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1. Introduction

Locomotion in terrestrial animals is governed by fundamental mechanical constraints, many shaped by gravity. One powerful framework to compare gait dynamics across species is dynamic similarity. This theory states that geometrically similar animals in similar gravitational fields and relying on pendulum-like mechanics, exhibit similar gait dynamics when moving at a same dimensionless Froude number (Fr):

$$\mathrm{Fr} = \frac{v^2}{gL}$$

where v is speed, L, the animal's leg length and g is gravitational acceleration.

Dynamic similarity predicts that animals of different sizes adopt similar preferred dimensionless speeds. In humans, Fr is ~0.25 at preferred speed, and ~0.5 at gait transition (Minetti, 2001). This holds across species, such as humans and gibbons.

In theory, then small and large animals should have dynamically equivalent gaits with different absolute speeds but similar Fr value. Does dynamic similarity still hold for extreme body sizes, such as elephants or sauropod dinosaurs? And how would these dynamics change under reduced gravity?

Dynamic similarity states that walking speed should scale with the square root of gravity. We tested whether dynamic similarity holds for some of Earth's largest living (elephants) and extinct (sauropod dinosaurs) terrestrial animals, assessing its predictive power when body size and gravity vary substantially. This analysis not only tests the robustness of dynamic similarity but also opens the door to speculations about how gravity shapes the upper limits of locomotion in massive animals. Understanding how big animals would move within different environments is a burgeoning field of research, exploring how mechanical constraints may influence locomotor evolution and body size limits in different gravitational contexts.

2. Methods

The kinematics 27 Asian elephants (Elephas maximus) were measured at the Thai Elephant Conservation Centre (Lampang, Thailand). Experiments were approved by the ethics committee of the Faculty of Medicine (UCLouvain).

Elephants moved at different speeds along a 50 m track. The average L was 1.67 m. Transition speed between gaits was defined on a clear change in trunk oscillation. The preferred walking speed of both elephants (1.26 ms^{-1}) and sauropods have been documented in the literature based on trackway analysis (Lee & Slowiak, 2025). We computed Fr at preferred and transition speeds based on the animal's average L. Finally, we assumed constant Fr to compute the preferred and transition speed at different gravities. In addition, we explored the leg length that would preserve dynamic similarity at a fixed walking speed on the Moon.We also compared these predictions with human data in simulated reduced gravity (Minetti, 2001).

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3. Results and Discussion

In elephants, gait transition is more continous than other species, without a clear aerial phase. The shift to a more bouncy gait occurs at 2.0 m·s⁻¹, consistent with observations in African elephants (Ren & Hutchinson, 2008).

Biomechanical reconstructions suggest that despite their vastly greater *L*, sauropods had preferred walking speeds similar to elephants (1.26 ms^{-1}) - 1.24 ms^{-1} for Diplodocus and 1.49 ms^{-1} for Brachiosaurus (Lee & Slowiak, 2025). This suggests absolute speed -rather than Fr - may be a more conserved determinant of preferred (and transition) speed in large animals. While smaller animals like humans and dogs transition at Fr ≈ 0.5, elephants transition around Fr ≈ 0.24. Sauropods, despite their towering size and *L*, appear to have walked at similar speeds, resulting in an even lower Fr. This suggests dynamic similarity may break down at extreme body sizes, possibly due to musculoskeletal constraints. This aligns with musculoskeletal simulations showing that maximal gait speed scales hyperbolically with body mass (Clemente et al. 2024). A similar conclusion was reached by Lees et al. (2016), who showed that both birds and mammals tend to walk at lower relative speeds and stride frequencies as body size increases.

Human studies in simulated reduced gravity environments suggest that individuals tend to adjust their walking speed to preserve a similar Froude number (Minetti, 2001). Transposing these dynamics to elephant at lower gravity, we calculated the equivalent walking and transition speeds for elephants, assuming constant Fr. On the moon, preferred walking speed in elephants would shift to ~0.51 $m \cdot s^{-1}$, and transition speed to ~0.81 $m \cdot s^{-1}$ – less than half their Earth-based speed. Although transition is continuous for elephants on Earth, weakened pendular dynamics under reduced gravity might trigger a sharper, more abrupt shift in gait. Yet, human studies in simulated lunar gravity show smooth and gradual gait transitions, without a clear discontinuity in movement patterns. Whether this applies to large animals is unknown, but the large limb inertia, reduced loading, and altered ground reaction forces may drive emergent gait strategies not observed on Earth, as revealed by model-based optimizations in human.

Finally, applying dynamic similarity in reverse, we estimated the *L* required to maintain a Fr ≈ 0.244 with a transition speed of 2.0 $m \cdot s^{-1}$ on the Moon. This yielded a theoretical *L* of approximately 10.2 meters, suggesting that in low gravity, much larger animals could walk using Earth-like mechanics. Although speculative, this illustrates how reduced gravity relaxes many of the structural and energetic constraints that limit body size. While speculative, this highlights how lower gravity could permit locomotion in much larger terrestrial animals, by relaxing structural and energetic constraints.

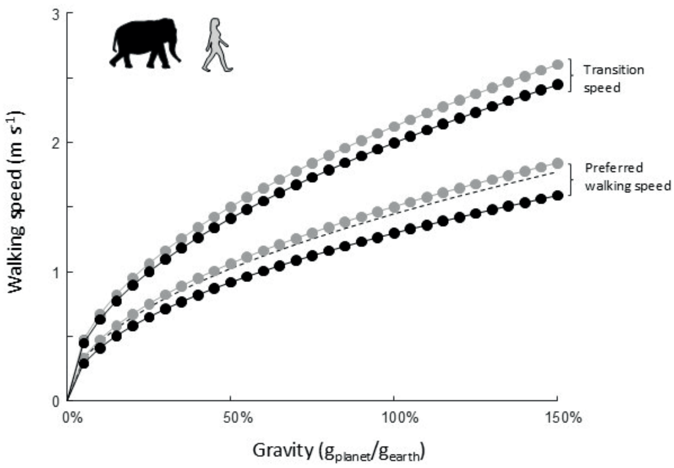

Figure 1.

We expressed gravity as a percentage of Earth gravity to generate a plot of preferred walking speed and transition speed.

4. Conclusions

Using experimental data and basic dynamic similarity principles, we investigated how gravity and body size interact in shaping gait mechanics. Although speculative, it allowed us to explore how gravitational context modulates gait and size constraints. Deviations from dynamic similarity in large animals suggest that absolute speed and musculoskeletal limitations may be better predictors of locomotion than Fr alone.

Conflict of Interest Statement

None

Contributor Roles

AD: Conceptualization, Methodology, Writing original draft; Writing- review & editing; RM & TT: Writing- review & editing.

Data, software, code availability

Data are available upon reasonable request.

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