Simple mathematical models are insufficient in explaining vertical jumping

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1. Motivation

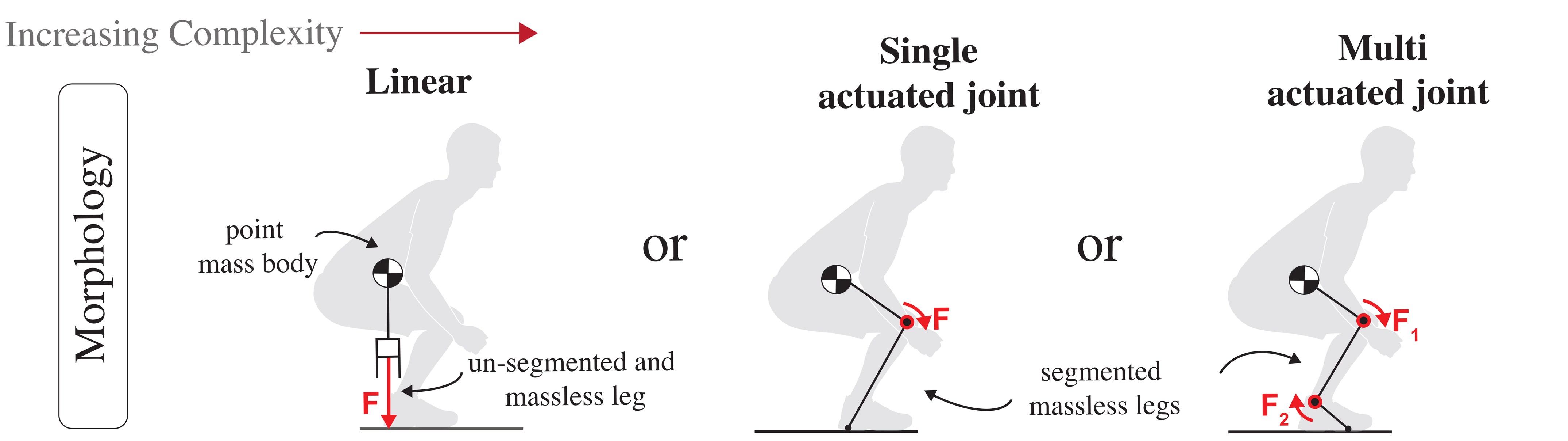
When executing a vertical jump, we can think of our legs behaving like a mechanical actuator that pushes against the ground to accelerate the body. In our work, we seek to understand how the mechanical characteristics of the leg actuator limit jumping performance and how higher vertical jumps could be enabled. To accomplish this, we design and test actuator models of varying morphological and physiological complexity and compare model predicted ground reaction forces to empirical data.

Our goal is to determine the simplest model of the leg actuator that generates human-like ground reaction forces with model parameters that are not dependent on jump depth.

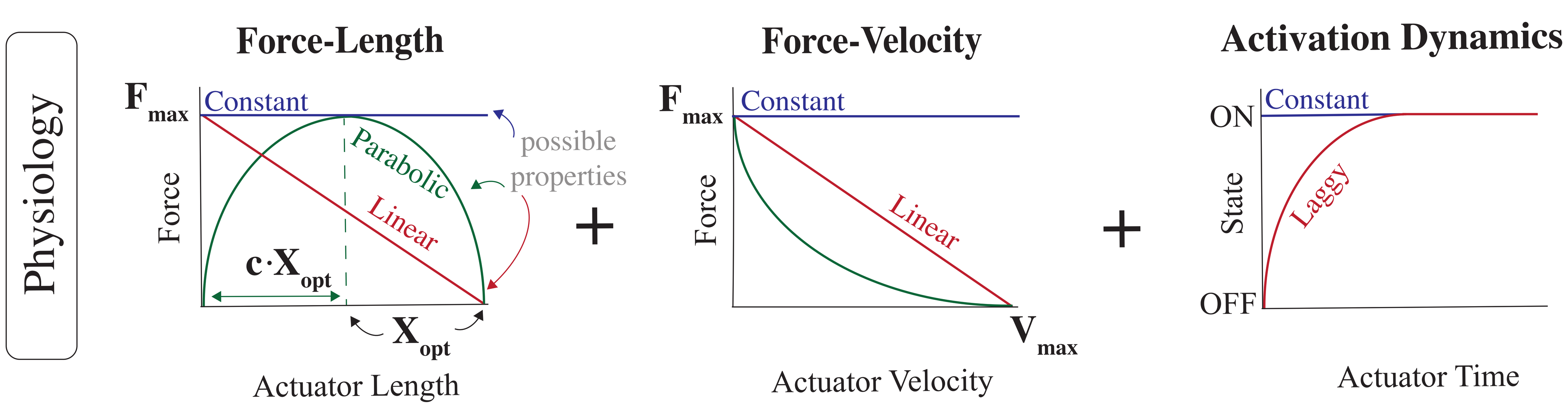
2. Study Design

a. Leg Actuator Model Design

We simulate models of different complexity by varying the morphological and physiological properties. We test morphological configurations that start from a simple point mass with un-segmented and massless legs to more complex morphologies with segmented legs and multiple joints .



The physiology of the force (F) that accelerates the COM upwards during the jump simulation has a combination of the following mechanical properties: Force-Length, Force-Velocity and Activation dynamics (based on known properties of muscles).

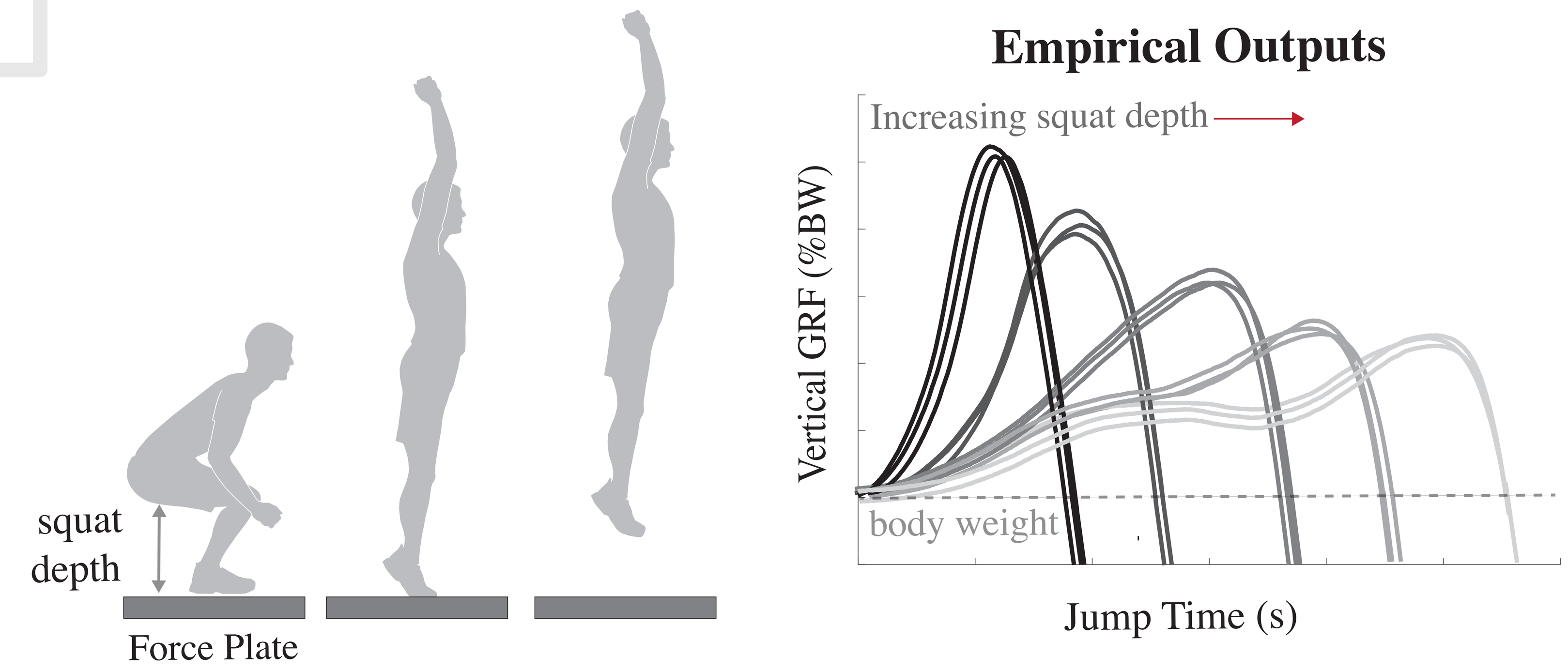


The number of unknown parameters can vary between models and at a most includes: maximum isometric force (**F_{max}**), maximum velocity (**V_{max}**), force-length parabolic width (**c**), and optimal operating length (**X_{opt}**). We evaluate the equations of motions of the morphology and combine that with the physiology to compare the model ground reaction forces to emprical data (see *c. Model Optimization*).

b. Empirical Data Collection

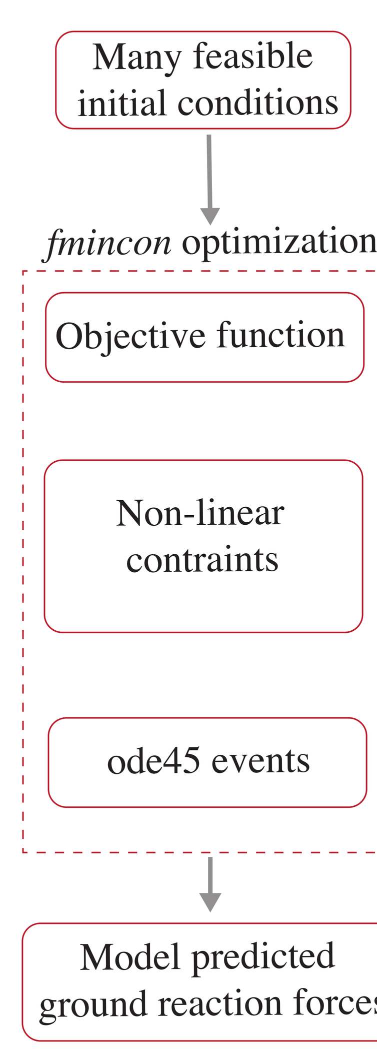
We collected ground reaction forces from a range of squat depths in order for people to employ a wide range of leg actuator forces, lengths, and velocities to which to fit into our models.

Subjects : n =10
Jump Type : Squat Jump
Trials : 30 jumps (at varied depths) + 20 jumps (at self-selected depth)
Instruction : Jump as high as you can

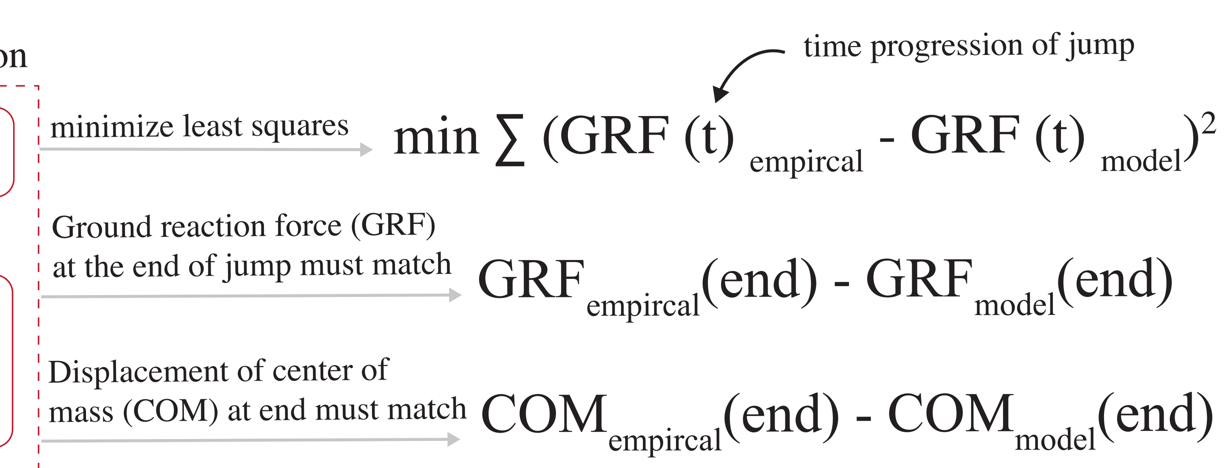


c. Model Optimization

For some models, we algebraically solve for the optimal unknown parameter(s) : **F_{max},V_{max},c, X_{opt}**. More complex models require us to solve for the best-fit unknown parameters by numerical optimization. We perform a constrained optimization using nonlinear programming implemented with MATLAB's optimization toolbox (*fmincon*, 2019a).



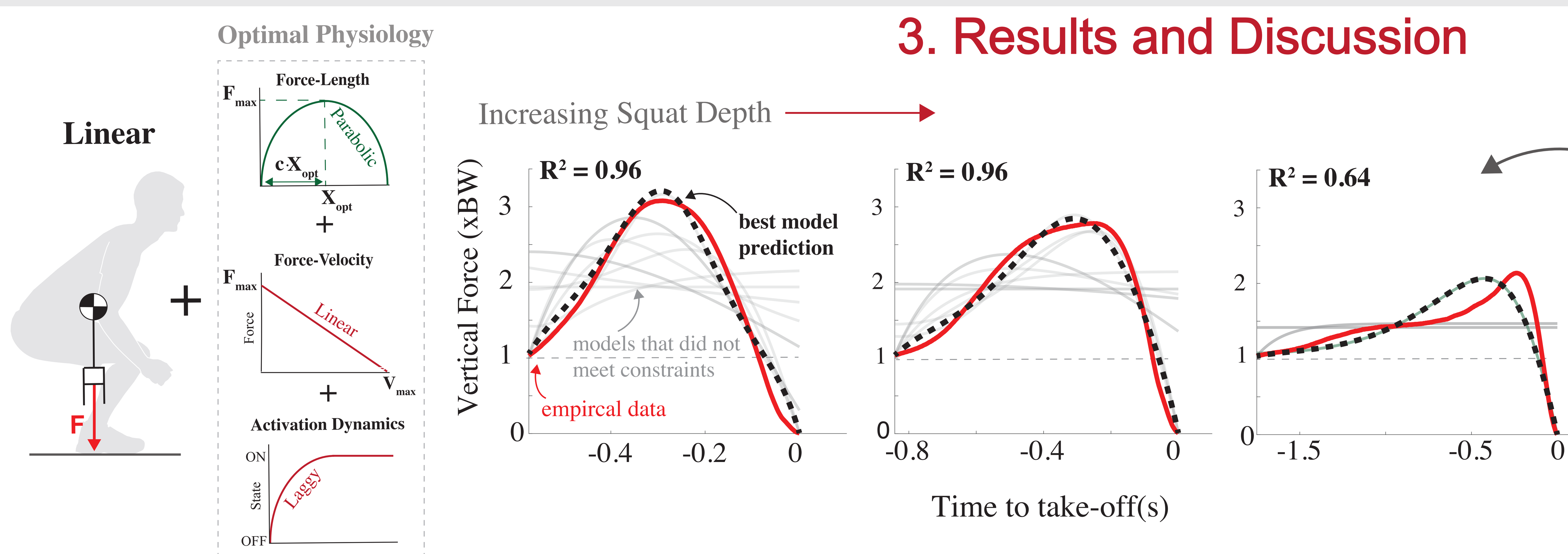
We start from many feasible initial conditions to gain confidence that we are converging on a solution that approaches the global optimum .



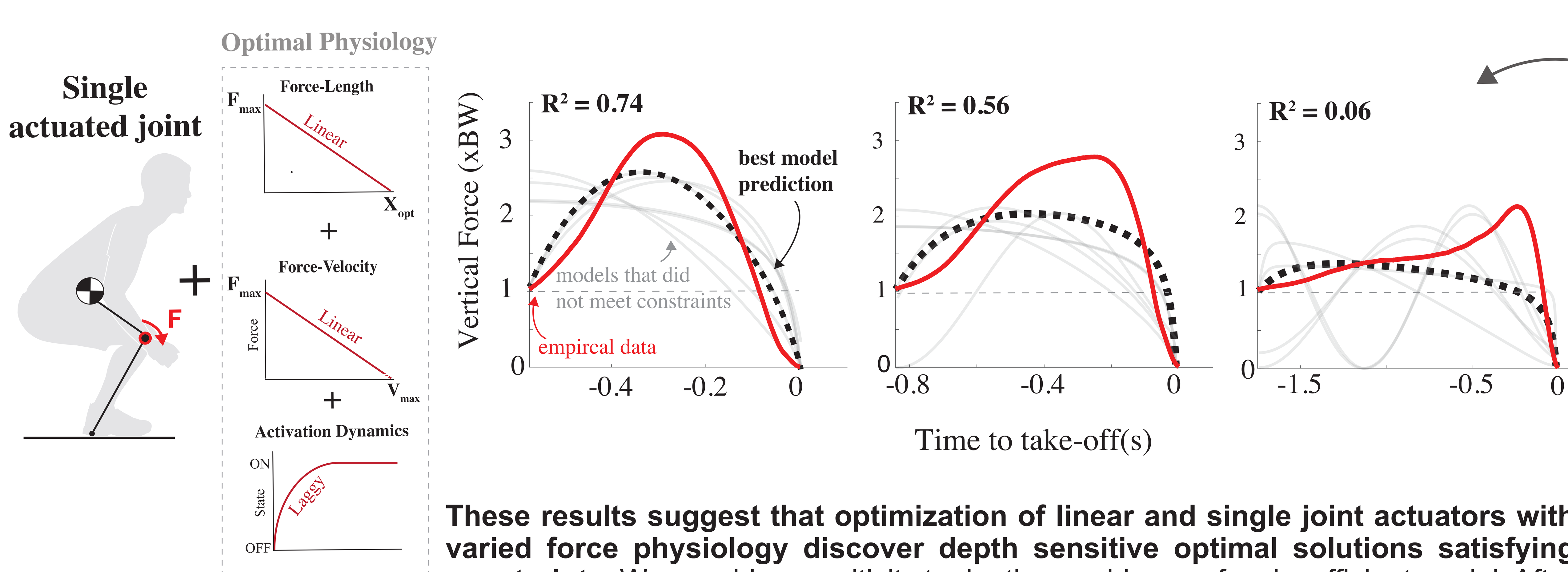
We set event detection in our differential equation solver (ode45) to terminate integration if a set of initial conditions drives the ground reaction force below zero.

Using the determined optimal set of unknown parameters we compare the vertical ground reaction force of the model to that of emprical data.

3. Results and Discussion



Although the linear model of the leg actuator well-predicted behavior, **the optimal parameters were depth dependent.** The reason for this is that for a linear actuator to meet our constraint that force is zero at the point of take-off, either the force-length or force-velocity characteristics must bring the force to zero. For most optimal solutions, we find that the width of the force-length parabola widens and contracts with depth in order for this constraint to be satisfied.



Preliminary results for the single actuated joint model suggest optimal parameters have a dependence to squat depth. We are currently running simulations from which we hope to gain more intuition too understand how morphology might play a role in depth independent solutions.

These results suggest that optimization of linear and single joint actuators with varied force physiology discover depth sensitive optimal solutions satisfying constraints. We consider sensitivity to depth as evidence of an insufficient model. After all, it is the same human jumping at both shallow and deep depths. Assembly of the multi actuated joint model is complete and simulations are currently underway.

References and Funding

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