Chronic limb loading results in a remarkable economy of walking with added limb mass

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***Abstract*—We used an animal model (guinea fowl) to test the hypothesis that altered limb mechanics during growth lead to adaptations in locomotor economy. Animals subject to chronic distal limb loading over their growth period used, on average, no more energy to walk with limb loads compared to walking unloaded. Moreover, the average cost of walking with the added limb mass was not different in chronically limb-loaded animals compared to that of walking unloaded in control animals. These data show a remarkable growth-period adaptation for economical locomotion in response to altered limb mechanics.**

Keywords—walking, energetics, adaptation, plasticity

I. Introduction

Over an evolutionary timescale, natural selection has resulted in specializations for locomotor economy in cursorial species [1]. Whether adaptations in locomotor economy occur across an individual's life span, however, remains less clear. This is an important question for applications such as wearable robotics, where limb mechanics are purposely altered to achieve locomotor assistance or augmentation. Long-term adaptations of locomotor economy could affect the efficacy of such wearable assistive technologies.

To understand better the scope of developmental plasticity of locomotor economy, we adopted a bipedal model (guinea fowl) that permitted drastic alteration of musculoskeletal loads across the growth span. We achieved this by increasing distal limb mass experimentally by a factor of ~ 2.5x over the biological limb mass across the maturation period. We hypothesized that animals subject to habitual increased limb mass would be more economical at carrying this extra limb mass compared to a habitually unloaded control group.

II. Methods

Twelve 1-day old guinea fowl (*Numida meleagris*) were obtained for this experiment (Privett Hatchery, Portales, NM). At one week of age, animals were randomly assigned to a control group (CON, n=6) and a limb-loaded experimental group (LL, n=6). A lead strip with mass equal to 3.3% of the individual's body mass (adjusted weekly) was chronically added to the right leg of the LL group throughout growth. Starting at three weeks of age, each group was exercised three times per week by herding animals around a circular course in 5-minute intervals for a total of 20 minutes.

Metabolic power was measured during standing and during treadmill walking (0.5 $m \cdot s^{-1}$) using a flow-through metabolic chamber system [2]. Metabolic power was measured in the habitual conditions (unloaded in CON; limb-loaded in LL), as well as in their novel condition (matched limb load in CON; unloaded in LL). Lastly, we used an interlimb design to investigate load carrying economy on the habitually loaded (right) leg versus the habitually unloaded leg in the LL group.

III. Results & Discussion

The LL group carried the added limb load 24% more economically compared to the CON group (Fig. 1; $p < 0.05$). Surprisingly, the large addition in habitual limb mass in LL did not result in an increase in walking metabolic power, on average, compared to walking without the load, nor was limb-loaded walking in the LL group different compared to unloaded walking in the CON group. However, we did observe a significant lower metabolic cost ($p = 0.05$) of carrying additional mass on the habitually loaded (right) leg compared to the unloaded leg in the LL group. Overall, our results support our hypothesis that locomotor economy responds plastically to altered amounts of load (functional demand) during growth and is tuned to the habitual loading environment.

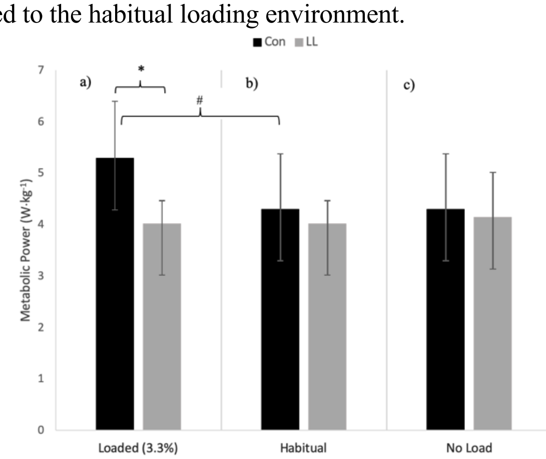

Fig. 1. Net body-mass specific metabolic power in (a) limb loaded conditions; (b) the habitual conditions (CON =Unloaded, LL= Loaded); and (c) the unloaded conditions. * significant difference between LL and CON; $p < 0.05$. # significant difference between conditions within the same group; $p < 0.001$.

References

[1] Alexander, R.M. (2003). *Principles of Animal Locomotion,* Princeton University Press, Princeton NJ.

[2] Cox et al (2020). *J. Appl. Physiol*., 128:1, p 50-8.