AN INDIVIDUALIZED MUSCULOSKELETAL MODEL FOR THE ANALYSIS OF AMPUTEE RUNNING

Uwe G. Kersting[1], Jason K. Gurney[2], Søren Lewis[3], John Rasmussen[4]

[1]Center for Sensory-Motor Interaction, Aalborg University, Denmark
[2]Dept. of Sport and Exercise Science, The University of Auckland, New Zealand
[3]Inst. of Biomechanics, The Technical University of Hamburg Harburg, Germany
[4]Dept. Of Mechanical Engineering, Aalborg University, Denmark

The purpose of this study was to develop and apply a three-dimensional full body model for the analysis of transtibial amputee athletes. Sprint running was used as an example with a female sprinter as a subject. Data were collected on a running track leading through a biomechanics laboratory with two force platforms in the runway. Inverse dynamics were calculated using a basic and an advanced model, the latter including detailed information on all important muscle groups. Results support what was published on submaximal running with regard to joint moments and power. The muscle model revealed highly asymmetric muscle forces around the hip joint which may explain the overuse injuries some of these runners experience. Future research is needed to improve the individualisation of the modeling approach.

KEYWORDS: amputee, sprinting, power, muscle activity.

INTRODUCTION: Introduction: Ambulation of unilateral or bilateral amputees has been studied in various papers, partially, to understand neuromuscular strategies adopted by individuals, to understand movement strategies, but also to develop or improve the design of prostheses. Only a limited number of published papers can be identified with detailed mechanical analyses on sports disciplines, such as running or long jump, carried out by amputee athletes (Czerniecki et al., 1992; Nolan et al., 2006). For transtibial amputee runners, it was shown that joint moments change at the knee and hip joint reflecting a greater power generation at the hip but a reduced power flow at the knee. For bilateral amputees similar alterations in power generation across joints were described but obviously the mechanisms in such cases are rather symmetric.
Especially in unilateral amputees, these alterations indicate a remarkably asymmetric pattern of muscle loading which may have implications for training strategies, overuse injuries and, possibly, their prevention.
The aim of this study was to provide a detailed, three-dimensional biomechanical analysis of an elite left-sided transtibial amputee sprinter.

METHOD: One female left-sided transtibial amputee served as subject for the study (syme amputation, level: lower third of left tibia). Full three-dimensional kinematics were collected from the athlete while equipped with 48 reflective markers (similar to Ferdinands, 2004). Markers were placed on anatomical landmarks and defined positions on the prosthesis. Marker trajectories were recorded using a Vicon MX system with eight cameras (250 Hz). Two Bertec force platforms (1000 Hz) were integrated to collect ground reaction forces. The athlete ran five times on a 70 m Mondo running track through the laboratory at submaximal speed (6 m/s).
Marker data were used to calculate joint kinematics, joint forces, moments, and joint powers using a basic customised model (Vicon Body Builder). The mass of the prosthetic was measured beforehand and inertial properties were estimated using basic geometric equations and fluid displacement measures carried out on the testing day.
A second individually scaled model was generated in the AnyBody (AnyBody Tech) modeling environment. In this model the prosthesis was connected visco-elastically to the amputated leg. The model was based on the TLEM model and individually fitted to the changes at the operated leg. The model geometry was individually scaled using an optimisation algorithm in AnyBody. Subsequently, muscle activations were calculated using the optimization

procedure of the AnyBody system resulting in forces generated by all different muscle groups.
After finalization of the set-up and static reference measurements, the subject was given sufficient time to warm up, get used to the force platform and acquire a consistent movement pattern. One difficulty with this was the braking phase after crossing the force plate. A crash mat was provided to assist with which required an extended customization period.

RESULTS: Force characteristics demonstrate a clear impact peak on the right but not on the prosthesis side (Figures 1 & 2). Joint kinematics show relatively small differences while joint moments vary substantially between body sides.

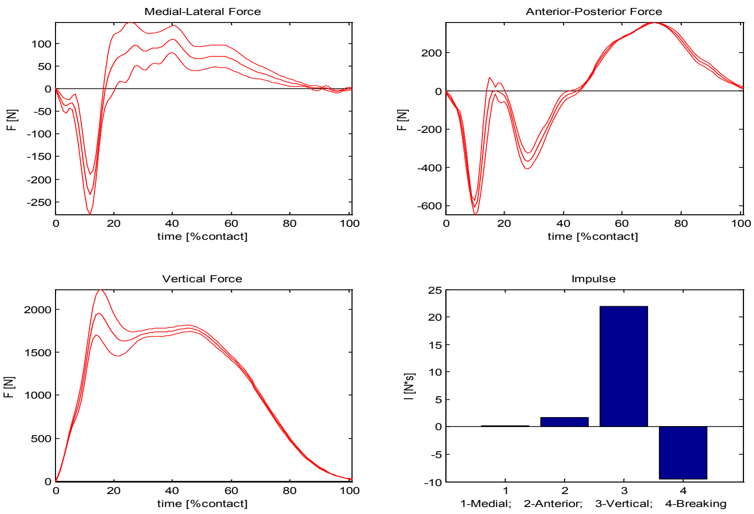

Figure 1. GRF analysis for the right leg at maximum speed (average of three trials).

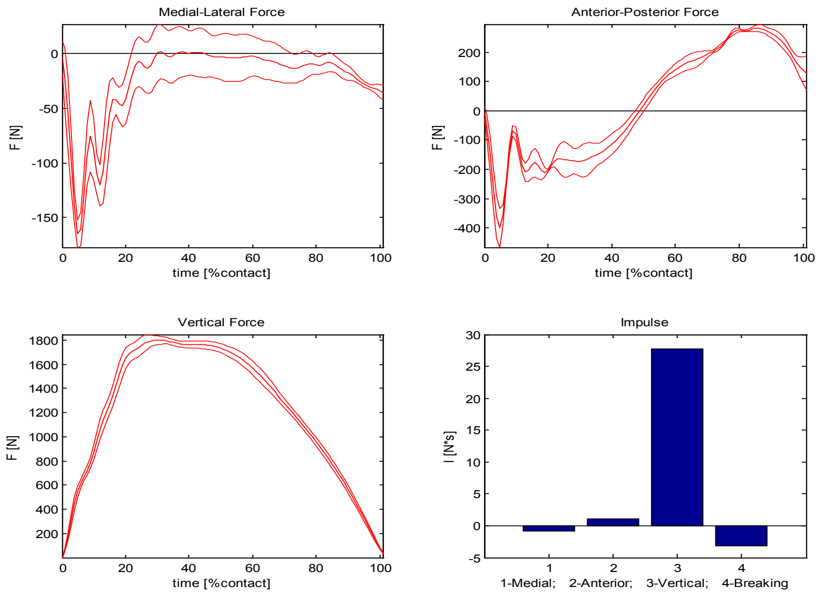

Figure 2. GRF analysis for the left leg at maximum speed (average of three trials).

With regard to the reaction forces, the breaking impulse is greater (i.e., more negative) on the intact side than on the prosthesis side. Still the total positive impulse (2) is larger for the right leg, meaning main propulsion resulting from the right leg. Interestingly, a greater vertical impulse is generated on the prosthesis side at similar contact times. The joint powers were markedly different (Figure 3).

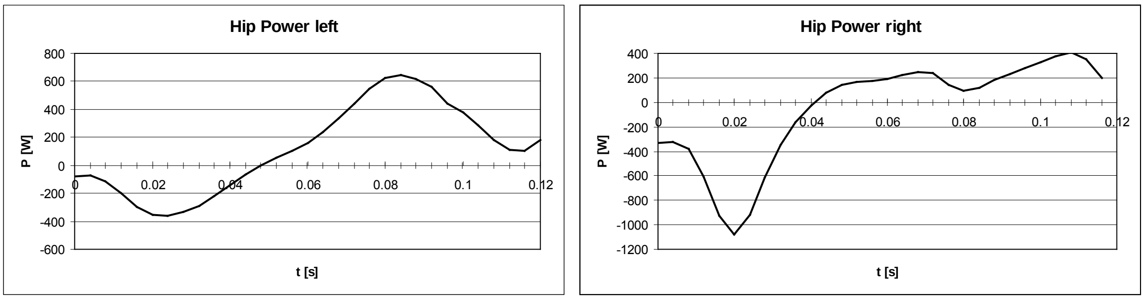

Figure 3. Hip joint power curves from BodyBuilder model.

The centre of mass position with regard to the point of ground contact was compared between legs and showed a highly asymmetric dynamic. This observation matches with the highly asymmetric joint moments at the hip joint and were connected to highly asymmetric muscle forces calculated by the AnyBody model. Substantially higher muscle forces were calculated for both the hip adductors and abductors on the amputated side.

DISCUSSION:

This paper summarises a study of a full three-dimensional analysis of an amputee runner where a detailed individually scaled body model was applied for data analysis. Results from a simple inverse dynamics model are in line with previously published 2D data (Czerniecki et al., 1992) who tested athletes running at 2.8 m/s. However, the differences observed here indicate a more pronounced difference in muscle loading between body sides especially around the hip joint. Additionally, marked changes with respect to trunk and upper extremity movements were observed. These changes reflected by highly asymmetric muscle loads around the hip joint with the main differences found in the ad- and abductor muscle groups. This will have implications for loading on these muscle groups and may help to develop training strategies which may need to be quite different from healthy subjects.

CONCLUSION:

In this study a highly complex model for the analysis of amputee athletes was proposed. Interesting observations were made which match this individuals training induced overloading symptoms. Also, the most remarkable differences were found for movement directions out of the sagittal plane indicating the need for such analyses when aiming at understanding biomechanical mechanisms in amputee running.

REFERENCES:

Czerniecki J.M., Gitter A., Munro C. (1991). Joint moment and muscle power output characteristics of below knee amputees during running: the influence of energy storing prosthetic feet. *Journal of Biomechanics*. 24(1):63-75.

Ferdinands, R.E.D. (2004). Three-dimensional biomechanical analysis of fast bowling in cricket. *Unpublished PhD Thesis*, University of Waikato.

Mero A., Komi P.V. Reaction time and electromyographic activity during a sprint start. (1990). European *Journal of Applied Physiology*,61:73-80.

Winter D.A., Sienko S.E. Biomechanics of below-knee amputee gait. (1988). *Journal of Biomechanics*. 1988;21(5):361-7.

Nolan L., Patritti B.L., Simpson K.J. (2006). *Medicine and Science in Sports Exercise*. ;38(10):1829-35.

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