

## Collision-based analysis of walking versus running in humans

Collision-based analysis quantifies geometrically and energetically the interaction between the center of mass (CoM) and the environment during legged locomotion. We define collision angle as the deviation from perpendicular of the angle between the instantaneous CoM velocity and force vectors. In one extreme, if these vectors were to remain perpendicular throughout a cycle of locomotion, the collision angle would be zero for that stride and no mechanical energy would be expended between the CoM and the environment if a point-mass model is assumed. Furthermore the 'actual collision', the instantaneous collision angle, can be expressed as a ratio of the 'potential collision', the sum of instantaneous force and velocity angles, to determine a collision fraction. The collision fraction would be zero in the previous example - indicating an idealized, complete collision reduction. On the other hand, the compliant spring-like inverted pendulum (SLIP) model typically applied to running would result in a collision fraction of unity - indicating that there is no collision reduction. Previous work in quadrupeds has shown substantial collision reduction during walking (0.26-0.48) and a moderate collision reduction during galloping (0.6-0.7) but almost no collision reduction in trotting (0.93-0.97) (Lee et al., 2011). Given that the dimensionless collision fraction so clearly distinguishes quadrupedal gaits, we have begun to apply the same analysis to bipedal and polypedal gaits thought to be functional analogues. Here we provide the first collision angle and collision fraction measurements for human walking and running and show that the collision fraction during walking is 0.50, compared with 0.83 during running. These values are comparable to collision fractions during quadrupedal walking and trotting, respectively, and show a similarly striking difference between gaits. These results further support the concept of collision reduction strategies during walking gaits compared with little to no collision reduction during running or trotting gaits. The collision fraction provides a unified model allowing direct comparison of CoM dynamics across, gait body size and leg number, while our ongoing work seeks to quantify the underlying time-varying collisions. Joint time-frequency analysis of collision angle reveals patterns that can be compared in bipedal versus quadrupedal gaits to explain variation in the interaction of the CoM with the environment.

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Lee, D. V., Bertram, J. E. A., Anttonen, J. T., Ros, I. G., Harris, S. L. and Biewener, A. A. (2011). A collisional approach to quadrupedal gait dynamics. *J. R. Soc. Interface.* 8, 1480-1486.