USING MATHEMATICAL MODELS, VERTICAL JUMPING, AND EXOSKELETON ASSISTANCE TO UNDERSTAND THE LIMITS TO HUMAN AGILITY

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INTRODUCTION

Humans are remarkably agile. We can move at fast speeds while rapidly executing motor control strategies that redirect body motion and reposition limbs. Studying agile behaviour can help us to understand the neuromechanical mechanisms that enable it, as well as the factors that limit it.

Maximum height vertical jumping is a useful entry point for studying agility. Jumping to high heights, and to long distances, increases the available space over which we can navigate, and high performance in jumping likely correlates strongly with other aspects of agility, such as maximum sprint speeds. Furthermore, the performance criterion in vertical jumping is unambiguous—maximally accelerate the centre of mass [1]. During vertical jumping, the ability to develop a high impulse, and in turn the ability to reach maximum height is highly related to the maximal power produced [2]. However, people with the same peak maximal power can achieve different vertical jump heights [2]. These differences can be attributed to the differences in their muscle force-velocity (F-V) and force-length (F-L) relationships [3]. Muscle force generation properties appear to be one candidate mechanism for limiting human agility.

Our purpose is to understand how muscle force generation properties enable high vertical jumps, and how the dependence of muscle force on its length and velocity limits performance. To accomplish this, we first parameterize a mathematical model of vertical jumping using empirical experiments and system identification techniques (Figure 1). We then use these models to identify assistive devices that ameliorate muscle's hypothetical limits to jump performance, and to optimize their design. Finally, we will design, build and test these assistive devices on human subjects, providing a strict test of our new understanding of the limits to human agility.

METHODS

Our model (Figure 1) considers the legs as a massless actuator and the body as a point mass (m). The legs generate an upwards force (F) on the point mass, accelerating it according to:

$$\ddot{x} = \frac{F}{m} - g$$

where $\ddot{x}$ is the point mass vertical acceleration, and g is gravitational acceleration. The leg actuator has the following linear F-V relationship and parabolic F-L relationship:

$$F(\dot{x}) = F_{max} - \frac{F_{max}}{V_{max}}\dot{x}$$

$$F(x) = F_{max}(1 - (\frac{x - x_{opt}}{C \cdot x_{opt}})^2)$$

where the unknown actuator properties include maximal isometric actuator force (F_{max}), maximum shortening velocity (V_{max}), optimal operating length (x_{opt}) and a parameter determining the width of the F-L relationship (C). Substituting (2) and (3) in to (1) yields the following differential equation:

$$\ddot{x} = -g - \frac{(F_{max}(\frac{x_{opt}-x}{C\cdot x_{opt}})^2 - 1) - \frac{\dot{x}F_{max}((\frac{x_{opt}-x}{C\cdot x_{opt}})^2-1)}{V_{max}}}{m}$$

We can numerically integrate this equation to predict ground reaction force as well as center of mass position and velocity for a given set of actuator properties. The next step is to identify the actuator properties used by people. To accomplish this, we: 1) have people jump from a range of depths and carrying a range of masses in order for them to employ a wide range of muscle forces, lengths, and velocities, 2) use optimization to find the set of unknown actuator properties that result in model predictions of force, velocity and length that best match our measured values.

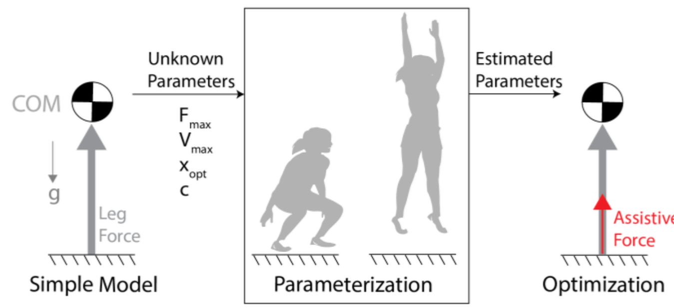

Figure 1: Conceptual model for jumping augmentation

Having identified a model that accurately predicts jumping mechanics, we will next test and design theoretical assistive devices to improve model jumping performance. The modeling results will help inform design principles for an exoskeleton that seeks to improve vertical jumping. We will test these assistive devices on human subjects. Our focus will be on designs that result in the maximal improvements and that are feasible to build.

RESULTS AND DISCUSSION

We have completed the initial modeling and have begun the first experiments on human subjects. We are currently developing our methods for identifying the unknown muscle properties from these empirical experiments.

REFERENCES

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