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Short communication

Effect of increased pushoff during gait on hip joint forces

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ABSTRACT

Anterior acetabular labral tears and anterior hip pain may result from high anteriorly directed forces from the femur on the acetabulum. While providing more pushoff is known to decrease sagittal plane hip moments, it is unknown if this gait modification also decreases hip joint forces. The purpose of this study was to determine if increasing pushoff decreases hip joint forces. Nine healthy subjects walked on an instrumented force treadmill at 1.25 m/s under two walking conditions. For the natural condition, subjects were instructed to walk as they normally would. For the increased pushoff condition, subjects were instructed to "push more with your foot when you walk". We collected motion data of markers placed on the subjects' trunk and lower extremities to capture trunk and leg kinematics and ground reaction force data to determine joint moments. Data were processed in Visual3D to produce the inverse kinematics and model scaling files. In OpenSim, the generic gait model (Gait2392) was scaled to the subject, and hip joint forces were calculated for the femur on the acetabulum after computing the muscle activations necessary to reproduce the experimental data.

The instruction to "push more with your foot when you walk" reduced the maximum hip flexion and extension moment compared to the natural condition. The average reduction in the hip joint forces were 12.5%, 3.2% and 9.6% in the anterior, superior and medial directions respectively and 2.3% for the net resultant force. Increasing pushoff may be an effective gait modification for people with anterior hip pain.

1. Introduction

High joint forces have been implicated in the development and progression of osteoarthritis and pain (Mavcic et al., 2004; Recnik et al., 2007). In particular, high anteriorly directed forces from the femur on the acetabulum may result in anterior hip pain, acetabular labral tears (Mason, 2001; McCarthy et al., 2001) and subtle hip instability (Shindle et al., 2006). Prior musculoskeletal simulation have demonstrated that anterior hip joint force increases with increasing hip extension during exercises (Lewis et al., 2007, 2009) and during gait (Lewis et al., 2010). Anterior hip joint force also increases with decreased strength of the iliacus and psoas muscles during hip flexion and gluteal muscles during hip extension (Lewis et al., 2007, 2009). Gaining a better understanding of how gait strategies affect these joint forces may improve rehabilitation outcomes (Heller et al., 2001).

Decreasing the anterior hip joint force may be particularly beneficial for patients with anterior hip pain (Lewis and Sahrmann, 2006). Clinically, we have noted that patients with anterior hip pain appear to walk with increased peak hip extension and have a delayed or decreased pushoff during gait. When these patients are instructed to decrease their hip extension and to push more with their foot when they walk, they report an immediate reduction in the hip pain. We have previously reported that walking with less hip extension reduced the anterior hip joint force (Lewis et al., 2010). We have also demonstrated that walking with increased pushoff resulted in a decrease in both the hip flexion and hip extension internal muscle moments (Lewis and Ferris, 2008). It is unknown if this alteration in gait also decreases hip joint forces. Therefore, the purpose of this study was to determine if walking with increased pushoff during gait decreases hip joint forces compared to the natural condition. The hypothesis was that increased pushoff would decrease anterior hip joint forces compared to natural pushoff.

2. Materials and methods

2.1. Subjects

Data from nine healthy subjects (3 males, 6 females) which were collected as part of a different study (Lewis and Ferris, 2008) were used in this analysis. (Table 1) All subjects agreed to participate voluntarily and provided written informed consent as approved by the Institutional Review Boards of the University of Michigan and Boston University.

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2.2. Instrumentation

We used a 3-dimensional motion capture system (Motion Analysis Corp., Santa Rosa, CA, USA) at 120 Hz and reflective markers to record the position of the foot, shank, thigh and trunk. Briefly, markers were placed bilaterally on the posterior heel, 5th metatarsal head, medial and lateral malleoli, medial and lateral femoral epicondyles, and anterior superior iliac spine. A single marker was placed on the sacrum between the posterior superior iliac spines. Rigid clusters of three markers were placed on the shank and thigh bilaterally. Position data were low-pass Butterworth filtered at 6 Hz with a zero phase lag to remove artifact. Subjects walked at 1.25 m/s on an instrumented treadmill which measured vertical, horizontal and lateral ground reaction forces and moments under each foot individually at 1200 Hz (Collins et al., 2009).

For a subset of our subjects ($N=3$) we also collected surface electromyography (EMG) data. Surface electrodes (1.1 cm diameter) with an inter-electrode distance of 2.5 cm were placed over the muscle bellies of the left medial gastrocnemius, soleus and iliopsoas per recommended guidelines (Konrad, 2005). These three muscles were measured as they were expected to change with condition. The iliopsoas electrode was placed medial to the rectus femoris, lateral to the femoral pulse, and inferior to the inguinal ligament (Gottschall and Kram, 2005). Correct placement was verified with movement tests (Cram and Kasman, 1998). Data were collected at 1200 Hz, high pass filtered with a 20 Hz zero-phase lag Butterworth filter, rectified and filtered with a 10 Hz zero-phase lag low pass filter to smooth the signal. Data were averaged over 10–12 strides for each condition.

2.3. Conditions

Each subject walked under two walking conditions. For the natural condition, subjects were instructed to walk as they normally would. For the increased pushoff condition, subjects were instructed to “push more with your foot when you walk”. Subjects were given only this simple instruction, and were not given feedback during the study. Subjects were given at least one minute to practice walking under the different conditions prior to data collection.

Table 1
Demographic data for the 9 subjects included in this study.

Subject demographics ($N=9$)	Mean	SD
Age (years)	26.7	6.7
Height (m)	1.70	0.09
Mass (kg)	65.0	10.4

2.4. Data acquisition and processing

Kinematic and kinetic data were recorded for 90 s during walking in each condition. Data were processed in Visual3D (C-Motion, Inc, Rockville, MD) to produce the inverse kinematics and model scaling files, specifically developed to be used with OpenSim (“Comparing Visual3D and SIMM exporting to OpenSim”, 2014). Those files were then imported into OpenSim 2.0 (Delp et al., 2007), an open-source musculoskeletal modeling software. For each subject, the generic gait model (Gait2392) was scaled based on the subject's height, weight, calibration data and segment geometry. The model of the lower extremities and trunk contains 23 degrees of freedom, which is the same as the Visual 3D model, and 92 actuators. In OpenSim, the residual reduction algorithm (RRA) was run, and the model was adjusted if indicated by adjusting maximum excitation values for residuals and re-running RRA until the simulation resulted in peak residual forces that were less than 10 N and RMS differences in joint angles and translations were less than 5° or 2 cm respectively, as stated in the OpenSim software documentation (Hicks et al., 2014). We then ran the computed muscle control (CMC) algorithm (Thelen and Anderson, 2006) to determine the muscle actuation necessary to match the kinematics and force data. Hip joint forces were calculated for the femur on the acetabulum in the pelvic reference frame using the Joint Reaction analysis (Steele et al., 2012). For each subject, we created average data normalized from left heel strike to subsequent left heel strike for 10–12 strides for each condition.

To evaluate how well the calculated muscle activations reflected the measured EMG data, we qualitatively compared the data in the subset of subjects. The predicted muscle activations were generally consistent with the measured EMG and demonstrated similar changes in muscle activation between conditions (Fig. 1). Specifically, the medial gastrocnemius and soleus were activated earlier and the iliopsoas was activated less during the Increased Pushoff condition compared to the Natural Pushoff condition. The one discrepancy was that an increase in peak soleus muscle activation was not predicted by the model, but was detected in the measured EMG.

2.5. Data analysis

As we were interested in the interplay between the hip and ankle, we limited our statistical analyses to those two joints. To verify that increasing pushoff had the same effects in this subset of data as previously reported (Lewis and Ferris, 2008), we compared the peak hip and ankle joint moments and angular impulses between conditions using paired t-tests. Angular impulse was calculated separately for the

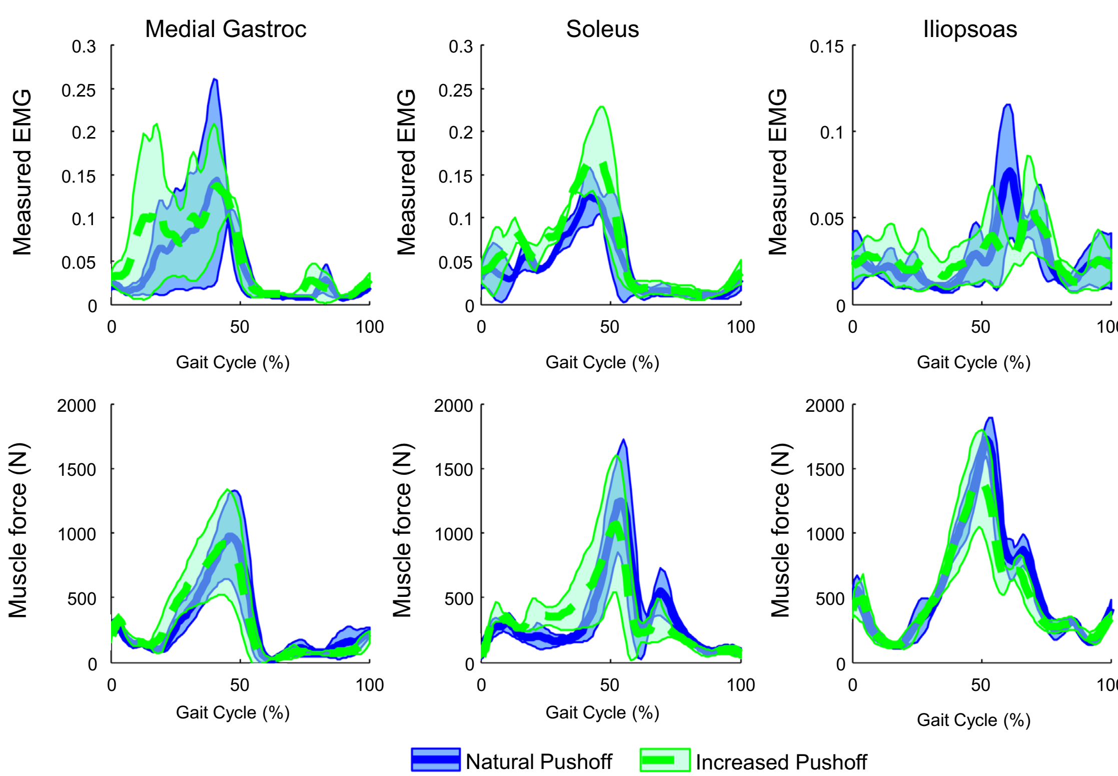

Fig. 1. Comparison of recorded EMG (top row) to muscle force calculated with OpenSim (bottom row) for the subjects with EMG data ($N=3$), mean and standard deviation (shaded area).