LOCAL FEEDBACK MECHANISMS FOR STABLE BOUNCING

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INTRODUCTION

Most studies addressing local feedback mechanisms are focused on posture and walking (Orlovsky et al. 1999), but only little is known about their role in fast locomotion.
Fast periodic movements like hopping and running are characterized by an almost sinusoidal shape of the ground reaction force with its maximum approximately at half contact time. This global feature of leg operation can be described by a simple spring-mass template (Blickhan, 1989) and has been successfully applied to predictions of experimental results. But it remains unclear, how this behavior is generated by the biomechanical system on the muscle-skeleton level.
We investigate to what extent local muscle reflex loops can suitably adapt the dynamic properties of muscle actuators to result in spring-like behavior on the global leg level.

METHODS

A three-segment model using Hill-type muscles is equipped with sensory feedback pathways to analyze the contribution of simple, single loop muscle reflexes to the generation of spring-like leg operation during fast periodic movements.
Each proprioceptive reflex pathway transmits only one of three possible signals from the muscle receptors: muscle fiber length or velocity from the muscle spindles, and muscle force from the Golgi tendon organ (representing Ia, II and Ib afferences, respectively). The signals are applied either as positive or negative feedbacks. Multiple reflex signals affecting one muscle are summed.
The excitation-contraction coupling, delaying the muscle activation behind its neural stimulation, links proprioceptive signals to muscle force production. For each muscle a stimulation bias is considered.
The control parameters - feedback time delay and signal gain for each reflex pathway and stimulation bias for each muscle - are mapped to find an optimal adjustment for a stable periodic hopping pattern.

CURRENT RESULTS AND DISCUSSION

So far the model contains two Hill-type muscles: knee and ankle extensor. Without reflexes, the muscle stimulation must be centrally adapted to result in periodic hopping.
With a constant stimulation bias, i.e. lacking a central signal adaptation, the model leg can be tuned to operate spring-like, if both muscles are governed by separate positive force feedbacks (Fig. 1). The movement pattern is robust with respect to changes in ground level.
This result coincides with former model investigations using a two-segment system including one Hill-type extensor muscle (Geyer et al. 2001) and suggests that positive muscle force feedback could be a powerful and fast mechanism to facilitate spring-like leg behavior in periodic movements.
However, in comparison to the system without feedbacks, the inner leg stability is not clearly improved using the separate force feedbacks. The system still tends to destabilize as predicted for a mechanical three-segment system (Seyfarth et al. 2001), if the muscle or feedback parameters are altered.
With a special focus on muscle reflexes, the goal of further investigations is to find the minimal neuromuscular architecture, which provides both spring-like leg behavior and inner leg stability in fast bouncing tasks.

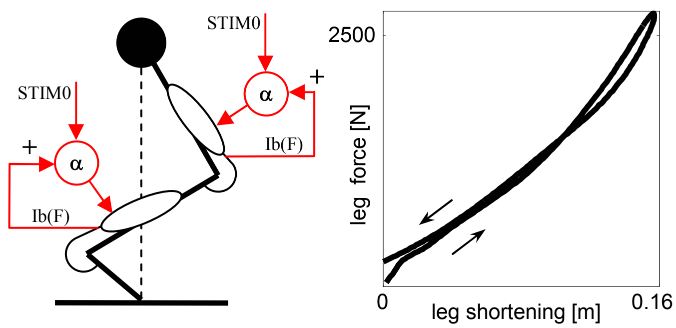

Figure 1: Spring-like leg behavior in hopping using separate positive force feedbacks ($Ib(F)^+$). The three-segment model is equipped with knee and ankle extensor muscles. The feedback motor commands are not influenced by central adaptations during stance (STIM0 = const).

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