LOWER EXTREMITY JOINT MOMENTS IN ATHLETICS CURVE SPRINTING

Josef Viellehner[1], Kai Heinrich[1], Johannes Funken[1], Tobias Alt[1] and Wolfgang Potthast[1, 2]

Institute of Biomechanics and Orthopaedics, German Sport University Cologne, Germany[1]
ARCUS Sportklinik, Pforzheim, Germany[2]

The purpose of this study was to identify the effect of curve sprinting on the three-dimensional joint kinetics and to specify the leg specific loading and functionality in the curve. Six male sprinters performed three submaximal curved and linear sprints. The findings point up different functionalities of the inner and outer leg. Peak knee and hip adduction moments were about twice as high at the inner leg compared to the outer leg during curve sprinting and compared to linear sprinting. Furthermore significantly higher peak external rotation moments in the knee and hip joints could be found during curve sprinting. In maximal sprinting these additional tasks may compromise propulsive force generation. These findings help to quantify the side specific load and provide information about involved muscles, which is helpful for the training process and injury prevention.

KEY WORDS: sprint mechanics, joint energy, joint kinetics, bend, track and field

INTRODUCTION: Curved sprinting is the predominating form of locomotion in athletics running competitions over 100 m (Meinel, 2008). Following the curved track path requires generation of centripetal force. Scientific publications investigating athletics curve sprinting considering the three dimensionality of motion is underrepresented in the literature. Compared to straight running, the generation of the centripetal force component causes leg specific alterations in three dimensional (3D) joint kinematics, ground reaction forces and joint kinetics, which might have a detrimental effect on propulsive mechanisms and therefore running velocity (Alt, Heinrich, Funken & Potthast, 2015; Churchill, Trewartha, Bezodis & Salo, 2015; Heinrich, Alt, Funken, Brueggemann & Potthast, 2015; Ishimura & Sakurai, 2010). Although sagittal kinematics are not majorly effected during curve sprinting, the impact on frontal and transversal plane kinematics is remarkable. The inside leg was found to follow an adduction-eversion strategy, whereas the outside leg pursuits a rotation strategy (Alt et al., 2015). Compared to the straight, Churchill et al. (2015) showed a decreased mean peak vertical and resultant ground reaction force for the left leg. Also left foot contact produced an increased inward impulse compared to the right foot contact. Likewise Heinrich et al. (2015) emphasized different functions of the inside and the outside leg in curve sprinting from an energy perspective. Especially the inside leg hip joint seems to be highly loaded by the curve sprinting. Therefore, the changes in the sagittal and frontal plane kinetics and kinematics may have a detrimental effect on propulsive force generation mechanism and bend sprinting performance (Luo & Stefanyshyn, 2012; Palastagana, Field & Soames, 2006; Chang & Kram, 2007). The analysis of 3D joint moments, as suggested by Churchill et al. (2015), will therefore provide a better understanding of the relationship between non driving frontal and transversal and propulsive sagittal moments. The scope of the study was to determine the effect of curve sprinting on the three-dimensional joint kinetics and to specify the leg specific loading and functionality in the curve to provide information for the training process and to identify potential injury mechanisms.

METHODS: A cross-sectional single cohort study was used to identify the effects of curved versus linear sprinting on kinematics and kinetics. Six male, healthy sprinters (age: 20 ± 2.6 years; mass 76.3 ± 8.2 kg; height 1.86 ± 0.06 m; 200 m personal best: 22.60 ± 0.33 s) performed six sprints (3 curve, 3 straight) at constant velocity. The athletes performed submaximal sprints at 90% of their observed maximal straight sprint velocity due to a possible velocity dependent effect (Arampatzis, Brüggemann, & Metzler, 1999). Radius of the bend inner lane restriction was 36.5 m following the IAAF regulations. This represents lane one of a standard track (Meinel, 2008). Analog data of four force plates (Kistler, Winterthur, CH; 1250 Hz, filtering: Butterworth, 4th order, cutoff frequency 50 Hz), tangentially placed at the bend's summit and kinematic data were collected with an motion capture system (16 infrared cameras, MX F40, Vicon Nexus 1.85, ViconTM Oxford, UK; 250 Hz, filtering: Woltring, predicted MSE value 15). 32 retro-refelective, spherical markers identified lower extremity reference points. Please refer to Alt et al. (2015) for exact marker placement and measuring of running velocity. Stance time, ground reaction forces (GRF) and external joint moments during ground contact were compared to identify curve- and side-specific effects. Moments are expressed in the proximal segment. All values were determined with the adjusted multibody human model dynamicus (Alaska dynamicus 8.2, Institute of Mechatronics, Chemnitz, GER). Descriptive and inferential statistics were conducted using Matlab (Matlab R2014B, The MathWorks, USA).

RESULTS: Moments of force for the lower extremity joints are visualized in Figure 1. Discrete values are presented in Table 1. Horizontal center of mass velocity during ground contact showed no significant changes between linear and curved sprinting due to the submaximal sprinting condition. The most significant differences could be seen for the left (inner) leg in curved sprinting (CL). Orientated to the bend center, left foot inward orientated GRF and impulse were significantly higher.

Table 1: Peak values and standard deviations of the hip, knee and ankle joint under the investigated conditions curved left (CL), curved right (CR), linear left (LL) and linear (right). a = significant difference to LL, b = significant difference to LR, c = significant difference to CL, d = significant difference to CR. Tendencies are marked by *

Joint Moment (Nm/kg/m)		**LL**	**LR**	**CL**	**CR**
Ankle	flexion	2.53 ± 0.15^{c}	2.63 ± 0.27	2.69 ± 0.20^{a}	2.59 ± 0.25
	extension	0.02 ± 0.02	0.03 ± 0.02	0.02 ± 0.01	0.03 ± 0.02
	eversion	0.01 ± 0.02	0.02 ± 0.07	0.06 ± 0.14	$<0.01 \pm 0.02$
	inversion	0.45 ± 0.20	0.53 ± 0.23	$0.40 \pm 0.11^{d*}$	$0.55 \pm 0.12^{c*}$
	external rotation	0.06 ± 0.09	0.06 ± 0.08	0.04 ± 0.03	0.10 ± 0.13
	internal rotation	0.17 ± 0.03^{c}	0.20 ± 0.08	$0.28 \pm 0.05^{a\,d*}$	$0.17 \pm 0.09^{c*}$
Knee	flexion	1.70 ± 0.27	1.80 ± 0.31	1.83 ± 0.23	1.85 ± 0.38
	extension	0.60 ± 0.27	0.65 ± 0.30	0.63 ± 0.15	0.65 ± 0.18
	abduction	0.26 ± 0.29^{b}	0.33 ± 0.27^{a}	$0.12 \pm 0.05^{d*}$	$0.44 \pm 0.29^{c*}$
	adduction	0.46 ± 0.04^{c}	0.47 ± 0.20	$0.88 \pm 0.13^{a\,d}$	0.38 ± 0.12^{c}
	external rotation	0.19 ± 0.05^{c}	0.23 ± 0.09	$0.34 \pm 0.07^{a\,d*}$	$0.20 \pm 0.13^{c*}$
	internal rotation	$0.05 \pm 0.02^{b*}$	$0.07 \pm 0.04^{a*}$	0.04 ± 0.03^{d}	0.08 ± 0.05^{c}
Hip	flexion	2.27 ± 0.60	2.73 ± 0.91	2.35 ± 0.24	2.37 ± 0.37
	extension	1.81 ± 0.43	1.85 ± 0.39	1.72 ± 0.25	1.83 ± 0.36
	abduction	0.72 ± 0.22	0.72 ± 0.29	0.64 ± 0.18	0.65 ± 0.17
	adduction	0.93 ± 0.22^{c}	$1.07 \pm 0.37^{d*}$	$1.68 \pm 0.38^{a\,d}$	$0.76 \pm 0.26^{b*\,c}$
	external rotation	$0.44 \pm 0.20^{c*}$	$0.51 \pm 0.19^{d*}$	$0.60 \pm 0.12^{a*d}$	$0.4 \pm 0.14^{b*c}$
	internal rotation	0.20 ± 0.08	0.23 ± 0.11	0.22 ± 0.04	0.22 ± 0.05
GRF [N/kg]					
	anterior	7.37 ± 0.79	7.84 ± 0.65	7.66 ± 0.61	7.95 ± 0.44
	posterior	9.97 ± 2.43	$11.03 \pm 0.86^{d*}$	10.42 ± 2.51	$12.04 \pm 1.16^{b*}$
	vertical	37.31 ± 3.50	38.91 ± 5.37	36.40 ± 1.68	38.52 ± 4.90
	inward			10.80 ± 0.68^{d}	6.84 ± 0.51^{c}
Stance time [ms]		106.2 ± 7.3	106.9 ± 7.5^{d}	$109.9 \pm 10.2^{d*}$	$103.3 \pm 7.0^{b\,c*}$
Velocity [m/s]		$9.57 \pm 0.3^{c*}$	9.56 ± 0.34	$9.38 \pm 0.40^{a*}$	9.38 ± 0.51

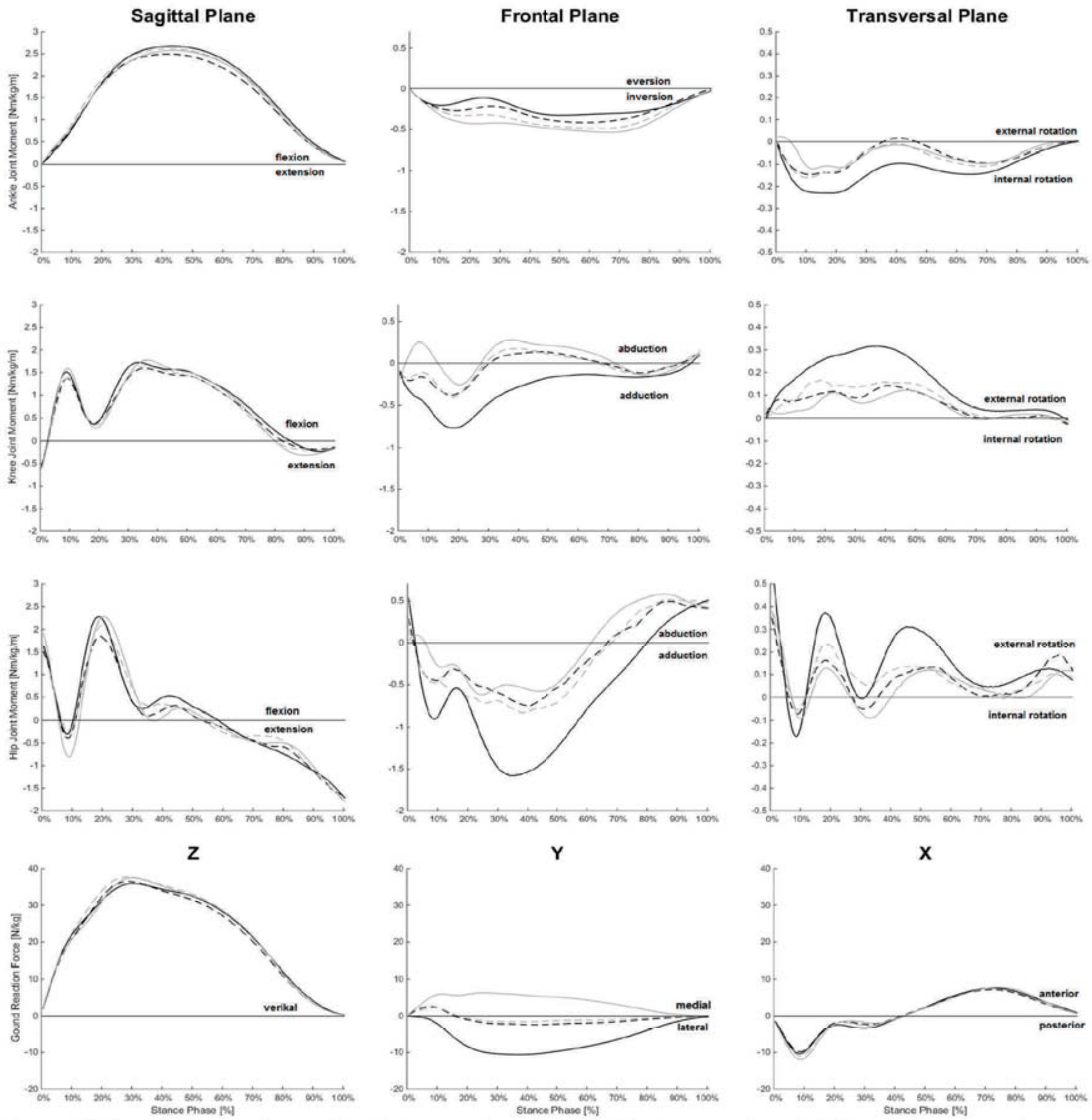

Figure 1: Time histories (normalized stance phase) of the hip, knee and ankle joint moments and ground reaction forces in the sagittal (first column), frontal (second column) and transversal plane (third column) under the four investigated conditions: curved left (black line), curved right (grey line), linear left (dashed black line) and linear right (dashed grey line)

CL knee peak adduction moment in the frontal plane differed significantly and was over twice as high as the curved sprinting right outer leg (CR) and nearly doubled compared to the linear sprinting (LL) value. Similar to this, CL hip joint peak adduction increased significantly and doubled compared to CR and LL. Significantly higher peak external rotation moments in the knee and hip joints could be found comparing the inner and outer leg during curved sprinting. The ankle joint showed significantly higher peak internal rotation moments. Only small changes were observed in the sagittal plane. The CL peak ankle flexion moment increased significantly in comparison to LL.

DISCUSSION: The scope of the study was to determine the effect of curve sprinting on the 3D joint kinetics and to specify the leg specific loading and functionality. Following the curved track path requires generation of a centripetal force and direction turning at every stance phase. The asymmetric increased medio-lateral GRFs illustrate besides a leg specific function also a side specific loading during curve sprinting. The inside leg produces a higher inward orientated impulse, as shown by Churchill et al. (2015). Therefore, frontal plane joint moments were effected the most. The finding of high peak adduction moments, especially at the left hip and the left knee joint supports a mechanism described by Alt et al. (2015), where the inner leg majorly contributes to frontal plane movement stabilization. Higher peak external rotation moments at the left leg hip and knee joint also demonstrate the inner leg relevance for transversal plane movement control. Similar to the findings of Heinrich et al. (2015), the left hip joint occurs as the most important instance for the non-sagittal planes of motion. The ankle joints showed the highest sagittal plane moments. Due to the constant velocity, the increased inner leg ankle extension moment was not sufficient to show an impact on the anterior-posterior impulse. However, no systematic effect was found on the peak sagittal plane moments. The reported kinematic changes (Alt et al., 2015) and kinetic alterations from the presented study show for curve sprinting clearly additional tasks and requirements for the lower extremity, compared to linear sprinting. Considering the involvement of muscles not only in sagittal but also in transversal and frontal ankle, knee and hip movement, it is very likely that these additional requirements interfere the propulsive mechanism in maximal sprinting (Palastagana et al., 2006; Chang & Kram, 2007).

CONCLUSION: The findings of the study point up the different functionalities of the inner and outer leg in curved sprinting. High loading of the left hip joint underlines its importance for the non-sagittal plane movement stabilization. These findings help to quantify the side specific load and provide information about involved muscles. This might help coaches setting the training focus right and to prevent overuse injuries by a better understanding of the pathomechanics. Probably due to the constant velocity, sagittal peak moments did not change during bend sprinting. The investigated peak moments provide general information about joint loading and force generation, examining the joint moment time history may provide further information. However, the results show higher requirements for the involved structures. These additional tasks may compromise propulsive force generation in maximal sprinting.

REFERENCES:

Arampatzis, A., Brüggemann, G.-P., & Metzler, V. (1999). The effect of speed on leg stiffness and joint kinetics in human running. *Journal of Biomechanics*, 32(12), 1349–1353.

Alt, T., Heinrich, K., Funken, J., Potthast, W. (2015). Lower extremity kinematics of athletics curve sprinting. *Journal of Sports Sciences*, 33 (6), 552–560.

Chang, Y. H. & Kram, R. (2007). Limitations to maximum running speed on flat curves. *Journal of Experimental Biology*, 210, 971-982.

Churchill, S. M., Trewartha, G., Bezodis, I. N., Salo, A. I. T. (2015). Force production during maximal effort bend sprinting: Theory vs reality. *Scandinavian Journal of Medicine & Science in Sports* 2015, 1600-0838.

Heinrich, K., Alt T., Funken J., Brueggemann G. P., Potthast W. (2015). Contribution of the lower extremity joints to mechanical energy in athletics curve sprinting. *ISBS - Conference Proceedings Archive: 33 International Society of Biomechanics in Sports (2015).*

Ishimura, K., & Sakurai, S. (2010). Comparison of inside contact phase and outside contact phase in curved sprinting. *ISBS - Conference Proceedings Archive: 28 International Society of Biomechanics in Sports (2010).*

Luo, G. & Stefanyshyn, D. J. (2012). Limb force and non-sagittal plane joint moments during maximum-effort curve sprint running in humans. *The journal of Experimental Biology*, 215 (24), 4314-4321.

Meinel, K. (2008). Competition area. In International Association of Athletics Federations (Ed.), *IAAF track and field facilities manual* (pp. 31–54). Monaco: Multiprint.

Palastanga N. & Soames R. (2006). Anatomy and human movement: structure and function. 6th ed. Philadelphia, Elsevier, 2006.