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## Introduction

In human periodic bouncing, reflexes influence muscle activation. Performance of reflexes can be studied in simulations [1] and verified with robots. For imitating reflex driven hopping with robots necessary time and magnitude resolutions of activation patterns are unknown. The objective of this investigation was to analyse bouncing performance depending on activation pattern resolution in time and magnitude domain. The task is maximum height periodic hopping at 2 Hz.

## Methods

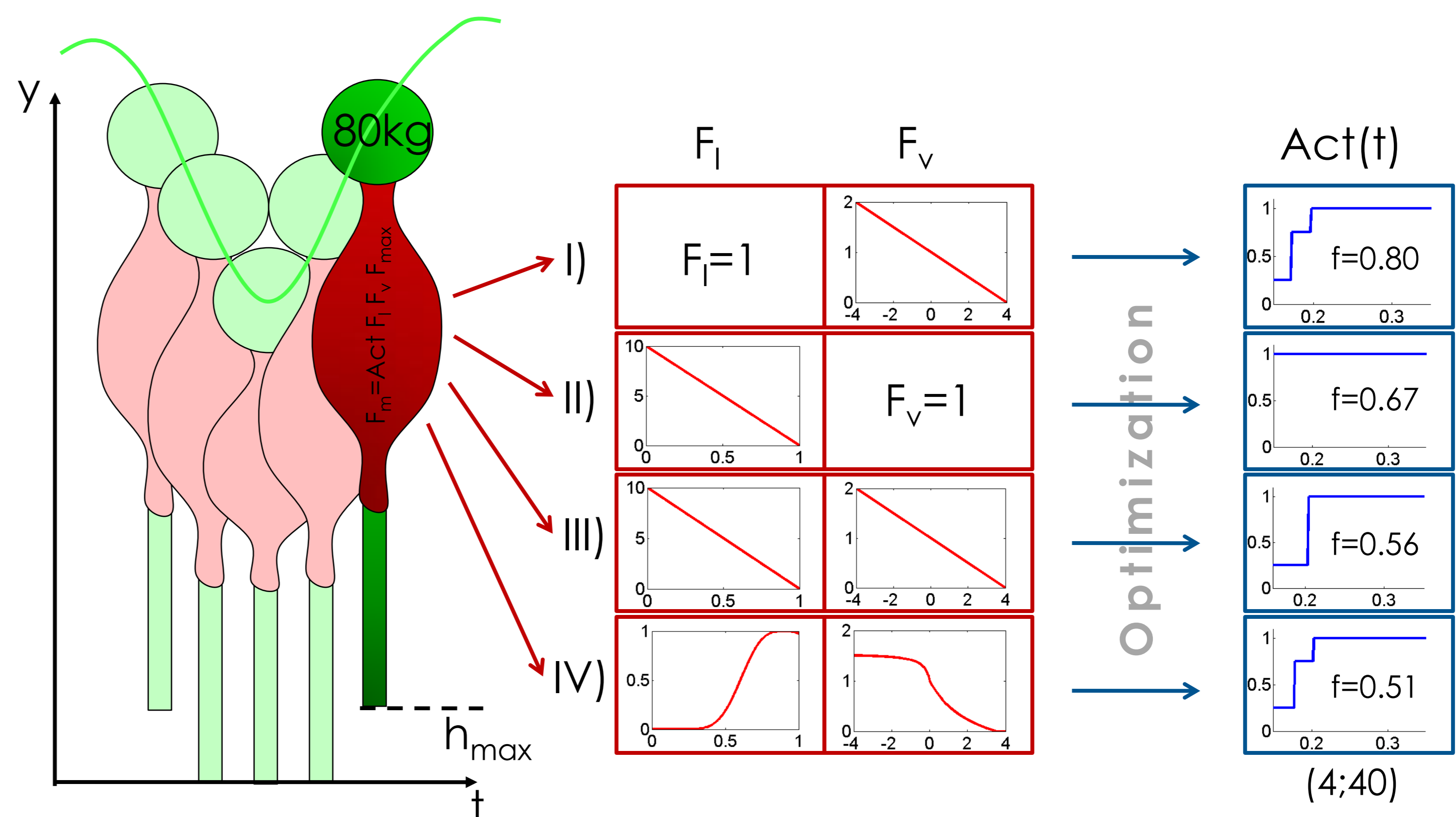
The Simulink model consists of a body, represented as a point mass and a simplified leg with one Hill-type muscle to counteract gravity in stance phase (fig.1):

$$m\ddot{y} = -mg + \{F_m\}_{y < y_0} \quad F_m = Act F_l F_v F_{max}$$

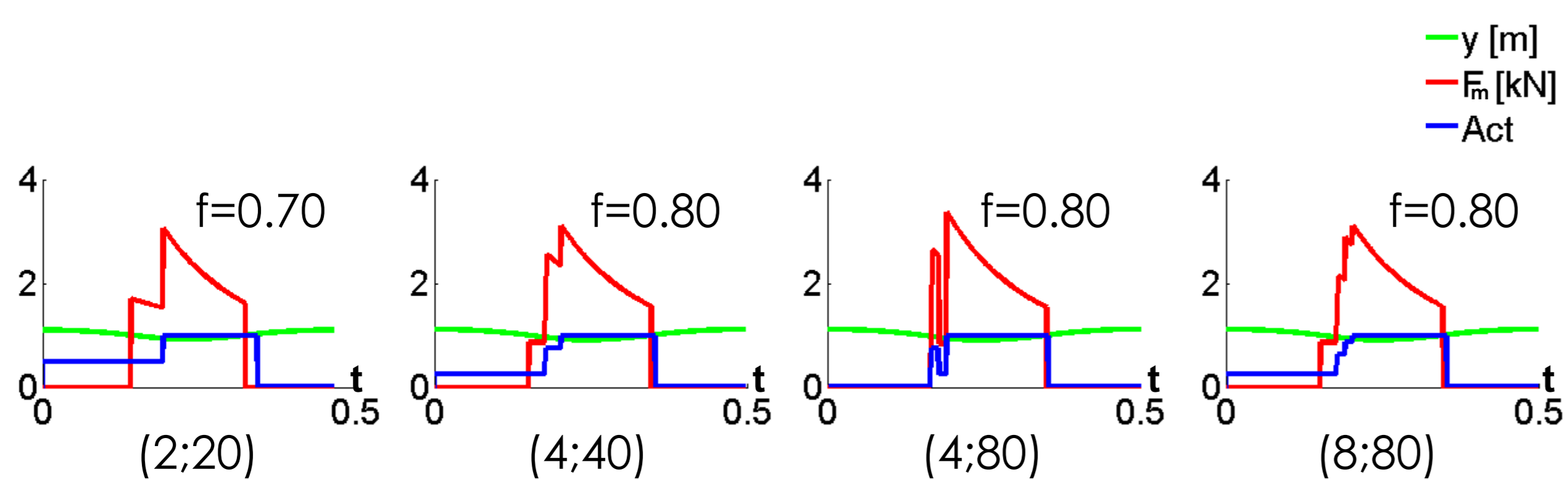
Activation pattern Act(t) time and magnitude resolutions were varied. Resolutions are specified as magnitude resolution [1]; time resolution [s<sup>-1</sup>]. For example (4;40) means 4 possible levels of activation at intervals of 1/40 sec. The pattern was optimized for maximum periodic hopping height at 2 Hz hopping frequency:

$$f_{fitness} = \frac{h_{max} \{2(1-t(y_2))\}_{t(y_2) > 0.5sec}}{f_{theor.maximum}}$$

Theoretical maximum fitness  $f_{tm} = 0.1445$  m. Optimization was done with an evolutionary optimization algorithm [2].



**Figure 1:** Model with different force-length and force-velocity relations. All components are normalized to  $F_{max}$ . Increasing complexity of the muscle from linear (I II and III) to Hill-type muscle (IV). Optimization of Act(t) results in different patterns. Example patterns are shown for Act(t) resolution (4;20) from touch down to take off.



**Figure 2:** Different Act(t) resolutions for muscle type (I). With increasing resolution the maximum fitness  $f$  increases. For resolutions higher than (4;40) the gain in fitness is < 1%

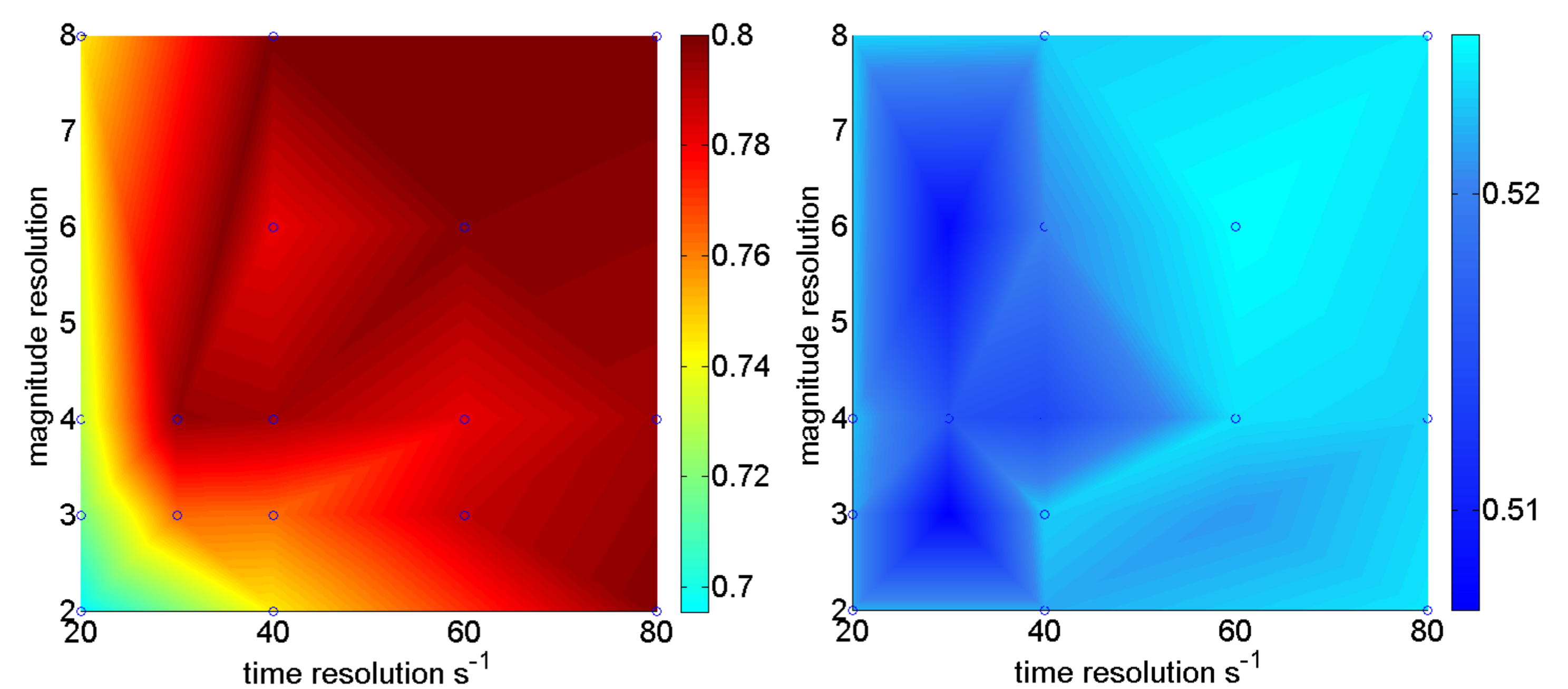
## Results

An activation pattern resolution of (4;30) (4 levels of magnitude and 1/30s<sup>-1</sup>) is sufficient to get within 1% of the maximum performance of the model type (I).

For (II) ongoing maximum activation Act(t)=1 gives maximum performance. This can be achieved by any resolution.

Increasing the resolution for (III) and (IV) resulted in <4% and <2% improvement.

The different levels of complexity for the muscle model resulted in a reduction of maximum performance. (IV) can only reach <55% of the theoretical maximum  $f_{tm}$ .



**Figure 3:** Performance dependent on the Act(t) resolution (time x-axis, magnitude y-axis). a) for muscle type (I) higher resolution increased performance by 10%. b) for muscle type (IV) improvement was < 2%.

## Discussion

Central pattern generators for human and robotic bouncing tasks do not need a high resolution.

Evolutionary optimization leads to two different activation strategies: with no damping or friction (II) Act == 1 is the optimal solution. If damping occurs (I, III and IV) less Act in the beginning allows longer stance phase and more time for acceleration before take off and therefore higher performance.