EXPLORING THE IMPULSE RESPONSE OF THE POSTURAL CONTROL SYSTEM

Pilwon Hur, Brett A. Duiser, Elizabeth T. Hsiao-Wecksler

University of Illinois at Urbana-Champaign, Urbana, IL, USA
Email: ethw@uiuc.edu   Web: mechse.uiuc.edu/research/ethw

INTRODUCTIONS

Investigating how individuals respond to disturbances to balance is essential to improving our understanding of the etiology of falls. We were particularly interested in the response of the postural control system after a transient perturbation. Previous studies of dynamic postural control have focused mainly on using persistent perturbations, such as continuous translations or rotations of a moving platform (e.g., Ishida, 1997). However, real-life loss of balance is sudden, such as a slip while walking or a bump while standing on a bus. Therefore, it is important to understand how balance and postural control mechanisms are utilized in response to unexpected and transitory disturbances. While impulse response and its associated characteristics are rudimentary concepts in engineering control theory, these issues have not been explored from a rigorous controls perspective in the postural control literature. In this investigation, the impulse loading and impulse response control-theory paradigm were used to examine the postural response to a mild, quick-release tug at the pelvis.

METHOD

Subjects

Thirty healthy adult subjects divided into three age groups (n=10 per group) were each tested during a single session. Age groups were young adults (20-30 years, YA), middle-aged adults (42-53 years, MA), and older adults (71-79 years, OA).

Experimental Protocol

Twenty randomized trials were conducted: 10 quiet standing trials and 10 perturbed trials, all 30s in duration. The subject was instructed to maintain a quiet, upright posture throughout the recording. The subject stood on a force plate (AMTI, BP600900) with arms crossed at the chest and eyes open (Fig. 1). During perturbed trials, the weight was released, causing a brief mild tug. During quiet-stance trials, no action was taken. Anterior-posterior (AP) ground reaction forces and center of pressure (COP) data were recorded. Tug force was recorded with a load cell (PCB Piezotronics, 208C02). Data were sampled at 1000 Hz.

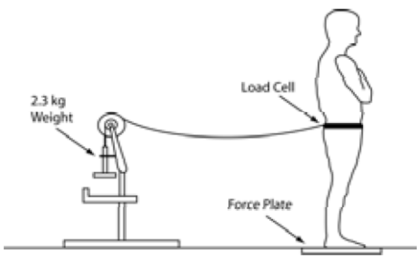

Fig. 1. Experimental setup.

Data Processing

From the perturbed trials, descriptive parameters of the AP COP, such as the maximum posterior displacement (*MaxDisp*), max displacement normalized by body weight, tug force and tug height (*NormMaxDisp*), difference between max and min displacements (*Range*), and time from peak tug force to MaxDisp (*Latency*) were calculated.

To further examine the postural control system impulse response, spectral analysis system identification (Peterka, 2002) was used to develop a model of the perturbed postural control system as a single-link inverted pendulum modulated by active and passive torques generated by a time-delayed proportional-derivative controller and a spring-damper compensator at the ankle (Fig. 2).

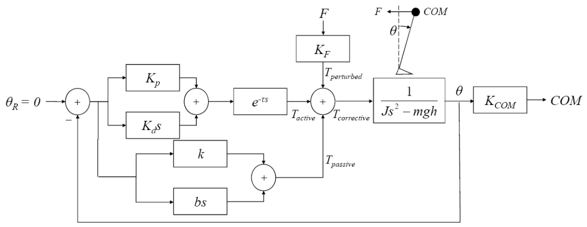

Fig. 2. Block diagram of control system

To compute the pendulum lean angle (θ), the horizontal displacement of the center of mass (COM) was derived from AP force and COP data using a modified gravity-line projection method (Zatsiorsky, 2000). A constrained nonlinear optimization algorithm was used to identify model parameters which best fit the experimental data.

We quantified the robustness of each age group by examining the maximum of the sensitivity function (*MaxSens*) of the modeled systems. The sensitivity function describes how sensitive a system is to small perturbations in the system; larger values indicate reduced robustness or decreased relative stability of the system.

RESULTS AND DISCUSSION

Parameter	YA	MA	OA	p-val
Peak Force (lb)	6.54 (0.48)	6.75 (0.70)	6.40 (1.29)	0.68
MaxDisp (mm)	20 (8)	18 (5)	23 (6)	0.22
NormMaxDisp	0.28 (0.09)	0.27 (0.07)	0.35 (0.08)	0.08
Range (mm)	29 (7)	26 (4)	32 (9)	0.19
Latency (ms)	183 (35)	157 (34)	157 (22)	0.11
MaxSens (dB)	9.31 (1.49)	8.66 (1.63)	10.9 (1.94)	0.02

Table 1. Average (standard deviation) descriptive and spectral analysis parameters for each age group.

No significant differences were found between the age groups for any of the descriptive response parameters (Table 1, ANOVA). However, significant age-related differences were found for *MaxSens*. OA were found to have significantly larger *MaxSens* values than both YA and MA (Tukey HSD post hoc test). This result suggests that while conventional descriptive parameters may not be able to detect age-related response differences, the sensitivity function may be a useful parameter to assess the relative stability of the postural control system.

SUMMARY AND CONCLUSIONS

This study investigated the postural sway response to an impulsive perturbation and examined how this response varies with age. We applied a mild backward tug to three different age groups. Descriptive measures did not detect any age-related differences in sway response. Maximum sensitivity values from spectral analysis, however, showed significantly larger values for older adults than young or middle-aged adults. Thus maximum sensitivity may be a useful parameter for measuring relative stability or robustness of the postural control system to external perturbation.

REFERENCES

Ishida et al., IEEE Trans Biomed Eng 44:331-336, 1997

Zatsiorsky et al., Motor Control 4, 185-200, 2000

Peterka, *J Neurophysiol* 88: 1097-1118, 2002

AKNOWLEDGEMENTS

This study is funded by the Center for Advanced Studies and the Campus Research Board at the University of Illinois at Urbana-Champaign.

<250 word summary:

This study investigated the postural sway response to an impulsive perturbation and examined how this response varies with age. Although most losses of balance result from a sudden disturbance, the majority of studies examining the response of the postural control system use continuous perturbations. Therefore, we explored the response to an impulse perturbation (i.e., a mild backward impulse force applied to the pelvis). Three age groups (n=10 each) were tested: young (20-30 years), middle-aged (42-53 years), and older adults (71-79 years). The sway response, anterior-posterior fluctuations of the center of pressure (COP), was evaluated using descriptive parameters and spectral analysis system identification. Descriptive parameters included COP displacement measures. Spectral analysis was used to fit each subject's response data to a single-link inverted pendulum model with active and passive torques generated by a time-delayed proportional-derivative controller and a spring-damper compensator at the ankle. We quantified the robustness of each modeled system by examining the maximum of the sensitivity function. The sensitivity function describes how sensitive a system is to small perturbations in the system; larger values indicate reduced robustness or decreased relative stability of the system. Descriptive measures did not detect any significant age-related differences in sway response. Maximum sensitivity values, however, were significantly larger for older adults than young or middle-aged adults (p=0.02). The maximum of the sensitivity function may be a useful parameter for measuring relative stability or robustness of the postural control system to external perturbation.