Sensitivity of Mechanically Admissible Squat Motion to Joint Moment Capacity Distribution

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This contribution presents a computational framework for analyzing the sensitivity of mechanically admissible squat motion to the distribution of joint moment capacities. The approach builds upon a previously developed model of load-constrained motion reconstruction, in which human movement is represented as the solution of a constrained optimization problem.

A three-dimensional multi-segment rigid-body system is considered, including feet, shanks, thighs, pelvis, and torso. Joint behavior is modeled using smooth elasto-plastic rotational elements with bounded moment capacity. A reference squat trajectory is first generated kinematically, and subsequently corrected by solving a frame-wise optimization problem subject to geometric and mechanical constraints.

The problem is formulated as minimization of the total mechanical cost [1,2],

$$J(\mathbf{q}) = \frac{1}{2}(\mathbf{q} - \mathbf{q}_{ref})^T \mathbf{K}(\mathbf{q} - \mathbf{q}_{ref}) + \sum_i \Psi_i\,(\Delta\theta_i) + W_{ext},$$

where the first term enforces trajectory tracking, the second term represents joint-level elasto-plastic energy contributions, and the last term accounts for external loading due to the barbell.

A parametric study is performed by varying the critical moment capacities assigned to individual joints while maintaining identical external loading conditions. The results demonstrate that the admissible squat posture is strongly governed by the relative distribution of joint strength, leading to systematic changes in pelvis backshift, torso inclination, and redistribution of rotational demand between lower-limb joints.

The study shows that squat technique should be interpreted not only as a response to external load but also as a consequence of internal mechanical capacity constraints, providing a consistent framework for analyzing strength-dependent movement adaptations.

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