Exploring the impulse response of the postural control system

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INTRODUCTION

- This study investigated the postural sway response to an impulsive perturbation and relative stability of the postural control system.
- Although most losses of balance result from a sudden disturbance, the majority of studies examining the response to continuous perturbations (e.g., [1,2]).
- Therefore, we explored the response to an impulse perturbation (i.e., a mild backward impulse force applied to the pelvis).

METHODS

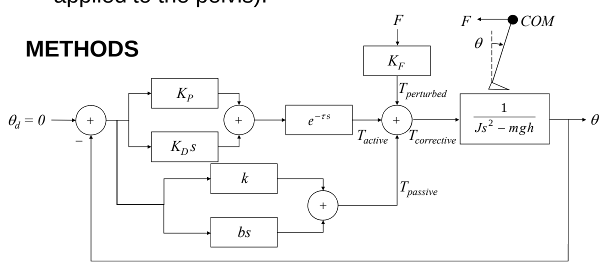


Figure 1. *The perturbed postural control system was modeled as a single-link inverted pendulum modulated by a time-delayed proportional-derivative controller with parameters (K_p, K_d, τ), passive spring-damper compensator (k, b), and unity feedback representing the sensory system.*

- The sensitivity function describes how sensitive a system is to small perturbations; larger values indicate reduced robustness or decreased relative stability.
- Relative stability of the modeled system was quantified by the maximum of the sensitivity function (*MaxSens*).
- Transfer function (TF) and sensitivity function (S) were defined as follows

$$\theta = TF(s)\theta_d + S(s)F$$

$$TF(s) = \frac{(K_P + K_D s)e^{-\tau s} + k + bs}{Js^2 + bs + k - mgh + (K_P + K_D s)e^{-\tau s}}$$

$$S(s) = \frac{K_F}{Js^2 + bs + k - mgh + (K_P + K_D s)e^{-\tau s}}$$

Frequency response function

- Frequency response function was experimentally calculated as

$$H(j\omega) = \frac{G_{F\theta}(j\omega)}{G_{FF}(j\omega)}$$

where $G_{F\theta}(j\omega)$ is auto power spectra of F, and $G_{FF}(j\omega)$ is cross power spectra of F and θ.

Determination of COM from force plate data

- The gravity-line projection method [3] was modified to derive horizontal COM displacement from AP force and COP data. The lean angle of the COM (θ) was then computed.

Model parameters

- K_P (proportional gain), K_D (derivative gain), τ (time delay), k (muscle stiffness), b (muscle damping), and $MaxSens$ were examined to explore impulse response and assess relative stability of the postural control system.

Optimization

- The model parameters were estimated such that the sensitivity function was fit to the frequency response function by minimizing cost function, $Error$, defined as

$$Error = \sum \frac{|S(j\omega) - H(j\omega)|}{|S(j\omega)|}$$

Experimental assessment

- To assess the efficacy of this model and sensitivity metric for quantifying relative stability, we examined experimental data collected from three groups of healthy adults (young, middle, and old).

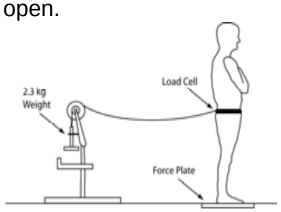
Subjects

Table 1. *Subject demographics, mean (SD), for young adults (YA), middle-aged adults (MA), and older adults (OA).*

Parameter	YA n = 10	MA n = 10	OA n = 10
Females	5	5	6
Mean age (y)	22.4 (3.1)	47.1 (3.8)	75.6 (2.6)
Age Range (y)	20 - 30	42 - 53	71 - 79

Experimental Protocol

- Twenty randomized trials were conducted: 10 quiet-standing trials and 10 perturbed trials, all 30 s in duration.
- The subject was instructed to maintain a quiet, upright posture throughout the recording.
- The subject stood with arms crossed at the chest and eyes open.



During perturbed trials, the weight was released, causing a brief mild tug. During quiet-stance trials, no action was taken. Ground reaction force and COP were recorded with a force plate (AMTI, BP600900). Tug force was recorded with a load cell (PCB Piezotronics, 208C02). Both sampled at 1000 Hz.

Figure 2. *Experimental setup*

RESULTS

Table 2. *Mean (SD) model parameters. * ANOVA results for comparison by age group.*

Parameter	YA	MA	OA	*p*-value*
Peak Force (lb)	6.54 (0.48)	6.75 (0.70)	6.40 (1.29)	0.68
K_p (N·m/rad)	1232 (222)	1306 (321)	1075 (294)	0.19
K_d (N·m·s/rad)	382 (89)	432 (75)	395 (138)	0.54
τ (ms)	149 (39)	148 (55)	141 (33)	0.91
k (N.m/rad)	134 (121)	147 (124)	11 (34)	0.01
b (N.m.s/rad)	40 (41)	37 (29)	4 (8)	0.02
MaxSens (dB)	-53.6 (2.6)	-54.6 (2.9)	-50.9 (3.4)	0.02

SUMMARY

- *MaxSens* was significantly larger for older adults than young or middle-aged adults suggesting that OA are closer to the point of instability.
- The sensitivity function appears to be a useful parameter for examining stability of the postural control system.

References:

[1] A. Ishida et al. *IEEE Trans Biomed Eng* 44: 331-336, 1997.
[2] R. Johansson et al. *IEEE Trans Biomed Eng* 35: 858-869, 1988.
[3] V.M. Zatsiorsky and M. Duarte. *Motor Control* 4: 185-200, 2000.

Acknowledgements:

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