Pseudo-Elasticity and Kinetic Energy Storage: Definitions and Applications to Human Movement

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INTRODUCTION

Tasks such as throwing and jumping often have a short preliminary phase where movement is away from the target. Traditionally this countermovement is explained by one of four mechanisms: 1) elastic energy storage in soft tissue allows muscular work done in the countermovement to be stored and released, 2) stretch from the countermovement increases the muscle forces in the later movement through force potentiation, 3) because of activation delays, countermovement allows full activation at an earlier time in the forward movement, and 4) stretching muscles in countermovement leads to reflex stimulation and hence higher forces.

We present an alternative explanation for countermovement that depends on the multi-link nature of the body. The idea, that kinetic energy storage in some links can be used in a manner analogous to elastic energy storage, is foreshadowed in a sketch in [1] in the context of jumping, and is discussed in the context of throwing in [2].

Here, to make the point especially clear in the extreme, we show that a collection of links with no springs whatsoever can behave almost identically to a spring. The idea has long been known at the molecular level where rubber elasticity is explained by the entropic contributions of numerous identical links [3]. Here we show that macroscopic multi-link systems, with no a-priori statistical or thermal inputs, naturally behave as a spring, with the end-point motion putting work in and out of the links almost reversibly.

This multi-link example is not meant to be literally applied to macroscopic biomechanics, but rather gives a cartoon that may apply partially and approximately in normal throwing and jumping tasks.

METHODS

We simulated various multi-link systems that illustrate the ideas. One example is a simple multi-link 2D pendulum with the last link more massive than the others (Figure 1). When dropped from a typical static configuration the lower mass turns out to move as if it was connected to an appropriate nonlinear spring instead of collection of links (Figure 2). With more degrees of freedom (more links or 3D rather than 2D) the elasticity emulation becomes more accurate.

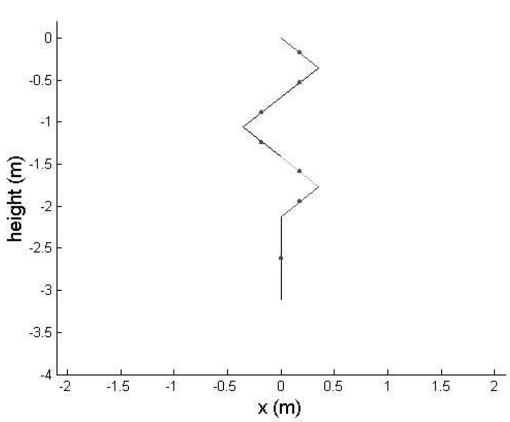

Figure 1: A 2D seven link pendulum with symmetric initial displacement. Gravity points down. The pendulum is anchored to the fixed frame at 0,0.

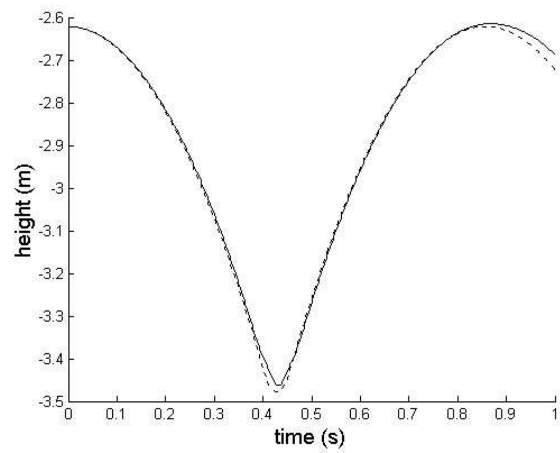

Figure 2: The height of the center of mass of the final link of a 2D seven-link pendulum (solid) and the position of a point mass on a spring in a gravity field (dotted).

RESULTS AND DISCUSSION

The relatively small number of links required to show this pseudo-elasticity, especially in 3D, suggests the relevance to human motions such as throwing and running.

In throwing, for example, it has long been known that kinetic energy transfer is important – the so-called "kinetic chain", but here we suggest that this kinetic energy transfer can act like a spring. From the point of view of the ball, the kinetic energy is stored in the arm and then returned to result in a faster, further, or more efficient throw. And, in detail, our model of throwing also illustrates the effect, although the spring analogy is somewhat disguised by the small number of links.

REFERENCES

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3. Noggle, J. *Physical Chemistry,* Harper-Collins, New York, NY.