.48)	5.40 (0.34)	4.90 (1.21)	5.10 (1.82)	4.40 (0.93)	6.97 (0.94)	10.80 (0.68)	6.84 (0.51)
Impulse [Ns/kg]								
anterior	0.24 (0.01)	0.30 (<0.01)	0.32 (0.01)	0.30 (0.04)	0.23 (0.02)	0.27 (0.01)	0.29 (0.02)	0.27 (0.02)
posterior	0.25 (0.02)	0.10 (0.02)	0.09 (0.01)	0.09 (0.03)	0.15 (0.02)	0.13 (0.03)	0.20 (0.05)	0.19 (0.04)
vertical	2.16 (0.08)	2.36 (0.14)	2.48 (0.09)	2.16 (0.25)	2.29 (0.17)	1.80 (0.15)	2.45 (0.17)	2.30 (0.14)
inward	0.58 (0.03)	0.40 (0.01)	0.41 (0.08)	0.37 (0.14)	0.31 (0.06)	0.35 (0.06)	0.67 (0.04)	0.39 (0.05)
Stance time [ms]	104.3 (1.2)	107.0 (1.4)	124.0 (0)	114.0 (4.1)	136.0 (2.0)	96.0 (1.7)	109.9 (10.2)	103.3 (7.0)
Velocity [m/s]	9.39 (0.14)	9.01 (0.07)	8.55 (0.03)	8.72 (0.26)	7.08 (0.04)	8.79 (0.02)	9.56 (0.30)	9.56 (0.34)

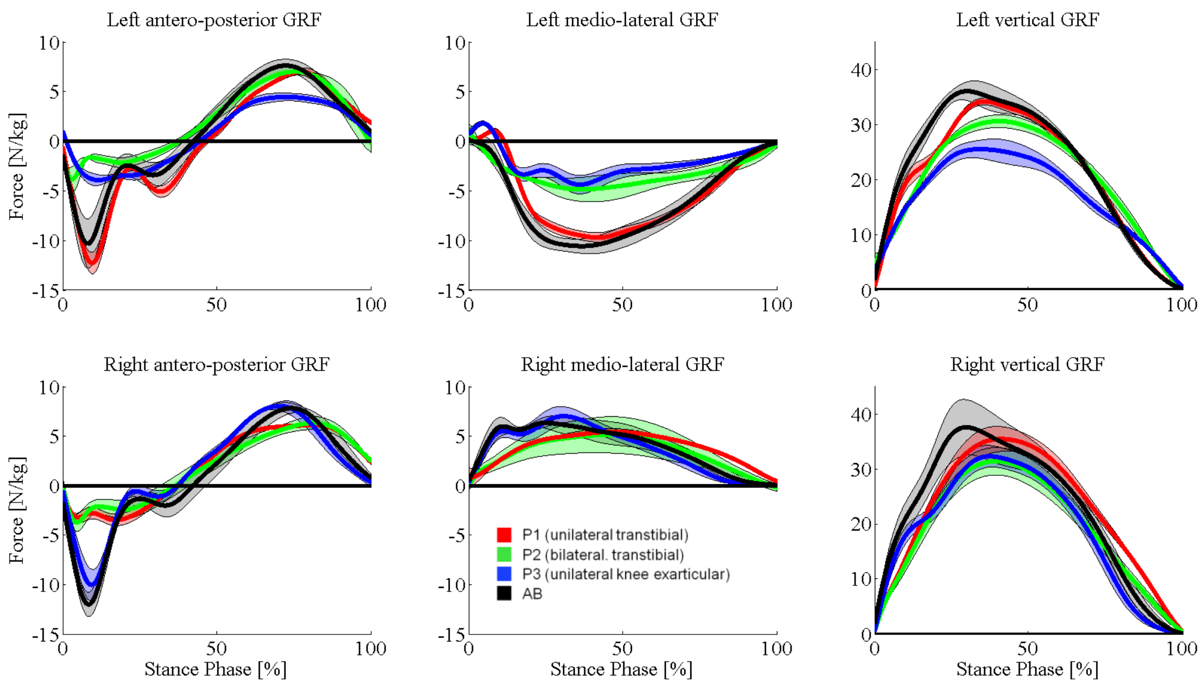

Figure 2: Mean GRF (thick) and standard deviation (shaded) for all subjects (P1 red, P2 green, P3 blue, able-bodied black) in antero-posterior (left), medio-lateral (middle) and vertical (right) direction for the left (top) and the right (bottom) limb.

In curve running the ability to create high inward orientated (centripetal) forces and impulses is essential to follow the circular path of the curve. The AB athletes showed a higher inward orientated impulse at their inside leg compared to their outside leg. This is in accordance with previous research (Churchill et al., 2015). For the amputee athletes this difference could only be found for P1, a right sided amputee athlete. For P2 and P3 the inward orientated impulses were about equal for left and right. Inward peak GRF of the AB athletes were one third higher for the left compared to the right leg. For P1 the left to right ratio of peak inward force was similar to the AB athletes. In contrast to that inward peak GRF of P3 was one third higher for the outside than for the inside foot. For P2, a bilateral amputee athlete, both legs generated a similar inward peak force with both legs. The sum (left + right leg) of the inward orientated impulses were higher for the outside unilateral amputee athlete and the AB athletes (0.98 Ns/kg, 106 Ns/kg) compared to athletes with an amputation at the inner leg (P2 = 0.78 Ns/kg, P3 = 0.66 Ns/kg). Interestingly, differences in total inward impulse were mainly based on differences in left inward impulses. Right inward impulses were more or less equal for all athletes. The results of this study suggest that athletes with amputations at the inner leg are limited in terms of generating high inward peak forces with their affected limb and have to somewhat compromise it with longer stance times resulting in lower running velocities.
No differences in peak vertical ground reaction force were found when comparing left to right limb with exception of P3. Peak vertical GRF of P3's left leg was about 25% lower than for his outside foot and lower as the left vertical GRF of all other athletes. This difference did not appear for his right leg. However, due to a longer stance time of the inside leg, the left vertical impulse of P3 was higher compared to his outside leg and similar to those of all other subjects. The vertical impulse of the prosthetic side tended to be higher than for the sound side for unilateral amputee athletes. The difference between left and right vertical impulse, however, was higher if the prosthesis was at the inside leg. Assuming that high vertical GRFs are not only associated with high linear running velocities (Weyand, Sternlight, Bellizzi & Wright, 2000) but also indicate for high curve running velocities, the ability of P3 to perform equally seems to be limited. As P3 was the only athlete with differences in peak vertical GRF between left and right leg it can be deduced that amputation at the inside leg is a performance limiting factor which is essential increased by his level of amputation.

CONCLUSION: Prosthetic curve sprinting kinetics depends on level and side of amputation. Athletes with amputations at the inside leg (unilateral or bilateral) seem to be disadvantaged in terms of generating high curve running velocities. As all athletes have to run counter clockwise this knowledge is important for training purposes and prosthetic designs. Future prosthesis might provide more degrees of freedom in the mechanical knee or the blade especially in the frontal plane. The illustrated findings suggest that current rules and regulations might have to be reconsidered in order to guarantee equal opportunities for all athletes. Whether this should affect the classification of amputee athletes, the running direction or race line-up (left side amputee on outer lanes) has to be shown in further studies.

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