# FROM RUNNING TO WALKING

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## INTRODUCTION

Animals and humans prefer to walk at comparable low speeds and to run at higher speeds. Both gaits can be distinguished by the path of the center of mass (COM). In walking, the COM reaches its highest point at midstance (inverted pendulum model). In contrast, in running it reaches its lowest point at this instant (spring-mass model). A maximum walking speed $v_{max}$ can be derived using the inverted pendulum model. At a Froudee number $Fr = v_{max}^2/(gl) = 1$ the ground contact is lost as the centripetal force equals the counteracting gravitational force: (g: gravitational acceleration, l: leg length). Experimental studies on species as different as humans and birds confirm this relationship surprisingly well, except the observed Froudee number is clearly smaller ($Fr \approx 0.5$). Several ideas have been suggested (e.g. metabolic costs, kinematic factors), yet a satisfying explanation of what the walk-run transition triggers remains elusive.

## SRING-MASS MODEL APPROACH

In our approach to this issue, we take a closer look at running. Individuals can not only walk faster but also run slower than the preferred transition speed. However, there is a gap between the COM trajectories in walking and running. A possible criterion for the walk run transition could be to minimize this gap, i.e. to ask for an almost straight line between touch-down and take-off (Fig. 1).

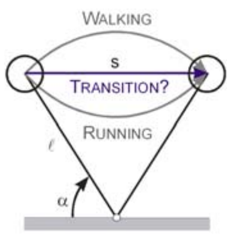


**Fig. 1**: Smoothness as criterion for the walk-run transition.

For running, this question can be addressed using the spring-mass model. During the stance phase, we restrict its kinematics to a horizontal movement, and estimate the leg stiffness k for minimum leg compression $\Delta\lambda_{min} = \lambda\cdot(1-\sin\alpha)$ using the leg length $\lambda$ and angle of attack $\alpha$. The horizontal movement defines the covered distance ($s = 2\lambda\cdot\cos\alpha$). The leg stiffness dictates the maximum time spent during contact $t_{max} = 2\pi\sqrt{\Delta\lambda_{min}/2g}$ . Hence, there is a minimum speed at which a smooth transition becomes possible is $v_{min}^2/gl = 2(1+\sin\alpha)/\pi^2$ .

## TRANSITION SPEED PREDICTION

Considering that for a reasonable angular range the sine function does not substantially alter, the Froude number for the minimum transition speed yields $Fr \cong 0.4$. As outlined in the introduction, there is ample experimental evidence that the transition occurs at $Fr \approx 0.5$. For example, the results of a study from Kram, Domingo, and Ferris (1997) are shown in figure 2.

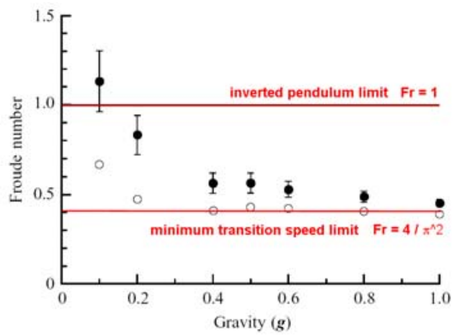


**Fig. 2**: Comparison of Froude numbers at walk-run transition (modified after Kram et al., 1997)

They found that for reduced gravity, the transition occurs at approximately the same Froude number (closed circle), except for very low gravity levels (≤0.2g). For the lowest gravity level (0.1g), the value exceeds the upper limit Fr = 1 given by the maximum walking speed. The authors concluded that the swing-leg motion likely evokes additional downward accelerations, and estimated corrected Froude numbers (open circle), which closely align with the minimum transition speed prediction.
Perhaps the most debatable assumption made in the model is that the walk-run transition is governed by a smoothness criterion minimizing the difference between both the running and the walking kinematics, and resulting in an almost straight trajectory at the transition. This is by no means imperative and it remains for further investigation to elaborate, whether this assumptions holds for biological systems.

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## REFERENCES

Kram, R., Domingo, A., Ferris, P.F. (1997). *J. Exp. Biol.* **200**: 821-826.