Frequency and Leg Stiffness Adaptation in Human Vertical Hopping Before, During and After Added Load

Luke N. Jessup[1], Raksha S. Konanur[2], Juwon Lee[3], Moira A. Williams[1], Alex Duman[1], James M. Finley[3], Kiisa C. Nishikawa[4], Monica A. Daley[1], Alexandra S. Voloshina[2]

[1]Department of Ecology & Evolutionary Biology, University of California, Irvine, USA
[2]Department of Mechanical and Aerospace Engineering, University of California, Irvine, USA
[3]Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, USA
[4]Department of Biological Sciences, Northern Arizona University, Flagstaff, USA
Email: ljessup@uci.edu

Summary

Hopping involves spring-like mechanics that can be perturbed through changes in inertial load, providing a window into neural control strategies. We investigated how humans adjust hop dynamics before, during and after experiencing added body mass load. In added mass trials, leg stiffness increased, maintaining constant hop frequency and similar stance work. In unloaded trials after exposure to added mass, leg stiffness was maintained, leading to higher hop frequency and lower stance work. We observed similar trends with bouncing (no aerial phase). The findings suggest that guided exploration elicited by added load led to optimization, allowing subjects to converge on a new preferred frequency that, based on previous research, is closer to the energetic minimum.

Introduction

Hopping is a simple constrained task that is comparable to locomotion. Like running, hopping involves compliant 'bouncing' motions, with interactions between muscle and tendon, leg geometry, and inertial loading. Perturbing these interactions provides a window into the neural control strategies that yield spring-like limb mechanics [1]. We investigated how humans adjust hopping frequency and leg stiffness during and after experiencing added body mass load.

Methods

Eighteen healthy subjects (8 F, 10 M) were instrumented with a lower-body reflective marker set. Subjects hopped on both legs during 90 sec trials while motion capture and force plate data were collected for inverse dynamics. Hop frequency and hop height were unconstrained. Trials included an initial body weight condition, followed by added mass conditions at +10% and +20% body weight, and then a final body weight condition. Rest was provided between trials. The same experiment was performed on the same sample during bouncing (without an aerial phase) to assess whether findings persisted with reduced task demands.

Results and Discussion

Subjects increased leg stiffness in response to added mass, maintaining constant hopping frequency, but then maintained a higher leg stiffness in the unloaded trial after exposure to added mass, resulting in higher hopping frequency and lower work during stance ($p < 0.001$) (Fig. 1). Likewise, preliminary findings from bouncing suggest an increase in bouncing frequency following added mass ($p < 0.001$) (Fig.2). We also note a significant effect of sex on all metrics ($p < 0.05$), except stance work, and highlight high interindividual variation in hop dynamics.

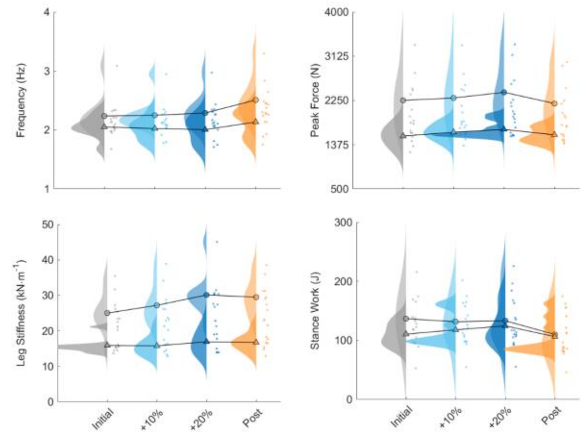

Figure 1: Mean hop metrics across each experimental condition. Circles and triangles represent male and female data, respectively.

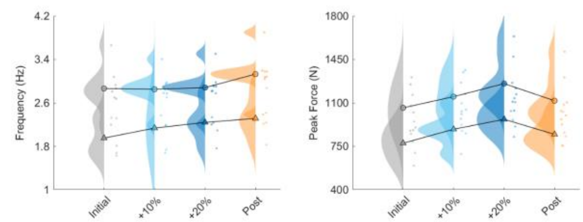

Figure 2: Mean bounce metrics across each experimental condition.

That subjects increased their preferred hopping and bouncing frequency is interesting considering it has been shown that humans prefer to hop and bounce at a frequency lower than the energetic optimum [2,3]. Proprioceptive feedback may have facilitated this adaptation, helping subjects identify movement frequencies that optimize elastic energy cycling.

Conclusions

The findings suggest that force exploration elicited by added load subjects to converge to a new preferred hopping strategy, closer to the frequency that minimizes energetic cost.

Acknowledgments

Supported by NSF-DBI 2319710.

References

[1] Robertson BD and Sawicki GS. (2015). *Proc. Natl. Acad. Sci. U.S.A.*, **112**: E5891–E5898
[2] Jessup LN et al. (2023). *J. Exp. Biol.*, **226**: jeb245614
[3] Raburn CE et al. (2011). *J. Exp. Biol.*, **214**: 3768–3774