HOW DO WE RECOVER FROM FALLING IN A HOLE? A JOINT LEVEL ANALYSIS

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INTRODUCTION

In our everyday lives, we continuously negotiate complex environments and unpredictable terrain. Our ability to stay upright in the face of obstacles, such as a hole in the ground, is quite remarkable. Yet, we understand relatively little about how humans adjust limb behaviour to recover from an unexpected perturbation. Previous studies in birds running over an unexpected drop in terrain height suggest that stability is maintained via adjustments in limb contact angle as well as energy absorption in lower limb joints [1,2].

Moreover, the ability for biologically inspired devices to both augment intact and restore impaired locomotor systems is rapidly enhancing the locomotor possibilities in healthy and diseased populations. Yet despite the impressive ability for these devices to emulate the biological behaviour of lower limb muscle-tendon units during bouncing [3] and walking gaits [4], the design of exoskeletons and prosthetics that can respond to unexpected perturbations remains a challenge.

How does the lower limb recover from falling in a hole during steady state hopping? In this study, we begin to tackle this question by determining how lower limb joint power is redistributed in response to an unexpected perturbation (via a drop in substrate height) during hopping.

METHODS

We asked subjects to perform steady state hopping at their preferred frequency while we collected kinematic and kinetic data. Subjects began hopping on a platform elevated above the level ground; between the 10th and the 20th hop we elicited an unexpected perturbation via removal of the platform. The subjects continued to hop following the perturbation. We tested two different perturbation heights (platform heights of 10 cm and 20 cm). An eight-camera motion analysis system (Vicon, Oxford, UK) was used to capture the three-dimensional positions of 36 reflective markers attached to the pelvis and lower limbs. Joint angles for the ankle, knee and hip were computed from a scaled musculoskeletal model and the motion capture data [5]. Three-dimensional ground reaction forces applied to the left and right legs were computed during hopping using a static split belt instrumented treadmill (Bertec, OH, USA). Inverse dynamic analyses were then used to compute the net joint moments. We calculated the time-varying net joint powers at the right ankle, knee, and hip by multiplying the net joint moments by the joint angular velocities.

RESULTS AND DISCUSSION

Within the lower limb, joint power is redistributed to recover from the drop in height. The ankle provides majority of the limb mechanical power in hops before and after the perturbation while the knee absorbs majority of the added energy during the initial contact (Fig. 1). Similar to previous hopping studies [6], the contribution of the hip to the overall mechanical power is minimal, and like birds [2], the hip appears to maintain relatively the same mechanical role in normal versus perturbed hopping. Joint level responses were similar, although of smaller magnitude, for the 10 cm drop height in comparison to the 20 cm drop height.

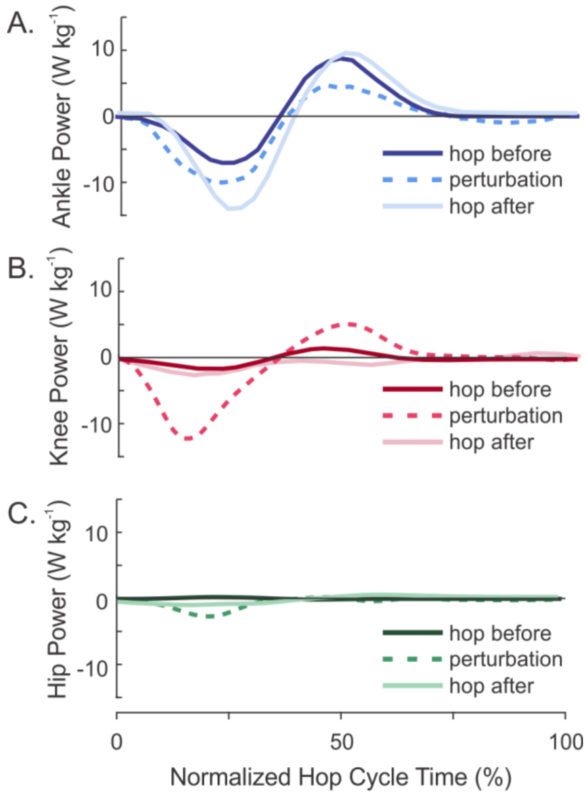

Figure 1: Joint power for the ankle (A), knee (B), and hip (C) over 3 hopping cycles for one subject at a 20 cm perturbation drop height. Data is shown for the hop prior to the perturbation (hop before), the hop when the platform was removed and subject landed on level ground (perturbation), and the hop immediately following the perturbation (hop after).

CONCLUSIONS

Further investigations into the muscle-tendon mechanics underlying these joint level responses will likely provide insight into the control strategies used to recover from perturbations and help provide biological inspiration for future designs of wearable exoskeleton and prosthetic devices.

REFERENCES

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