CURVE SPRINTING KINEMATICS EXHIBITED BY ATHLETES USING A SINGLE, TRANS-TIBIAL PROSTHESIS

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The purpose of our study was to determine whether kinematics exhibited during the curve section of a 200 m sprint are influenced by 'limb type' (prosthetic vs nonprosthetic limb) or 'prosthetic limb side' ('inside' compared to the 'outside' of the curve). Two video cameras (60 Hz) were used to capture 13 male athletes using a single, trans-tibial prosthesis during an international, 200 m T-44 competition. From mixed-model ANOVA ($p < .05$), prosthetic and nonprosthetic limb kinematics were different, but differences were dependent on the prosthetic limb side. The inside versus outside prosthetic limb may be affected more due to the rotational influences that affect the inside and outside foot differently. Therefore, athletes whose prosthetic limb was on the inside may be at a disadvantage compared to those with an outside prosthetic limb.

KEYWORDS: running, trans-tibial amputation, 200m race, T-44 Paralympic classification.

INTRODUCTION: Elite runners who use a trans-tibial prosthesis adapt their technique and kinetics of each limb to compensate and control the prosthetic limb movements, but the mechanisms proposed remain controversial (Buckley, 1999; Grabowski et al., 2010; Sanderson & Martin, 1996; Weyand et al., 2009). Moreover, it is not known how using a prosthesis influences sprinting technique when running curves. Curve running is an essential component for successful sprinting of distances longer than 100 m. As curve running requires generating centripetal force and maintaining a curved path, the step and hip joint kinematics vary between the 'inside' and 'outside' prosthetic limbs (prosthetic limb location relative to inside of the curve) (Hamill, et al., 1987; Ishimura & Sakurai, 2010). Therefore, the purpose of our study was to determine if the kinematics exhibited by elite runners during the curve section of a 200 m sprint are influenced by 'limb type', i.e., limb with a prosthesis (prosthetic limb) versus no prosthesis (nonprosthetic limb); and the 'limb side' ('inside', 'outside') that the prosthesis is used. We anticipated that the prosthetic limb would exhibit different kinematics than the nonprosthetic limb and differences would depend on which side that the prosthesis was worn.

METHODS: The performances of 13 elite, male sprinters wearing a single, trans-tibial prosthesis during the 200 m semifinals of an international competition were videotaped. Two digital video cameras (60 Hz, 720×480) positioned approximately 90° apart were used to capture one stride for each limb of the sprinters running in the midsection of the curve (Fig.1). 17 points on the body were manually digitized, reconstructed into 3-dimensional coordinates using the DLT method (54 control points, 11 parameters, mean square error of 3D calibration error =0.021m) (Abdel-Aziz & Karara, 1971; Shapiro, 1978) and filtered (low-pass filter; cutoff =10 Hz) (Peak Motus 9©; Oxford, UK). Test-retest intra-class correlations of the digitized points for both intra-investigator ($\alpha = .96 - .99$) and inter-investigator ($\alpha = .95 - .96$) indicated high reliability. The athletes were divided into 2 prosthesis limb-side groups, GroupIN (prosthesis on the inside, n= 6) and GroupOUT (prosthesis on the outside, n = 7). Overall step kinematics, peak joint angles and maximum angular displacements of the lower extremities for the support and swing phases were compared between limb-side groups (between-subject factor) and between limbs for a given athlete (within-subject factor) using two-way, mixed-model ANOVA. Relevant post-hoc comparisons were performed using Tukey's HSD. All comparisons were evaluated at $p < 0.05$.

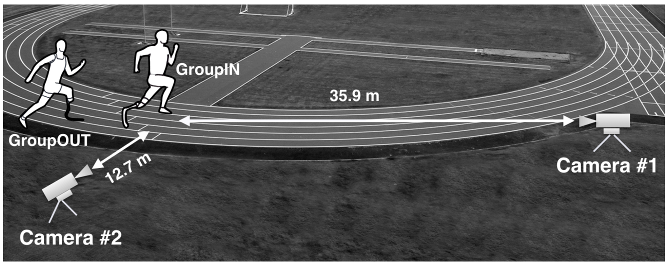

Figure 1: Camera set up during the 200 m competitions.

RESULTS: For overall step kinematics, significant interaction effects (Fig. 2) were detected for the support time ($F_{(1, 11)}$ = 11.8, p < .01), swing time ($F_{(1, 11)}$ = 6.8, p = .03), toe clearance ($F_{(1, 11)}$ = 64.1, p < .01) and step length ($F_{(1, 11)}$ = 5.1, p = .04). The prosthetic limb of both limb-side groups demonstrated lower toe clearance than all nonprosthetic limbs. ForGroupIN, their prosthetic limb displayed longer support and shorter swing times and shorter step lengths than their nonprosthetic limb. When comparing the inside limbs, GroupIN's prosthetic limb also displayed shorter step length than the nonprosthetic limb of GroupOUT. GroupOUT's prosthetic limb displayed longer support time than the nonprosthetic ('outside') limb of the other group but no interlimb differences. For sagittal plane kinematics, significant interaction effects (Fig. 3) were detected for max hip extension angle ($F_{(1, 11)}$ = 13.5, p < .01) and displacement in support ($F_{(1, 11)}$ = 11.2, p < .01); peak knee flexion angle during swing ($F_{(1, 11)}$ = 9.6, p = .01) and support ($F_{(1, 11)}$ = 10.4, p < .01); and max ankle dorsiflexion angle ($F_{(1, 11)}$ = 5.7, p = .04) and displacement during the support phase ($F_{(1, 11)}$ = 12.5, p < .01). In general, the limb-side group differences were observed mostly between the 'inside' limbs: GroupIN's prosthetic compared to GroupOUT's nonprosthetic limb exhibited reduced max hip extension angle and displacement in support; reduced max knee flexion in swing and increased max knee flexion in support; and reduced max dorsiflexion angle in support. The prosthetic limb of both limb-side groups exhibited reduced ankle plantarflexion displacement than all nonprosthetic limbs. Inter-limb differences were group dependent. For GroupIN, the prosthetic limb had less max hip extension and greater max knee flexion in support. For GroupOUT, the prosthetic limb also had less hip extension displacement in support, but reduced max knee flexion in swing and reduced max dorsiflexion in support. Reduced plantarflexion displacement in support was observed for the prosthetic limb of both groups. The only significant main effect of limb side observed was for maximum hip flexion in swing phase ($F_{(1, 11)}$ = 5.4, p = .04), indicating the inside limb exhibited 5° – 10° greater hip flexion than the outside limb.
For the frontal plane kinematics, the main effect of limb side was significant for max hip abduction angle during swing ($F_{(1, 11)}$ = 183.6, p < .01) and hip abduction displacement during support ($F_{(1, 11)}$ = 26.4, p < .01) with greater abduction values for the inside limb.

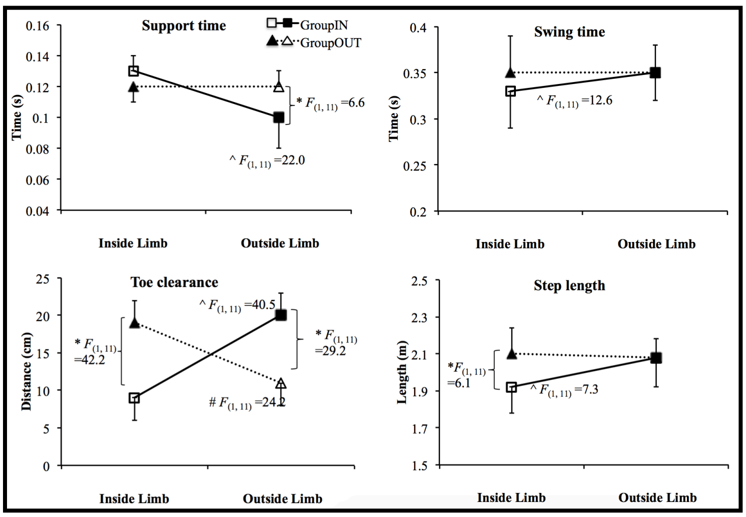

Figure 2: Overall step kinematic variables that displayed a significant limb-type × limb-side interaction. Open symbol indicates prosthetic limb, whereas solid black symbol indicates non-prosthetic limb. * indicates a significant difference between prosthetic limb-side groups (GroupIN, GroupOUT) for a given limb side. Significant inter-limb differences within a group: # = for GroupOUT, ^ = GroupIN. All comparisons: *p* < .05.

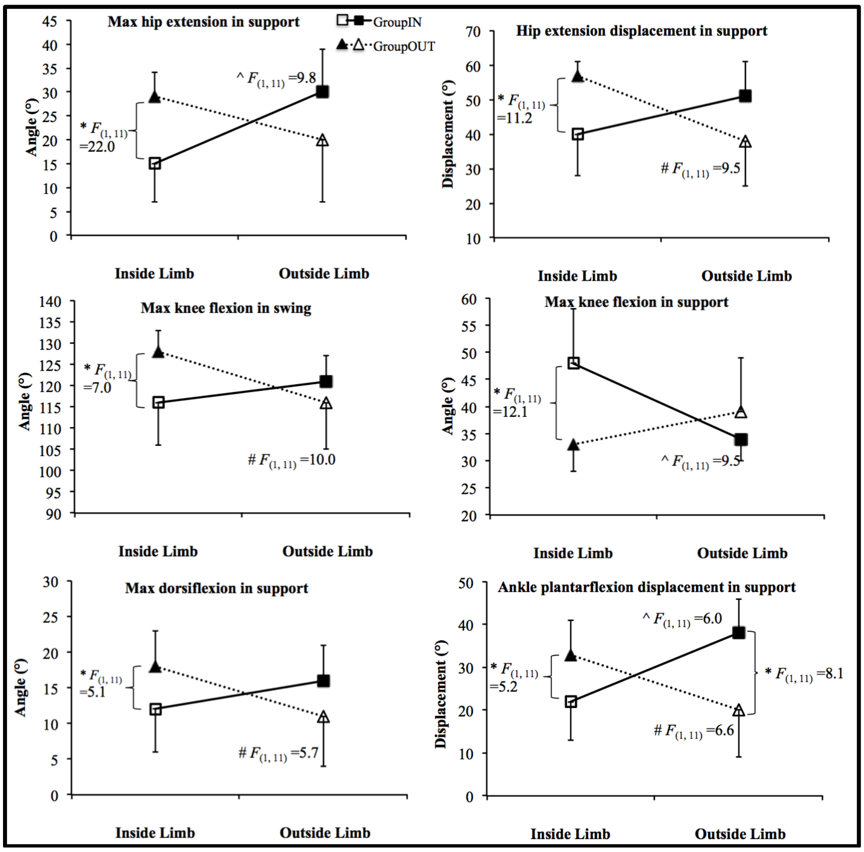

Figure 3: Sagittal plane kinematics that displayed a significant interaction effect. Open symbol indicates prosthetic limb, whereas solid black symbol indicates non-prosthetic limb. * indicates significant between-group difference for a given limb side; # and ^ indicates significant inter-limb difference for GroupOUTand GroupIN, respectively. (p < 0.05).

DISCUSSION: Overall step kinematics: GroupIN's prosthetic limb was on the inside, and as such, it displayed longer support time than their outside nonprosthetic limb. The longer inside limb support time pattern is similar to that of typical-limb athletes (Alt, Heinrich, Funken, & Potthast, 2014), but the inter-limb difference in support time is greater in the present study (0.035 s vs. 0.012 s, respectively). This longer inside-limb support time was associated with a shorter swing time for GroupIN. However, for GroupOUT, their prosthetic limb did not exhibit more rapid repositioning of the swing leg than their nonprosthetic limb to prepare for the next step, as suggested by Weyand and Bundle (2010). Lower PRO-L toe clearance and limited knee flexion during swing suggests a greater radius of gyration/, that, all else equal, would increase moment of inertia.

Sagittal angular kinematics: Less peak hip extension angle and displacement for prosthetic limbs during support, regardless of the limb side that the prosthetic limb was located, indicates that hip extension kinematics were influenced by the use of a prosthesis. This also has been observed for straight path sprinting (Buckley, 1999). Limited hip extension may affect the propulsive work that the prosthetic hip generates (Cziernecki, 1996). During the support phase, a greater flexed knee position for GroupIN's prosthetic limb compared to GroupOUT's nonprosthetic limb may be indirectly due to the tibial flexion about the 'ankle joint' that, consequently, also affects knee flexion angle. Sprinters using a trans-tibial prosthesis tend to maximize dorsiflexion displacement by rotating the body over the foot during the support phase to store more elastic energy (Nolan, 2008). The prosthetic limb exhibited reduced knee flexion angle during swing for GroupOUT and a similar tendency for GroupIN, congruent with other reports on straight-path sprinting (Sanderson & Martin, 1996; Buckley, 1999).

Frontal angular kinematics: The inward lean of the trunk, used to maintain balance and generate centripetal force, may account for the more abducted hip position for the inside limb, regardless of whether the limb was a prosthetic or nonprosthetic limb. Additionally, increased hip abduction of the prosthetic limb of either limb-side group was not used to increase the toe-clearance height, as toe clearance was lower for the prosthetic limb of both groups.

CONCLUSION: To our knowledge, the present study was the first one to describe the lower extremity kinematics for elite trans-tibial amputee athletes during curve sprinting. Kinematic differences were observed between the prosthetic and nonprosthetic limbs and often were dependent on the side that the prosthesis was used. The prosthetic limb, when on the 'inside', may exhibit more atypical kinematics than an outside prosthetic limb, possibly due to more rotational influences on the inside limb (Alt, Heinrich, Funken, & Potthast, 2015). Therefore, athletes whose prosthetic limb was on the inside may be at a disadvantage compared to those with an outside prosthetic limb. We conclude that the unique mechanical demands of curve sprinting appear to interact with the constraints of using a prosthesis, and should be considered when training athletes who use a prosthesis for running events involving negotiating curves.

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