

## IS EFFICIENCY A VIABLE CRITERION FOR SUB-MAXIMAL VERTICAL JUMPING?

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### INTRODUCTION

For the execution of a maximal vertical jump from stance, humans show a unique movement pattern. Over the past decades, researchers have tried to identify the criterion that generates the control signals for this. Through simulation studies it has been shown that a unique movement pattern most likely generates the maximal height achieved by the musculo-skeletal system [1]. In a recent study we found that for jumps towards a sub-maximal target height, humans also have stereotyped movement patterns across individuals [2]. These mainly consisted of decreasing countermovement amplitude for decreasing target heights. According to [2], this indicated that humans could minimize energy-consumption for a sub-maximal jump. Another possibility is that humans simply minimize the total duration of the jump. The purpose of this study was to test the hypothesis that one of these criteria causes the stereotype adaptations for sub-maximal jumping in humans. For this purpose, sub-maximal vertical jumps of a simulation model were generated and the movement patterns were compared with movement patterns observed in humans.

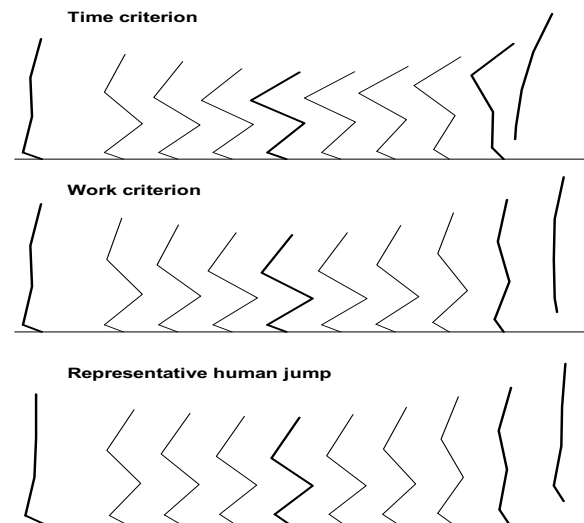
### METHODS

An existing 4-segment model with 6 muscle actuators [3] served to simulate countermovement vertical jumps from stance. The initial state of the model was an upright standing position. Switching the muscle actuators “off” and “on” controlled the movement of the model. Two different objective functions were used, one of which generated a given sub-maximal jump height in a minimum amount of time (= minimal time criterion) and the second achieving it with minimal work (= minimal work criterion). The latter criterion involved a rough estimate of energy consumption, counting both eccentric work and concentric muscle work in a ratio of 1:3. Jumps towards heights of 50-60-72-86-93-98-100% of maximal jump height were simulated.

Joint kinematics and kinetics were compared with those of human sub-maximal jumps. The experimental setup was described previously [2], and contained jumps towards heights of 25-50-75-100% of maximal jump height.

### RESULTS AND DISCUSSION

Optimizations with both the minimal time and minimal work criterion resulted in unique movement patterns for jumps to heights of 50%-100% of maximal jump height (75% example in figure 1). Both criteria led to similar movement patterns for jumps that were close to maximal jump height (90-100%). For lower jumps (50-90%), solutions of the minimal time criterion were different from those of the minimal work criterion in that



**Figure 1:** Stick figures showing simulations of minimal time and minimal work optimizations and a human jump for a vertical jump of approximately 75% of maximal jump height.

they led to incomplete joint extensions and excessive rotational and horizontal energies at toe off. Throughout all jump heights ranging from 50 to 100%, optimizations with the work criterion generated movement patterns that showed a greater resemblance with those of human jumps (representative example in figure 1). Typical adaptations were decreasing hip extension, slightly decreasing knee extension and constant ankle plantar flexion as jump height decreased.

### CONCLUSIONS

Solutions obtained with the minimal time criterion had poor correspondence with humans because of flexed joints, backward velocity and body rotation at take off. Solutions with the minimal work criterion, on the other hand, showed less countermovement in a sub-maximal jump than in a maximal jump and more extended joints and more vertical velocities at take off. This has good correspondence with human jumps and demonstrates that minimized energy-consumption is a viable criterion for sub-maximal jumping.

### REFERENCES

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3. Van Soest AJ & Bobbert MF, *Biol Cybern* **69**, 195-204, 1993.