

# CHANGES IN THE POSTURAL CONTROL SYSTEM FOLLOWING LOCALIZED MUSCLE FATIGUE: A TIME-DELAYED STABILITY ANALYSIS

Bradley S Davidson, Michael L Madigan, and Maury A Nussbaum

Virginia Polytechnic and State University, Blacksburg, VA, USA

E-mail: [bsd@vt.edu](mailto:bsd@vt.edu), Web: [www.biomechanics.esm.vt.edu](http://www.biomechanics.esm.vt.edu)

## INTRODUCTION

Despite the growing support for localized muscle fatigue (LMF) increasing postural sway (Gribble and Hertel 2004), the mechanism behind this increase in sway remains unclear. Some have speculated that LMF introduces inaccuracies in proprioceptive feedback (Lundin et al. 1993). It is also possible that LMF elicits changes in the postural control system itself. Therefore, the purpose of this study was to develop a feedback-controlled model of the postural control system that accurately reproduces body kinematics during small postural perturbations, and investigate changes in gain parameters and time-delay stability with LMF.

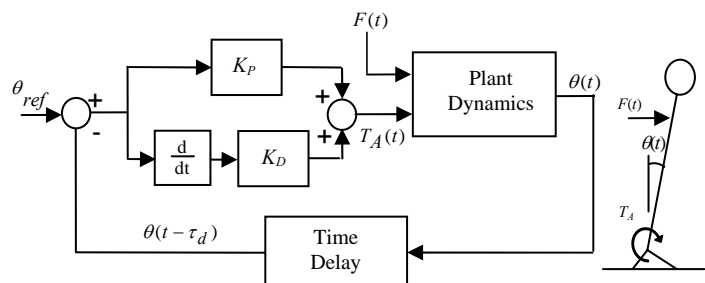
## METHODS

Participants included 16 older ( $62.2 \pm 5.1$ ) and 16 younger ( $19.4 \pm 1.4$ ) adults. During the experimental session, small magnitude postural perturbations were administered before and after fatiguing the lumbar extensor muscles.

Padded ballistic pendulums were used to administer five randomly-timed gentle forward perturbations (6 N·s) at the inferior margin of the scapulae. During the perturbations, participants stood with feet together and eyes closed, with hands clasped behind their back. Following an initial set of unfatigued perturbations, the lumbar extensors were fatigued to 70% of the unfatigued maximum voluntary contraction with repeated isotonic contractions

(Davidson et al. 2004). Immediately after the exercise, a series of five fatigued perturbations were administered in the same manner as before the exercise. Kinematics during response to perturbations were recorded using reflective markers.

A feedback-controlled dynamic model of upright stance was created to simulate the experimentally recorded data. The 2-D model consisted of an inertially correct body segment with passive ankle stiffness and damping. Input to the model was the experimentally recorded pendulum force,  $F(t)$ , and the controlling ankle torque,  $T_A(t)$ , was composed of time-invariant proportional and differential feedback gains operating on the time-delayed state. An arbitrary reference angle was included to simulate the naturally occurring forward lean (Figure 1).



**Figure 1:** Schematic and free body diagram of controlled dynamic system

The linearized time-delayed equations of motion in 1<sup>st</sup> order form are given as:

$$\dot{x}(t) = A_0 x(t) + A_1 x(t - \tau_d) + (g + bF(t))$$

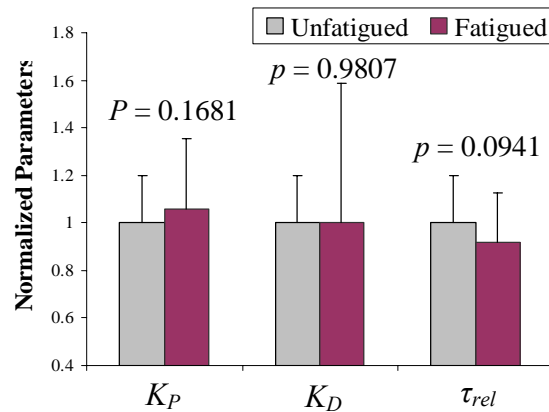
where  $x$  is the state vector,  $(g + bF(t))$  is a vector containing the constant and transient torques due to pendulum force and body mass, and  $A_0$  and  $A_1$  represent the non-delayed and delayed state matrices, respectively. Simulations began at the instant of pendulum contact using the recorded initial conditions, and continued for two seconds.

After determining system parameters, system stability was quantified by the delay margin (the maximum time-delay a system can encounter before it becomes unstable). In short, the delay margin was calculated with a frequency-sweeping method (Gu et al. 2003) that solves the generalized eigenvalue problem containing the non-delayed and delayed state matrices from above. The delay margin of the system relative to the identified time-delay was calculated. A two-way repeated measures analysis was used to test for effects of LMF and age on  $K_P$ ,  $K_D$ , and  $\tau_{rel}$ .

## RESULTS AND DISCUSSION

In general, the parameterized simulations performed well in modeling the experimental data ( $R^2=0.823\pm 0.154$ ). Statistical analysis revealed no significant ( $p < 0.05$ ) changes with LMF or age (Figure 2). However, the differential gain,  $K_D$ , demonstrated a trend towards a significant age effect ( $p=0.0808$ ). These differences in age are consistent with findings with respect to quiet stance (Maurer and Peterka, 2005).

One other important trend occurred in the relative delay margin,  $\tau_{rel}$ , with LMF ( $p=0.0941$ ). Following the fatiguing exercises, mean  $\tau_{rel}$  decreased from 398 to 365 msec (8.3%). A decreasing delay margin indicates a diminishing region of stability with respect to time-delay. LMF did not produce an unstable postural control



**Figure 2:** Plot of variables with LMF

system. Instead, these results imply that the fatigued system is less robust to noise, inaccurate or conflicting afferent information, and other sources of variance.

## CONCLUSIONS

In summary, a feedback-controlled dynamic model was created that can accurately simulate the response to small perturbations to upright stance. This model was used to identify postural control gains, and was combined with a novel time-delayed stability analysis to identify possible LMF-induced changes in postural stability.

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