BLADE KINETICS OF A UNILATERAL PROSTHETIC ATHLETE IN CURVE SPRINTING

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In athletics sprinting longer than 100 m, athletes will run more than 50% in a curve. No data on ground reaction forces or joint kinetics of prosthetic curve sprinting can be found in the scientific literature. The purpose of this study was to analyze GRFs and moments acting on the prosthesis' blade using a 3D motion capture system and four force plates. A left sided unilateral amputee athlete (knee exarticulation) of highest international level, ran 30 m straight and curved clockwise and counter clockwise. GRFs show differences between curve and straight running. Results show different loading applied to the blade of a prosthesis when curve running in comparison with straight running. The study gives an inside into the kinetics of amputee curve running and might affect the construction and design of future prosthesis generations as well as performance diagnostics.

KEYWORDS: athletics, modeling, GRF, moment, velocity.

INTRODUCTION: With increasing professionalism of amputee athletics and a great progression of prosthetic technology, athlete's performance improved greatly in the last decade. In the 400 m semi final of the Olympic Games 2012 an amputee athlete was able to perform at the same level as his opponents. Brüggemann et al. (2008) analyzed the same bilateral transtibial amputee athlete in maximal straight running and reported differences to able-bodied athletes in case of ground reaction forces (GRF) and joint moments at the ankle joint. These findings were confirmed by Weyand et al. (2009). Although curve running has a quantity of over 50% in competitive track and field distances over 100 m, published investigations concerning able-bodied curve sprinting is highly underrepresented in the literature. Regarding amputee curve sprinting there are no publications with respect to kinetics of the blade. The purpose of this study was to determine the load on the blade and GRFs in all three movement planes for straight and curved athletic sprinting.

METHODS: The study took place on an indoor athletics track. One left sided unilateral amputee athlete (knee exarticulation; mass = 80.4 kg, height = 1.81 m) of highest international competitive level and medallist of the 2012 Paralympic Games, participated in this study. He was asked to perform straight (SR) and curved (CR) runs at maximal speed with a run-up of 30 m. A minimum of three valid trials, where the touchdown of the prosthetic limb was centered on one of the force plates were recorded for each condition. He also performed curved runs in the opposite (clockwise) direction (CRC). One of these trials was included in this study. For CR the prosthetic limb was the inner leg, for CRC the prosthetic limb was the outside leg. According to the IAAF rule for the first lane for a standard track, the curvature of 36.3 m radius was marked on the ground. The kinematic data were collected by a 3D camera system (VICON™, Oxford, UK) consisting of 16 infrared cameras (MX F40) operating at 250 Hz. Kinetic data were determined by four force plates (90 x 60 cm, Kistler™, Winterthur, CH) operating at 1000 Hz. Ninety-three retro-reflective markers were placed on anatomic landmarks and the prosthesis of the athlete. In this paper only the 28 markers representing the blade, 2 markers representing the knee joint axis of the prosthesis (figure 1) and four markers representing the pelvis were used for further calculations. All calculations were executed in MATLAB® (R2013b, The Mathworks, Natick, USA). Kinematic and kinetic data were filtered by a 4^{th} order recursive butterworth filter with a cutoff frequency of 20 Hz (kinematics) or 100 Hz (kinetics). All data were normalized to stance phase. Running velocity was approximated as the mean horizontal velocity of the four pelvis markers collectively recorded over the whole measured volume (length: 8 m, width: 3 m, height: 2.5 m). Ground

contact time was determined by use of the unfiltered vertical ground reaction force with a threshold of 40 N.
In order to define the ankle joint, the blade was reconstructed as a multi-body system consisting of 13 rigid segments connected with a ball joint at the center of the contact area between two adjoining segments. The positions of all segment joints were used to generate a polynomial of 7th order representing the curvature of the blade. The sound ankle joint is the point where the segments shank and foot realize their greatest alteration of bending to each other. Therefore the ankle joint of the prosthetic limb is defined as the point where the polynomial had in average of all used trials' stance phase the greatest bending. In the next step the complex geometry of the blade was reduced to a rigid body model consisting of two segments and inverse dynamic calculations were executed (figure 1).

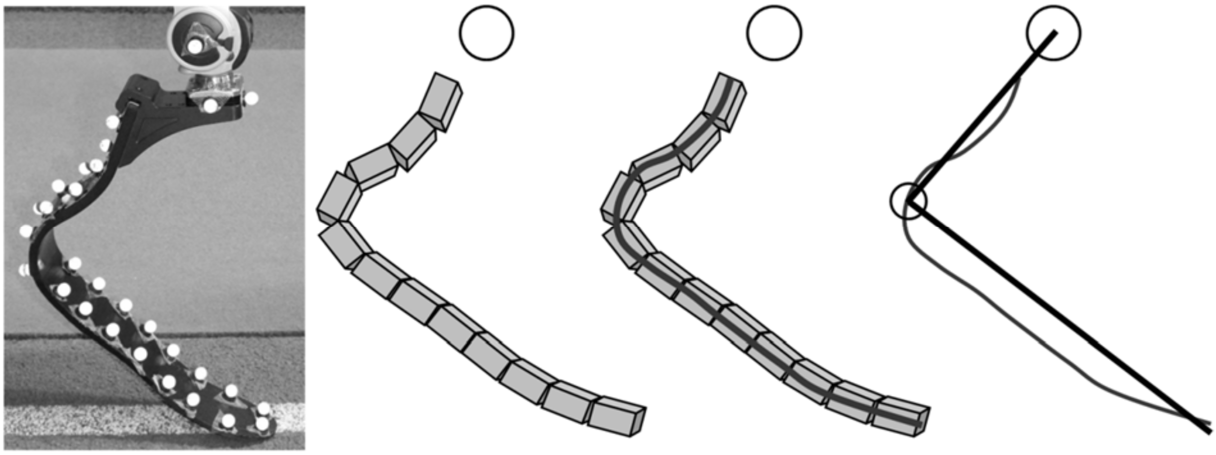

Figure 1: The marker placement on the blade is shown. Furthermore an exemplary progression of the prosthesis modeling and the definition of the prosthetic ankle joint are pictured.

RESULTS AND DISCUSSION: The athlete was asked to perform all trials at maximal speed. However, he was not able to run at the same horizontal velocity in CR (7.73 ± 0.08 m/s) as he did in SR (8.56 ± 0.26 m/s) and CRC (8.32 m/s). Mean ground contact times were higher in CR (134 ± 2 ms) and CRC (128 ms) as in SR (120 ± 1 ms).
Mean maximal antero-posterior forces were 321.5 ± 44.4 N (decelerating) and 360.4 ± 28.9 N (accelerating) for CR, 479.1 ± 65.2 N (decelerating) and 409.7 ± 6.7 N (accelerating) for (SR) and 438.8 N (decelerating) and 453.6 N (accelerating) for CRC. The differences in the maximal vertical ground reaction forces and the maximal flexion moment between SR (2644.9 ± 119.4 N; 519.5 ± 18.9 Nm) and CR (2062.7 ± 144.1 N; 418.8 ± 35.9 Nm) and CRC (2723.3 N; 539.5 Nm) respectively can be explained with the lower running velocity of CR. Mean peak medio-lateral forces were found to be 178.9 ± 9.4 N (medial) and 359.9 ± 75.6 N (lateral) for CR, 295.4 ± 20.5 N (medial) and 48.8 ± 16.3 N (lateral) for SR and 15.1 N (lateral) and 618.2 N (medial) for CRC. The results of the medio-lateral GRF in the first 10% of CR's stance time show a peak in medial direction causing a centrifugal force acting on the athlete during ground contact of the inner leg. For CRC there was just a medial force causing a centripetal force during ground contact of the outside leg (figure 2). In curve running the athlete has to generate a centripetal force to stay on the circular path. Centrifugal forces will let him drift to the outer face of the lane. The rigid construction of the blade might be the reason for the athlete's unability to produce a centripetal force from the very beginning of stance phase with his inside leg in CR. This is a disadvantaged in terms of generating a high circular velocity on a predetermined circular path. The depicted results might be useful to identify parameters for diagnostics which focus on maximizing running velocity of amputee athletes on a curved track. However more research has to be done to investigate this phenomenon for athletes with other level of amputation.

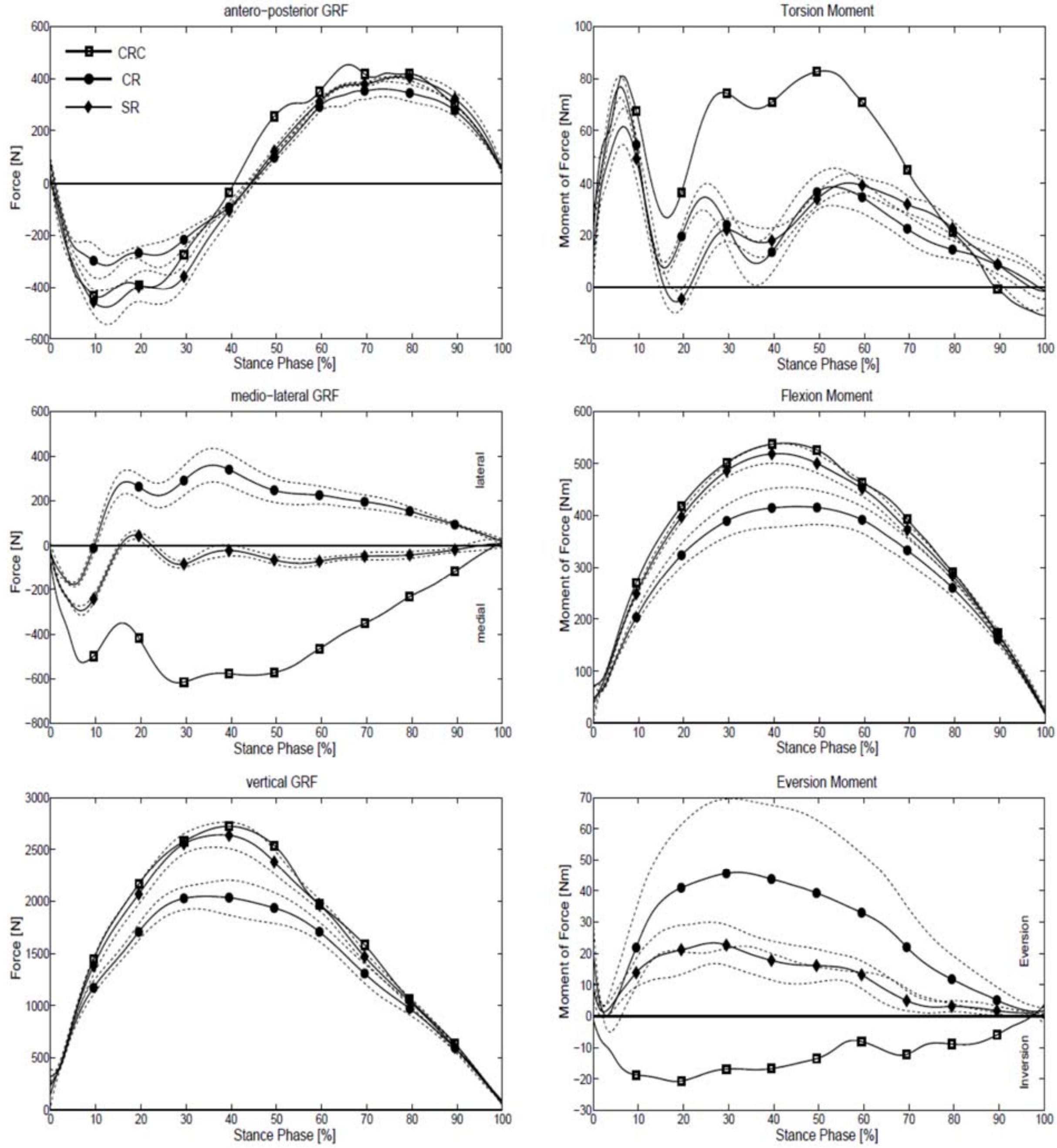

Figure 2: GRFs and moments at the prosthetic ankle are shown in all three movement planes.

Mean maximal torsion moments were 77.0 ± 4.2 Nm (CR), 61.6 ± 6.9 Nm (SR) and 83.0 Nm (CRC). CRC shows a maximal inversion moment of 20.8 Nm while CR and SR show maximal eversion moments of 46.0 ± 23.7 Nm and 23.4 ± 6.6 Nm respectively. Accordingly loading in this movement plane is different in magnitude and direction for CR and CRC. As all athletes have to run counter clockwise the laterality of the athletes should be considered in prosthetic construction and development.

CONCLUSION: The results suggest that the magnitude and the orientation of loading applied on the blade while curve sprinting is directly dependent on the running direction or the affected side respectively. Consequences can be that for future prosthesis generations also the laterality of the athlete should be considered for construction purposes. Athletes with the inner leg affected may need optimized prostheses which allow for compensation differences resulting from GRFs. Furthermore comprehensive research should be done to clarify if athletes with amputation at the inner leg might be disadvantaged in terms of attainable curve running speed.

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