AN INTERMITTENT EP-MODEL FOR FAST POINT-TO-POINT MOVEMENTS

Dinant Kistemaker, Knoek van Soest and Maarten Bobbert
Institute for Fundamental and Clinical Human Movement Sciences,
Vrije Universiteit, Amsterdam, The Netherlands; e mail: d.kistemaker@fbw.vu.nl.

INTRODUCTION

It has been widely acknowledged that the visco-elastic properties of muscles are beneficial to the control of posture and movement. An important class of control models that exploit these properties are equilibrium point (EP) models. Extensions of EP-models for fast point-to-point movements (e.g., co-contraction and 'virtual' trajectories) have been proposed to overcome limitations in terms of movement speed. Unfortunately, EP-models and their extensions have often been tested with models that lack a realistic description of the (dynamic) behavior of the muscle-tendon complex. The purpose of this study was to investigate whether EP-models can account for experimentally observed fast single-joint point-to-point movements [1], without making use of 'virtual' trajectories. To this end, we used an arm model with muscle models that reproduced the salient dynamical properties of muscles. We also examined intermittent control as a neurophysiologically plausible method to increase maximal movement speed.

METHODS

The 2D model of the arm (Fig. 1) was actuated by four Hill-type muscles consisting of a contractile element (CE), a series elastic element (SE) and a parallel elastic element (PE). Activation dynamics was modeled to describe the relation between muscle stimulation ($STIM$) and active state. Feedback of contractile element length (l_{CE}) and contraction velocity (v_{CE}) was linear, and a 25 ms time delay (denoted by δ) in the feedback loop was adopted using a fifth-order Padé approximation.

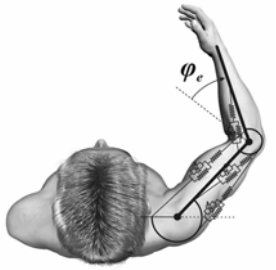

Figure 1. Schematic drawing of the arm model. φ_e = elbow angle (extension positive).

The desired trajectories were based on experimental data of Gottlieb (1998) and covered 100^0 in 0.2 s (Fig.2E). In accordance with the experiments, the model was constrained to move in the elbow joint only. The musculoskeletal model was respectively driven by an α-controller:

$$STIM = STIM_{open}$$

a λ-controller:

$$STIM = k_p[\lambda - l_{CE}(t-\delta)] + k_d[-v_{CE}(t-\delta)]$$

and a hybrid EP-controller:

$$STIM = STIM_{open} + k_p[\lambda - l_{CE}(t-\delta)] + k_d[\dot{\lambda} - v_{CE}(t-\delta)]$$

In these controllers, $STIM_{open}$ was the open-loop muscle stimulation that created a stable EP with maximal stiffness. Stiffness was calculated using a linearization of the model in an equilibrium point. k_p and k_d are feedback gains and λ and $\dot{\lambda}$ denote desired l_{CE} and v_{CE}. In the intermittent controllers $STIM_{open}$, λ and $\dot{\lambda}$ were updated with a frequency of 10 Hz.

RESULTS AND DISCUSSION

All implemented EP-models gained maximal movement speed when control signals were sent out intermittently. The implementation of intermittent control was based on experimental studies indicating that humans control their movements with a frequency of 6-10Hz. Maximal movement speed of the α-controller depended on the stiffness in the EP that was set. The stiffness produced by the present model was in accordance with values reported in the literature. Although $STIM_{open}$ was chosen such that it maximized stiffness, the α-controller was not capable of producing fast movements as observed by Gottlieb (1998). The λ-controller was also incapable of generating sufficiently fast movements, because time delays imposed limits on feedback gains to prevent stability problems.

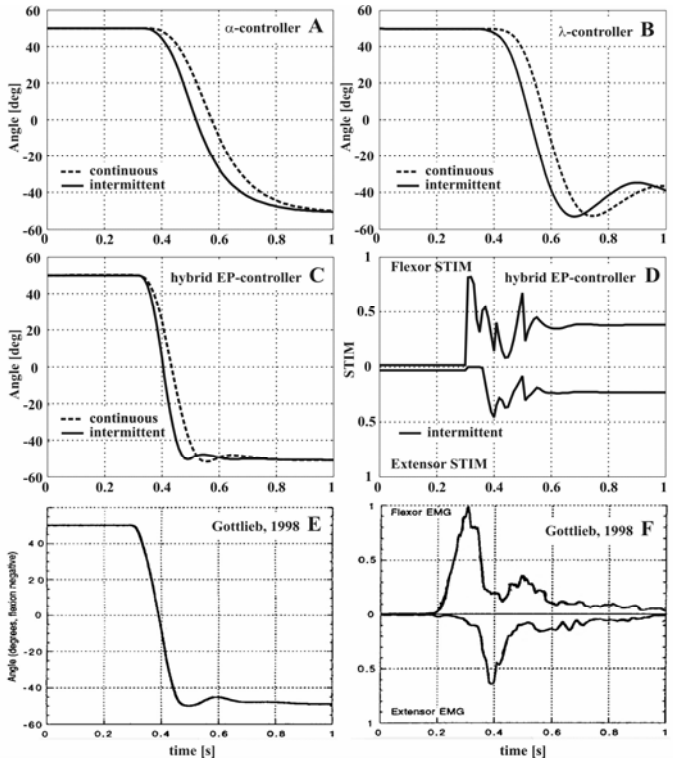

Figure 2. Experimental data of Gottlieb (1998) and model simulations with the three different EP-controllers.

The hybrid EP-model was able to accurately reproduce fast movements as observed experimentally [1], albeit only when control signals were sent out intermittently (Fig. 2C). Furthermore, this model showed a stimulation pattern (Fig. 2D) that resembled the observed tri-phasic EMG pattern, indicating that this pattern does not need to be pre-programmed.

REFERENCES

1. Gottlieb GL. *J Neurophysiol*. 80, 1860-7, 1998.