An integrative view on legged locomotion obtained from the bipedal spring-mass dynamics

[1,2]Hartmut Geyer, [1]Andre Seyfarth, and [1]Reinhard Blickhan
[1]Friedrich-Schiller-University Jena, [2]Massachusetts Institute of Technology;
email: hgeyer@media.mit.edu

A VIEW THAT SEPARATES WALK-RUN DYNAMICS

Do walking and running share similar dynamics? In the classical picture, they do not; rather, it is assumed that the two gaits reflect two contrasting mechanical concepts of legged locomotion: walking is considered as vaulting over stiff legs; and running, as rebounding on compliant legs with intermittent flight phases [1].

These two concepts are idealized by the inverted pendulum model for walking and the simple spring-mass model for running. Both models much advanced our understanding of legged locomotion; but they also showed that whereas rebounding on compliant legs well explains the dynamics observed in running, stiff-legged vaulting cannot truly reproduce that of walking [2].

This discrepancy is mainly related to the double support, which, because it requires leg compression, can not be addressed with an inverted pendulum. Indeed, more complex models that (partially) include the double support describe the dynamics of walking much closer than the inverted pendulum model [2]; conceptually, however, compliant leg behavior remained to be regarded as additional but not essential to the walking motion.

A MODEL THAT CONTRADICTS THE CLASSICAL VIEW

In contrast to this classical view, we could recently show that not stiff but compliant legs are essential to obtain walking mechanics [3]: with the simplest walking model that includes leg compliance, a bipedal spring-mass model, we could reproduce the characteristic walking dynamics that result in the observed small vertical oscillation of the body and the observed out-of-phase changes in forward kinetic and gravitational potential energies (left and center panel in Figure 1).

This result challenges classical views about walking efficiency and the origin of the walk-run transition, which both are based on the stiff-legged motion as mechanical concept underlying the walking gait. It moreover demonstrates that the dynamics of walking and running can be united within one mechanical concept that is based on compliant leg behavior (Figure 1).

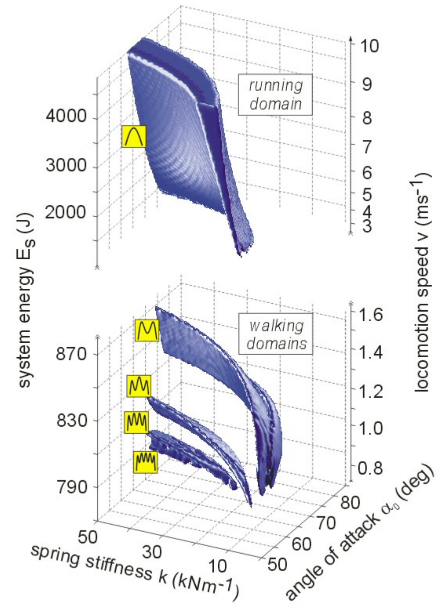

Figure 2: Parameter domains for stable locomotion include steady-state dynamics that, from fast to slow speeds, range from the single-peak running pattern to an infinite number of multi-peak walking patterns.

A VIEW THAT INTEGRATES WALK-RUN DYNAMICS

But the bipedal spring-mass model not only combines walking and running dynamics in one simple but compelling mechanical template, it also suggests that both gaits are just two members out of a family of stable solutions to legged locomotion that share similar dynamics (Figure 2).

This integrative view on the walk-run dynamics may change our intuition about legged locomotion, for instance, about the origin of gait transitions. Moreover, it could trigger the development of (nearly) passive dynamic robots that walk and run.

REFERENCES

1. Dickinson et al., *Science* **288**, 100-106, 2000.
2. Pandy, *Phil Trans Roy Soc Lond B* **358**, 1501-1509, 2003.
3. Geyer et al., In: *Proc ISB XXth Congr* 737, 2005.

ACKNOWLEDGEMENTS

DFG (SE1042/1-5) and EU (MOIF-CT-20052-022244).

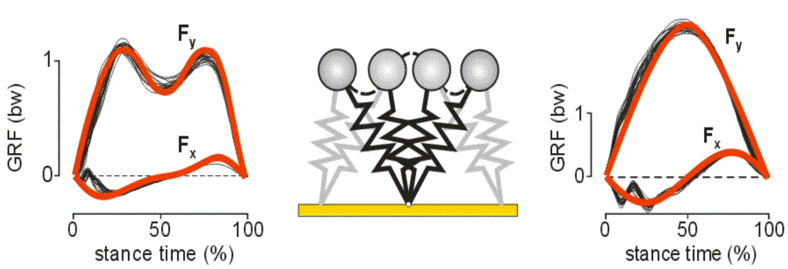

Figure 1: The bipedal spring-mass model (center) explains walking (left) and running dynamics (right). Thick red lines: ground reaction forces (GRF) predicted by the model; thin lines: experimental GRF traces (Fx and Fy: horizontal and vertical GRF measured in body weight, bw).