Runners as Biomechanical Systems:
New Approaches with the Spring-Mass Model

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Abstract:
Running is fundamentally a simple activity, but the physical realization of it is complex. The gait patterns of a runner are the product of ever-changing systems and interactions of biomechanical components, and as such, the study of these mechanical characteristics is challenging. Traditional methods have focused on discrete components of gait and thus struggle to contextualize observations. Systemic analyses have been limited to simple descriptive models, often with exclusive or restrictive assumptions. This dissertation sought to develop novel methods for the systemic analyses using an established canonical model of the running gait – the spring-mass model – as a template. It further sought to conduct a series of biomechanical studies using this template-based approach as a framework to interpret the observations. Specifically, a method is first presented to estimate the system-level spring-mass characteristics of a runner using nonlinear regression with only the vertical ground reaction force time series of the runner. To facilitate this method, a novel parameterized form of the sinusoidal vGRF approximation was derived and validated. This NLR-based analyses yielded leg stiffness estimates that were consistent with traditional methods and further suggested that additional systemic parameters do not behave as traditional methods assume. Next, two investigations are presented that explore this method along with new methods for spring-mass dynamics comparisons and with established methods for spring-mass parameter analysis. These investigations included a cohort comparison of elite Kenyan distance runners against a cohort of non-elite recreational runners and a paired comparison of subjects before and after an ultramarathon. It was shown that the Kenyan runners behaved more like the simple elastic system than the recreational runners and that the ultra-marathon runners demonstrated consistent systemic patterns but greater overall template dissimilarity following the race. Finally, traditional methods of spring-mass analyses were applied with a more comprehensive mixed-model experimental design to fully characterize the system-level behavior of elite middle distance runners across a spectrum of speeds. The mixed-model template-based analysis revealed that the elite runners ran as stiffer systems than their sub-elite counterparts and that their mechanical behavior was more persistent across speeds. Together, this series of investigations established and validated new methods and improved upon the implementation of existing methods with which to assess running gait holistically and analyze it as a system. It is hoped that this work will provide useful tools, new frameworks, and fresh inspiration for scientists, coaches, and athletes to assess and interpret the movements of runners.