Shod and Unshod Kinematic Response of the Female Lower Extremity under Dorsiflexion Loading

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I. INTRODUCTION

Females have an increased risk for foot and ankle injury in automobile collisions compared to males, a difference in risk that has often been attributed to a difference in footwear [1-3]. Despite an increased risk of foot and ankle injuries for females, few studies containing female PMHS have been performed to characterise the dorsiflexion response and injury tolerance of the ankle, and there have been no studies comparing male and female responses. In addition, no studies have evaluated the response of small female PMHS in dorsiflexion loading similar to that of an automotive environment, and little work has been done to evaluate the effect of shoes on injury risk, previously limited to investigations with dummy legs only [4]. This study describes experiments on 12 female PMHS specimens subjected to dynamic dorsiflexion, and presents preliminary kinematic and tibia and fibula force differences between shod and unshod female extremities.

II. METHODS

Six matched pairs of female PMHS legs were tested in dynamic dorsiflexion. Target anthropometry was the 5th percentile female, with the following inclusion criteria: mass between 38.6 and 54.4 kg, height between 147 and 162 cm, and age less than 75 years. The testing rig (Fig. 1) and test conditions were selected to match previous testing by Rudd [5]. For each test, the knee was constrained in the axial, lateral and anterior directions, and the femur was constrained in flexion using metal cables and an inline load cell attached to the mid-shaft. The foot was placed on a cylindrical loader (simulating a simplified brake pedal) that was rigidly attached to the transfer piston load cell. During testing, an impactor (56.2 kg) struck the brake pedal loader assembly at a velocity of approximately 3.0/s, and forced the foot into dynamic dorsiflexion. The tibia was oriented approximately horizontally (between 0 and 1 degree, foot-down), the ball of the foot was centered on the middle of the loader with little to no internal or external rotation of the ankle, and the foot was positioned such that the ankle was initially in 15 degrees of dorsiflexion.

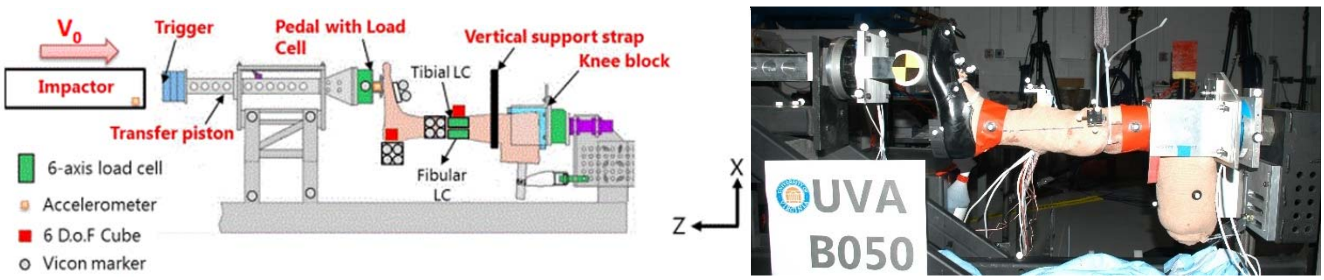

Fig. 1. Schematic of UVA dynamic dorsiflexion lower extremity test set-up (top), and photo from test (bottom).

Implantable tibia and fibula load cells were used to measure reaction moments and forces generated in the leg. These were inserted using a specialised jig to ensure proper alignment of all anatomical components [6]. High-speed video was collected for lateral and oblique views. Kinematics were also captured with a Vicon 3D motion capture system, with retroreflective marker arrays attached to the impactor, test rig, tibia, fibula, calcaneus, and second and third metatarsals (Vicon MX, Vicon, Oxford, UK).

To evaluate the effect of shoes, one PMHS from each pair was tested barefoot (unshod), and the other was tested with a shoe (shod). The selection of shod and unshod was pseudo-random, such that half of the shod tests were performed with the right feet, and half with the left. Shoes used in this test were women's low-heel, dress, black, oxford shoe with standardised design by the United States Military Standard (MIL-SPEC, MIL-S-21711E), also designated for use with the Hybrid III 5th percentile female.

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INITIAL FINDINGS

Early findings indicate that the kinematics of the foot, ankle and leg are different between the shod and unshod conditions. Figure 2 depicts an oblique view of the motion of a matched pair of PMHS during the initial loading portion of the test. For the shod foot, the motion remains almost entirely in the sagittal plane. The ankle maintains its initial internal/external rotation position throughout the test, and the dorsiflexion angle increases as the pedal intrudes. The heel of the foot drops slightly during the motion. During the unshod test, the kinematics look similar to the shod test for the first 25 ms of pedal intrusion, with dorsiflexion increasing with time. Around 25 ms, the ankle begins to externally rotate, in addition to continuing to dorsiflex. These external rotations continue in both the ankle and the midfoot, while the dorsiflexion rate slows down. Overall, there is significant motion in both the sagittal and transverse planes in the unshod condition. When the pedal slows to a stop around 60 ms, the shod foot has a much higher angle of dorsiflexion than the unshod foot, while the unshod foot has a much higher degree of external rotation.

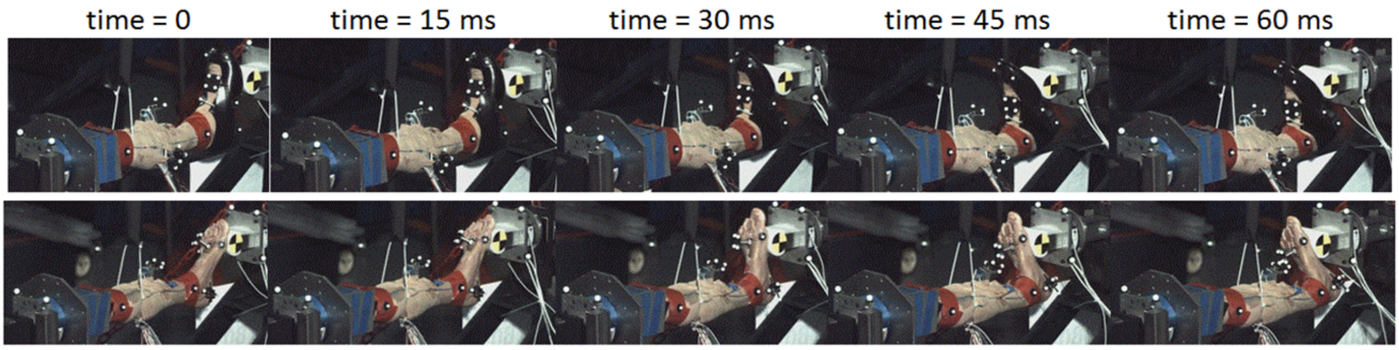

Fig. 2. Representative kinematics of dorsiflexion impact tests for the shod (top) and unshod (bottom) conditions from high-speed video. Time=0 corresponds to the initial impact.

Additionally, initial data analyses show that while the total axial force (anatomical z-axis) measured in the combined tibia and fibula load cells does not differ between the shod and unshod cases (shod: 1449.5 ± 143.2 N, unshod: 1488.5 ± 227.5 N), there may be a difference in the percentage of the total load the fibula supports at the time of maximum compression. For the unshod case, the fibula bears 39.4 ±7.5% of the combined tibia and fibula load, while the shod condition yields 32.0 ± 13.2% of the tibia and fibula load. This is likely due to difference in rotation of the leg between the shod and unshod conditions.

III. DISCUSSION

The kinematics suggest that the shoes stiffen the midfoot in bending, inversion/eversion, and rotation. This, combined with increased friction on the simulated pedal loader from the shoe bottom, results in motion predominantly constrained to the sagittal plane. However, when barefoot there are many more degrees of freedom (DOF) in the midfoot, which causes complex foot deformation and kinematics when the foot is loaded in dorsiflexion. A limitation of this study is that only one type of shoe was tested, and different types of shoe have been shown to have very different force transmission responses [4]. Since this was a relatively stiff shoe, however, it may represent a reasonable upper bound with which to contrast to the lower bound represented by a bare foot.

Future work includes processing of Vicon data to quantify this kinematics data relative to anatomical and global coordinate systems, analysis of force and kinematic data with respect to injury, and comparison of these female data to the male study, with a comparable test set-up, performed by Rudd [5].

IV. ACKNOWLEDGEMENT

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V. REFERENCES

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