# Optimising sit-to-stand control in birds: multi-objective performance criteria

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## Summary

Standing up from a seated or prone position is a fundamental movement across terrestrial animals, yet the underlying high-level control goals driving the selection of a specific movement pattern remain elusive. We investigated control principles governing the sit-to-stand (STS) transitions in birds using both simplified 2D models and 3D musculoskeletal models of emus (*Dromaius novaehollandiae*) and pheasants (*Phasianus colchicus*). Applying optimal control methods, we evaluated multiple STS performance criteria—including time, muscle activation, force rate, and force minimisation—to determine which best captures observed STS dynamics. We found that a combined control strategy minimising both muscle activation and force rate most accurately describes avian STS. This suggests a common control strategy in STS between humans and birds.

## Introduction

STS is a key motor task, but the control mechanisms remain poorly understood. In humans, various optimal control criteria have been proposed, such as muscle force derivatives [1] or control effort [2], where control effort is typically modelled as the cost associated with muscle activations and joint torques. For non-human animals, the biomechanics and control of STS remains almost unexplored. This study aims to answer the question: what control strategies do birds use when standing, and does it differ between species?

## Methods

We first evaluated performance criteria using a simplified two-link STS model, constrained to vertical motion with a single-mass, single-joint, single-muscle system. Using multiple-shooting methods, we explored the sensitivity of solutions to different performance criteria based on time, muscle force rate, activation, and force. Next, we applied these performance criteria to 3D musculoskeletal models of emus and pheasants using direct collocation methods [3,4]. By comparing to empirical trends, we determined which optimising criteria have the largest explanatory power.

## Results and Discussion

Although no single criterion captured all STS features, combining force rate and muscle activation led to the best match between simulated and experimental data, capturing key STS characteristics such as peak ground reaction forces (GRFs) near heel-off, an initial forward pitch, and a proximal-to-distal joint extension sequence (Figure 1).

However, the uniqueness of this strategy remains uncertain, as multiple criteria may yield similar outcomes. The inclusion of force rate in simulating STS was based on the notion that gradual, controlled increases in muscle force—rather than rapid fluctuations—optimised metabolic efficiency (e.g., [5]). While this study did not use energy as a cost, prior simulations in humans found that minimising energy alone could not reproduce essential features of STS [1]. More experimental data is needed to evaluate model predictive power.

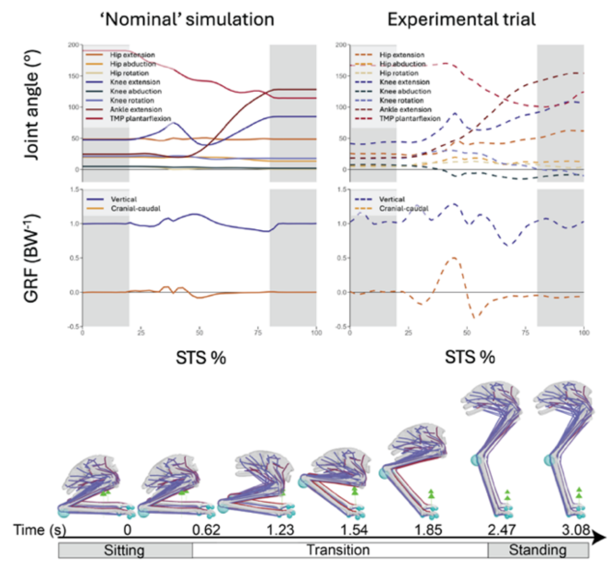


**Figure 1**: Time histories of limb kinematics and GRFs in the nominal emu simulation, compared with experimental data [6].

## Conclusions

Both pheasants and emus appear to minimise muscle activation and force rate during STS, suggesting a common underlying control strategy. This appears similar to human studies, suggesting similar control mechanisms. Future research will examine how musculoskeletal properties influence STS performance across body sizes, offering insights into biomechanical and evolutionary constraints.

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## References

[1] Pandy MG, et al. (1995). *J Biomech Eng*, 117(1):15–26.
[2] Bobbert MF, et al. (2016). *Clin Biomech*, 37:83–90.
[3] Falisse A, et al. (2019). *J. R. Soc. Interface*, 16(157):20190402.
[4] D'Hondt L, et al. (2024). *10th IEEE RAS/EMBS BioRob*, p.1208–13
[5] Hogan MC et al. (1998). *Am J Physiol-Endocrinol Metab*, 274(3):E397.
[6] Lin Y, et al. (2024). *J Exp Biol*, 227(24):jeb247519.