DYNAMIC STABILITY IN A ROUGH ENVIRONMENT: THE INFLUENCE OF INITIAL LIMB POSTURE ON BODY DYNAMICS DURING AN UNEXPECTED PERTURBATION.

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INTRODUCTION

Little is currently known about the capability, mechanics and time-course of recovery from the types of perturbations that animals face while running in the natural world. Work on humans reveals that changes in k_{leg} help maintain similar CoM motions over surfaces of varying compliance [e.g., 1, 2], and these changes in k_{leg} can occur through intrinsic changes in limb mechanics [3]. Furthermore, stability of running can be improved by adjusting leg contact angle, which can be accomplished automatically if the leg retracts during late swing phase [4]. Thus, proper tuning of limb parameters in the face of a changing external environment is required to maintain locomotor stability. However, the relative importance of different control mechanisms during real-world perturbations is not yet clear. In this study, we perturb the running of guinea fowl by subjecting them to an unexpected drop in substrate height (ΔH). The goal of this study is to investigate how body centre of mass (CoM) mechanics deviate from steady running dynamics in response to an unexpected ΔH, and how limb dynamics mediate the response.

METHODS

The drop in substrate height is camouflaged to remove any visual cue about the upcoming change in terrain (Figure 1). Ground reaction forces (GRF), measured in the vertical and fore-aft directions, were recorded at 5000Hz and used to calculate instantaneous kinetic and potential energies of the CoM. Limb kinematics during the response were obtained from synchronized high-speed digital video recorded in lateral view at 250 frames s^{-1}.

RESULTS AND DISCUSSION

The birds stumbled or fell in fewer than 6% of the unexpected perturbations. In contrast, during visible substrate drops, they stumbled or fell in 20% of the cases, and came to a complete stop in an additional 25%. Due to altered timing between limb retraction and limb loading, an exchange between potential and kinetic energy occurs during the perturbed step, unlike during steady running. The birds exhibited three CoM energy exchange patterns in response to the unexpected ΔH, each characterized by a distinct combination of altered magnitude and direction of the ground reaction force (GRF) impulse.

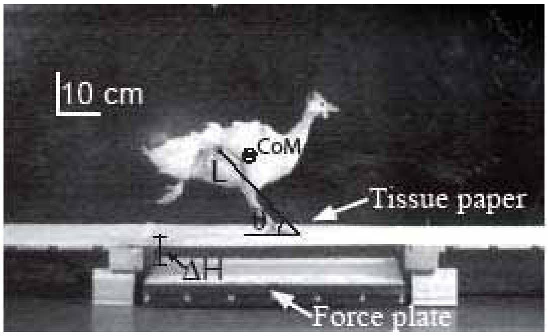

Figure 1: Still frame of a guinea fowl as it encounters a hidden drop in terrain, illustrating the experimental setup.

Overall, the results suggest that decoupling of limb retraction from limb loading plays a primary role in determining the dynamics of the response. Limb angle at the time of ground contact explains much of the variation in CoM dynamics during the response (Figure 2). In contrast, k_{leg} during the unexpected ΔH varies dramatically but does not predict the CoM dynamics. Therefore, it appears that limb posture at ground contact plays a larger role in the response to the perturbation than does k_{leg} alone. The variation in stance phase CoM dynamics during the perturbation likely relates to altered intrinsic mechanics when the leg contacts the ground with a different posture.

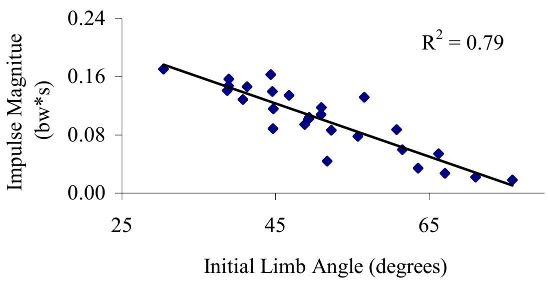

Figure 2: The relationship between limb contact angle and GRF impulse magnitude.

CONCLUSIONS

Despite large changes in CoM dynamics and a great deal of variability in the response to an unexpected ΔH, guinea fowl are quite successful in maintaining dynamic stability, as they rarely stumble or fall. Further investigation of the joint and muscle dynamics underlying this variation could yield further insight into the control mechanisms that allow such robust dynamic stability during running in the face of large, unexpected perturbations.

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