IMPACT OF INDUCED GAIT ASYMMETRY ON KNEE JOINT REACTION FORCES

*Emily M McCain1, Michael D Lewek2, and Gregory S Sawicki3, Katherine R Saul1
1Department of Mechanical Engineering, North Carolina State University, Raleigh, NC, USA
2Division of Physical Therapy, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
3George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, USA
email: *emmccain@ncsu.edu

Introduction

Chronic injury- or disease-induced asymmetric gait deviations are metabolically costly and may precipitate changes in joint loading associated with joint pain and osteoarthritis [1]. Therefore, interventions often target restored gait symmetry to minimize harmful consequences of gait deviations. In many clinical populations, neurological and/or anatomical changes make isolating the impact of any specific gait deviation difficult. Our previous work employed ankle and knee bracing to impose limitations on joint range of motion (ROM) and induce asymmetric gait in unimpaired participants [2]. Here, we extend this work by conducting musculoskeletal simulations driven with experimental kinetics and kinematics and constrained by electromyography (EMG) to determine the interaction between induced asymmetry and knee joint reaction forces (KJRF). Our hypotheses are that (1) asymmetric restrictions will result in increased KJRF loading rate and peak value on the ipsilateral (due to reduced knee compliance) and contralateral (due to asymmetric propulsion) limb when compared to unrestricted walking and (2) changes in propulsive asymmetry will correlate with changes in contralateral KJRF loading rate.

Methods

Data were recorded on 8 (4M/4F) healthy controls walking at 0.8 ms⁻¹ while a 3D printed ankle stays and knee bracing (DonJoy T-ROM) were used to restrict the ankle (r-ank), knee (r-knee), and combined ankle and knee (r-a+k) ROM; trials were compared to unrestricted (unr) walking where bracing was worn without restriction (T-ROM unlocked). We recorded ground reaction forces, kinematics, and EMG of 6 lower limb muscles bilaterally. Recorded marker locations were used to scale a lower limb adaptation of a full-body model to each participant [3]. Personalized models, experimentally determined kinematics, and GRFs were used with the computed muscle control (CMC) tool to determine simulated muscle activations guided by EMG-driven timing constraints [4]. A joint force analysis probe calculated KJRF along the long axis of the tibia. We normalized KJRF by body weight and averaged values across ten stance phases for each participant. The 1st peak KJRF was found as the maximum in the first 50% on stance phase, the KJRF loading rate was defined as the median gradient between heel strike and 1st Peak KJRF timing. Propulsive asymmetry was determined as the ratio of the max to the sum of peak anteriorly directed GRFs. A one-way repeated measures ANOVA performed in SAS was used to determine whether restriction type (unr, r-ank, r-knee, r-a+k) significantly affected outcomes. Post-hoc analysis t-tests with Bonferroni corrections for multiple comparisons were performed for significant factor levels. We determined significance of Pearson’s linear correlations for comparisons with Δpropulsive asymmetry using a custom MATLAB script.

Results and Discussion

Our EMG-informed CMC simulations produced subject averaged KJRF profiles over stance phase (Fig 1a,b) within the range of values reported in literature [1]. We reject h1 because KJRF peak values and loading rates do not significantly increase on either limb when compared to the unr condition. Specifically, peak contralateral KJRF were not significantly affected, and ipsilateral peak KJRF values (Fig 1c) were significantly reduced in the r-ank condition when compared to the unr (p=0.008) and r-knee (p=0.041) conditions. While not significant (p=0.2), ipsilateral KJRF loading rate (Fig. 1d) tended to decrease with restriction in contrast to our hypothesis that reduced knee compliance would lead to increased KJRF. While ROM restriction did not significantly affect contralateral KJRF loading rate (Fig 1e), it tended to increase with knee restriction (r-knee, r-a+k) when compared to ankle restriction. Lastly, we observed a weak relationship between the ΔKJRF load rate and △propulsive asymmetry (r²=0.25; p=0.01) indicating additional factors may drive increases in KJRF load rate contralaterally.

Significance

Musculoskeletal simulations offer an opportunity for further decoupling of the interaction between gait deviations and the resulting changes in JRFs. Future work should investigate the impact of joint restriction on the hip and consider whether additional factors such as the limitation of compensatory degrees of freedom may explain the variance in the KJRF data.

Acknowledgments

NIH grant F31 HD097872-01 to EMM

References


Figure 1. Subject averaged KJRF on the (a) ipsilateral and (b) contralateral limbs plotted over stance phase. Ipsilateral (c) peak KJRF and (d) loading rate and contralateral (e) KJRF loading rate are illustrated (mean ± st. dev). Hatched patterns indicate a joint restriction on plotted limb.