MECHANICS OF BIPEDAL RUNNING TURNS

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INTRODUCTION

Maneuvering is an essential aspect of locomotion. Efforts to design rehabilitation strategies or neural prostheses to assist locomotion following neuromotor injury must ultimately confront the need for maneuverability. Moreover, maneuvering is a controlled perturbation that may reveal control strategies used for stable locomotion under many conditions. However, relatively little is known about the mechanical requirements for maneuvers and the control strategies used for their execution.

To begin to understand the mechanical requirements for maneuvers, I developed a simple algebraic model for legged maneuvers based on the hypothesis that body rotation should match movement deflection (the change in velocity direction) over the course of a turn. The model leads to two predictions: (1) humans will over-rotate if they only generate the lateral forces necessary to turn during running; and (2) ostriches, with more horizontal body orientation and higher inertias relative to their mass, can effectively turn using only the lateral forces necessary for deflection. I used experimental data on humans and ostriches to test these predictions.

METHODS

The model assumes that a biped of mass M and moment of inertia about the vertical axis I, traveling at velocity V, seeks to deflect the direction of movement by θ_d during a step. At the beginning of the step, the foot is placed at an anterior extreme position $P_{AEP,imd}$ with respect to the center of mass (COM) parallel to the initial movement direction (*imd*), and generates a sinusoidal lateral force $F_p(t)$ for the duration of stance. If the foot does not remain directly lateral to the COM, generating the lateral impulse necessary to change the movement direction will result in a torque that rotates the body by θ_p. The proportion that θ_p matches θ_d can be estimated by a "leg effectiveness number", an indication of the degree to which generating the forces necessary for deflection maintains body orientation aligned with movement deflection. The leg effectiveness, ε, is determined by a simple algebraic equation based on behavioral and morphological parameters,

$$\varepsilon = \frac{\theta_p}{\theta_d} = \frac{MV\tau}{2I}\left(P_{AEP,imd} - \frac{4V\tau}{\pi^2}\right), \qquad (1)$$

where τ is the stance period. Values of ε close to 1 represent conditions where little modulation of *imd* forces is required for body rotation to match movement deflection at the end of the turn. In the case where *imd* forces are required, their magnitude can be predicted using the equation

$$F_{imd,\max} = \frac{\pi I(1-\varepsilon)\theta_d}{\tau^2 P_p}, \qquad (2)$$

where P_p is the foot placement relative to the COM, perpendicular to the *imd*.

Humans (74 kg) and ostriches (22 kg) ran at 3 m s^{-1} and executed sidestep (left turns with the right leg) or crossover (left turns with the left leg) cutting turns on a force platform. Forces in the *imd* were calculated for each turn using eq. (2), and compared to *imd* forces used by humans and ostriches (Jindrich et al., 2006; Jindrich et al., 2007).

RESULTS AND DISCUSSION

Whereas humans generated almost exclusively deceleratory (braking) forces in the *imd* during crossover and sidestep cuts (Fig. 1), ostriches generated braking forces in only 60% of turning trials (Fig. 2). This difference can be explained by differences in leg effectiveness. Humans had leg effectiveness numbers of 2.0-4.2 depending on turn magnitude, indicating that over-rotation must be overcome by braking forces. In contrast, ostriches showed values for ε of 0.9 - 1.2 for crossovers and sidesteps. Ostrich ε values were close to 1, indicating that mis-rotation is less likely to occur. On average, ostriches can effectively turn using primarily the forces necessary for deflection.

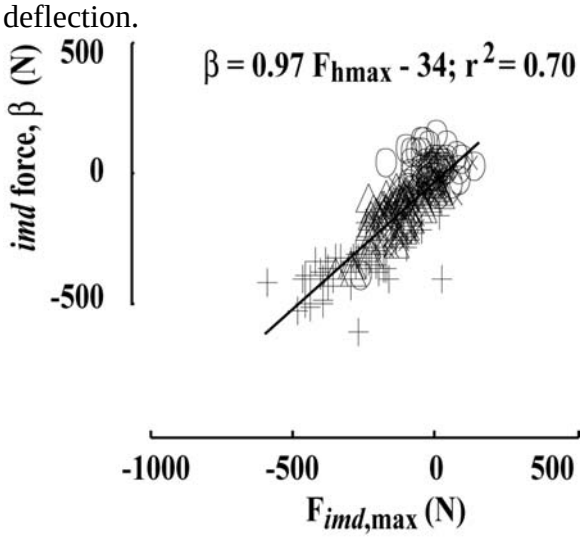

Figure 1. Comparison of forces predicted using eq. (2) to forces in the *imd* for humans. Sidesteps of 28°±1° (triangles) and 42°±5° (plus signs), crossovers of -24°±4° (crosses) and straight-running trials (circles) are shown. Black line is a linear fit.

Despite differences in body shape, body mass, and turn type, the simple algebraic turning model was able to explain over 70% of the variance in *imd* forces for both humans and ostriches (Figs. 1 and 2).

Although ostriches generated small *imd* forces on average, the range of forces observed shows that for individual trials, forces in the *imd* were used to modulate body rotation.

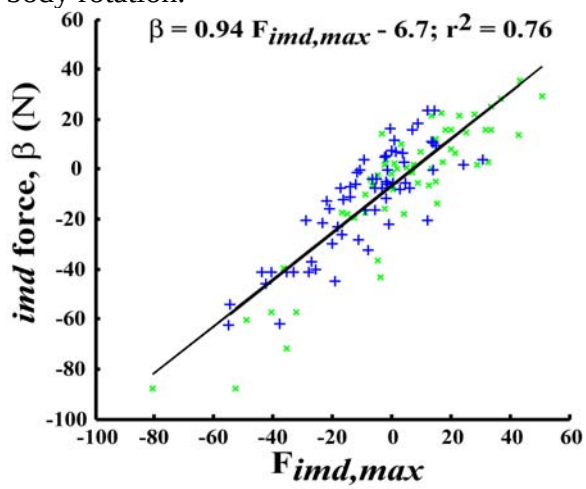

Figure 2. Comparison of forces predicted using eq. (2) to forces in the *imd* for ostriches. Sidesteps of 18°±0.6° (blue plus signs) and crossovers of 14°±0.6° (green crosses) are shown. Black line is a linear fit.

SUMMARY/CONCLUSIONS

Differences in body shape influence the forces necessary to control maneuvers in a predictable way that can be captured by a simple algebraic model.

REFERENCES

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