LOWER LIMB JOINT ANGLE VARIANCE AS A FUNCTION OF OBSTACLE HEIGHT DURING OBSTACLE CROSSING

[1]Chuyi Cui, [2]Brittney Muir, [1]Jeffrey Haddad, [3]Richard van Emmerik, [1]Shirley Rietdyk, [1]Satyajit Ambike
[1]Department of Health and Kinesiology, Purdue University, IN, USA
[2]Department of Occupational Therapy, The Sage Colleges, Troy, NY, USA
[3]Department of Kinesiology, University of Massachusetts, Amherst, MA, USA
email: cui111@purdue.edu, web: https://www.purdue.edu/hhs/hk/Biomechanics-MotorBehavior/

INTRODUCTION

Tripping is a main contributor to falls and fall related injuries. To ensure crossing an obstacle without tripping, one has to elevate the foot higher than the upper edge of the object. Typically, the trail foot (the foot that crosses second) contacts visible stationary obstacles more frequently than the lead foot (the foot that crosses first) [1].

The variability of foot clearance has been commonly used to quantify the risk of tripping during obstacle crossing [2]. During swing phase, lower limb segments from stance foot to swing toe form an open kinematic chain with multiple joint angles that influence the configuration of the swing foot. Foot variability clearly arises from the variability in joint angles. Although mean foot clearance and joint angles during obstacle crossing have been studied extensively, it is essential to study joint angle variances to understand toe height variability.

The purpose of this study is to (a) quantify the lead and trail toe height variability when crossing obstacles of different heights, and (b) investigate the source of the toe height variability by examining the lower limb joint angle variance.

METHODS

Ten young adults (age: 23.8±3.4 years, 3 females) walked along a 15 m walkway and stepped over an obstacle. Four obstacle heights were examined: unobstructed (no obstacle), 3, 10, and 26 cm. 10 trials of each condition were performed in block randomized order. Kinematic data were collected using the Qualysis Track Manager at 100 Hz.

Measures were calculated at the frame where tripping was most likely to occur: when the lead toe and the trail toe were above the obstacle, and at minimum toe clearance for unobstructed trials for both limbs.

We computed the across-trial standard deviation of the toe height (henceforth toe variability), the variances of lower-limb joint angles (sagittal hip, knee, and ankle of stance and swing limb), and the total joint angle variance as the sum of all six joint angle variances (henceforth total joint variance). Two-way mixed model ANOVA was conducted with *obstacle height* (unobstructed, 3, 10, 26 cm) and *limb* (lead, trail) as fixed factors. Tukey post hoc pairwise comparisons were conducted.

RESULTS AND DISCUSSION

Six of the 10 subjects contacted the obstacle one time (contact rate 2%; all with the 26 cm; five with the trail toe). Since contacting the obstacle modified gait in subsequent trials [3], data from the 26 cm condition was excluded from statistical analyses.

There was a significant interaction (*obstacle height by limb)* observed for toe variability ($F_{2,57}=3.27$; $p=0.04$; Fig. 1). Post hoc comparisons revealed that toe variability was not different for the lead and trail limbs for unobstructed and the 3 cm obstacle trials, but it was 72% higher for the trail limb for the 10 cm obstacle. Toe variability was 273% higher for 3 cm obstacle versus unobstructed ($p<0.01$). It was 80% higher for the 10 cm obstacle than the 3 cm obstacle, but only for the trail limb ($p<0.01$).

A significant interaction *(obstacle height by limb*) was observed for total joint variance ($F_{2,57}=4.82$; $p=0.01$; Fig. 2). Post hoc comparisons revealed that total joint variance with the trail crossing was 98% higher than the value of lead crossing for the 10 cm obstacle ($p<0.01$), whereas no difference for lead and trail crossing was observed for the unobstructed and 3 cm obstacle conditions. Total joint variance for trail

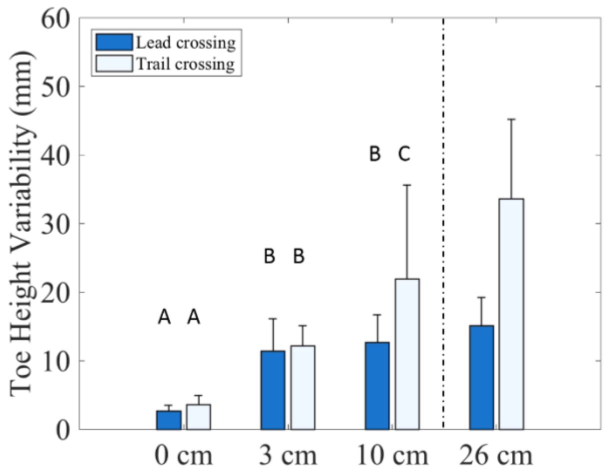

Figure 1: Effect of obstacle condition and limb for toe variability. 26 cm shown but not included in statistical analysis due to obstacle contacts. Letters A, B, C distinguish significantly different conditions.

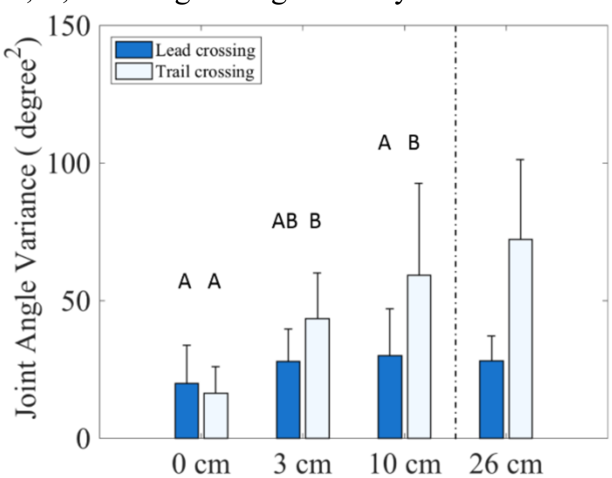

Figure 2: Effect of obstacle condition and limb for total joint angle variance.

crossing increased 164% for the 3 cm obstacle ($p<0.01$) and 259% for the 10 cm obstacle ($p<0.001$) compared with unobstructed walking; no significant obstacle effect was observed for lead crossing.

Overall, similar patterns were observed in toe variability and total joint variance (Fig. 1,2) as a function of obstacle height and limb: higher toe variability generally corresponded to higher total joint variance, consistent with the idea that total joint variance prescribes toe variability. There is an important exception – while toe variability and joint variance for the trail limb increased as a function of obstacle height, only toe variability increased for the lead limb. Future research should determine if the joint angles covary in a task-specific manner to control the variability in the toe height.

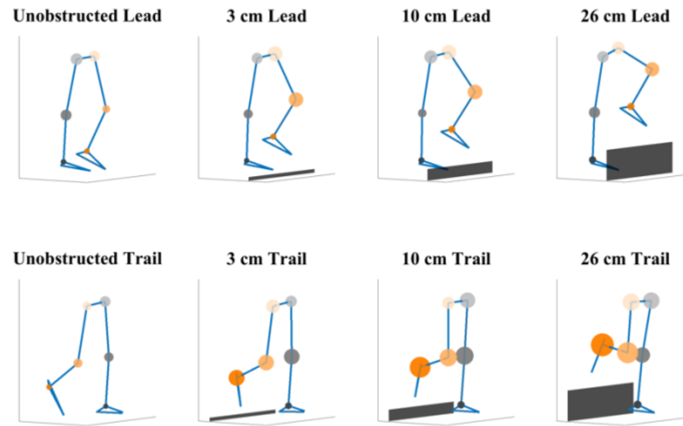

Figure 3: Individual joint angle variance marked on illustrative lower limb stick figures as circles. The area of circle reflects the amount of variance. Black rectangles are the obstacles.

We examined variances in each joint angle to locate the source of the toe variability. Qualitatively, variances in joint angles tended to be larger (quantified as larger circles on each joint, Fig. 3) during the trail crossing than lead crossing, and this pattern became more apparent for larger obstacles. The contribution from the stance limb joint angles to the toe variability is substantial. Although most research on obstacle crossing focus on the swing limb, stance limb behavior cannot be ignored.

CONCLUSIONS

Larger toe variability and total joint variance for the trail limb, especially for taller obstacles, is consistent with observations of greater failures with the trail foot [1]. Furthermore, the joint angle variances are distributed over the joints of both the swing and stance limb, indicating that the contribution of the stance limb to obstacle contacts must be considered. This suggests existence of compensatory covariance in the lower limb joint angles to control toe height. Further investigation into coordination between the individual joints of both limbs is necessary.

REFERENCES

1. Heijnen et al., Exp Brain Res, 2014
2. Mills et al. Gait Posture, 2008
3. Heijnen et al., Exp Brain Res, 2012