

Analysis of positive feedback in the control of movement

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ABSTRACT

Over the past three decades, neurophysiologists studying the neural circuitry responsible for control of skeletal muscles have developed several different general theories of sensorimotor control. These have usually invoked one or more of the sources of proprioceptive signals (e.g. muscle spindle and Golgi tendon organ afferents) in positive or negative feedback loops to the homonymous alpha motoneurons. In this paper we consider to analyze the role of positive feedback in combination of negative feedback due to important role of them in stabilizing the neuromuscular system.

Keywords: Positive Feedback; Negative Feedback; Hill Model; Reflex Model

1. INTRODUCTION

The stretch reflex differs in decerebrate and intact animals and since Sherrington's time it has come to be realized that several CNS mechanisms may contribute components of different latency to the stretch reflex response. At the segmental level, muscle spindle Ia afferents activated by muscle lengthening monosynaptically excite homonymous alpha motoneurons which in turn cause the muscle to resist the stretch. In static postures Ib input generally results in homonymous inhibition, but it has been shown that this switches to longer-latency homonymous excitation during locomotion [1], at least in cat extensor muscles. Group II input from muscle spindles has also been implicated in long latency components of stretch reflexes [2,3,4]. Ia homonymous excitation represents negative displacement feedback, which augments the intrinsic stiffness of active muscles in the face of length perturbations. Ib homonymous feedback on the other hand represents positive force feedback. Positive feedback is synonymous with instability and oscillation in engineering systems, but when muscles are the actuators; their nonlinear length-tension properties turn out to stabilize the positive feedback loop [5].

2. INTERACTIONS BETWEEN POSITIVE AND NEGATIVE FEEDBACK

According to linear systems theory, positive feedback loops alone produce instability, while negative loops alone may require very high gains to be useful. The general advantage of combining positive and negative feedback loops is that it reduces the sensitivity of system response to unpredictable variations in any of its components, for example, fatiguing of a muscle or increase of a mechanical load [5], without requiring excessive negative feedback gains.

On the other hand, Prochazka [6] demonstrated that positive force feedback could also perform this role assisted by negative length feedback.

Positive force feedback through group Ib afferents may work in parallel to the positive length feedback through the loop and/or group II afferent modulation of activity [7,8]. In the case of Ib force feedback, the loop is polysynaptic so that transmission through it is state dependent. One possible advantage of loops is that they influence and motoneurons monosynaptically [6].

In current research we analyzed the role of positive feedback in combination of negative feedback due to important role of them in stabilizing the neuromuscular system. We used a simple reflex model to show the behaviors of neuromuscular system. Whole of these models were done using MATLAB software.

2.1. Reflex Model

Figure 1 shows a highly simplified model of a reflex system. In this model, key elements of real neuromuscular systems such as tendon compliance, dynamic transfer functions of sensor, and length and velocity dependence of muscle force production are omitted or simplified. The load in this model is a mass of 1 kg.

In this model, muscle force is modeled by a first-order active component and a viscoelastic parallel stiffness. The force velocity relationship [9,10], the muscle length tension curve and tendon compliance are all neglected. 12 are used to represent the image obtained by limb leads.

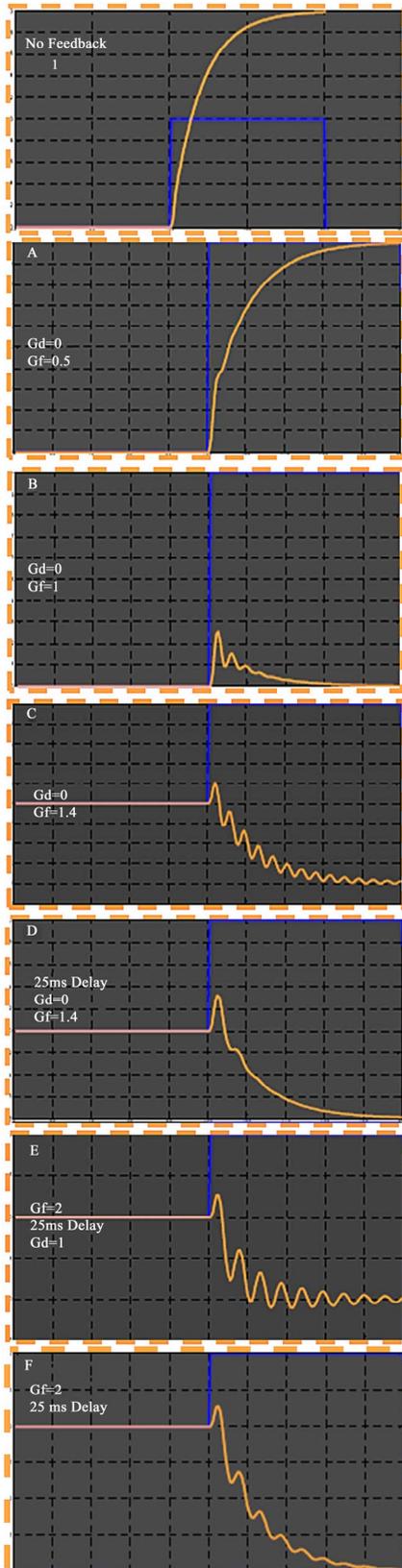


Figure 2. Simulations based on static reflex model of Figure 1.

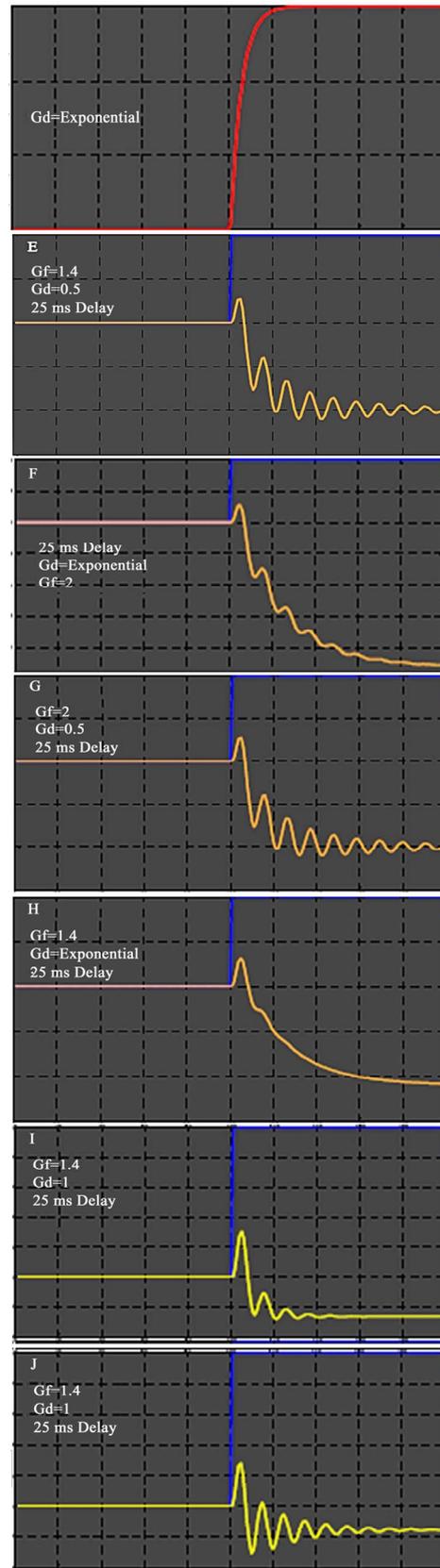


Figure 3. Exponential displacement feedback.

isometric frequency response characteristic of cat triceps surae muscles of Rosenthal that positive force feedback may be appropriate in some *et al.* 1970. A mass of 1 kg represents the inertial load borne by a cat hind limb. A force increment of 10 N represents the mean force developed by triceps surae during the stance phase of slow gait [11]. Inherent muscle properties are simplified to a linear viscoelastic element with a stiffness of 0.5 N/mm. The force feedback and displacement feedback signals are represented without dynamics. It was clear that the reflex mechanism in question represented positive feedback and this was normally associated with instability. It was tacitly assumed that the nervous system would somehow always limit positive force feedback gain within a range consistent with stability. Our results suggest that a combination of intrinsic muscle properties, concomitant negative displacement feedback, and reflex delays found in neuromuscular may provide this automatic gain control.

Our experiments and analysis verify that positive force feedback in the neuromuscular system can provide stable and effective load compensation. The analysis also shows that the conclusions regarding the stabilizing influence of muscle intrinsic properties, length feedback, and delays in positive feedback pathways were robust in the face of large parametric and structural variations in the systems considered. Stable behavior for large values of positive feedback gains was unexpected and initially quite puzzling. However, it became apparent that loop gain did not remain high, but rather it was automatically attenuated when muscles shortened and thereby reduced their force producing capability.

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