Characterizing the sway response of the human postural control system to an impulse perturbation



INTRODUCTION

- 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 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

Subjects

Table 1. Subject demographics, mean and (S.D.), for young adults (YA), middle-aged adults (MA), and older adults (OA). No significant differences in weight or height (p<0.05).

| 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 |
| Weight (kg) | 69.2 (8.1) | 76.0 (12.8) | 72.7 (15.3) |
| Height (cm) | 170.0 (18.7) | 169.1 (11.9) | 166.0 (11.4) |

Experimental Protocol

- Twenty randomized trials were conducted: 10 guietstanding trials and 10 perturbed trials, all 30 s in duration.
- The subject was instructed to maintain a guiet, 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.

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Data Processing

- Anterior-posterior (AP) sway response was evaluated using
 - Descriptive parameters of the center of pressure (COP)
 - Spectral analysis system identification of a postural control model based on lean angle of the center of mass (COM).

Descriptive parameters of AP COP data:

- MaxDisp (max posterior displacement)
- NormMaxDisp (MaxDisp*Weight / Height*TugForce)
- Range (difference between max and min displacements)
- Latency (time from the peak tug force to MaxDisp)



Latence

Spectral analysis system identification:

The perturbed postural control system was modeled as a singlelink inverted pendulum modulated by active and passive torques generated by a time-delayed proportional-derivative controller with parameters (K_{α} , K_{d} , τ) and a spring-damper compensator (k, b), respectively



The gravity-line projection method [4] was used to derive COM displacement from AP force and COP data. The lean angle of the COM (θ) was then computed.



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- Spectral analysis sysID was used to fit experimental response data to the model and compute model parameters [3]
- Robustness of the modeled system was quantified by the maximum of the sensitivity function (MaxSens).
- The sensitivity function describes how sensitive a system is to small perturbations; larger values indicate reduced robustness or decreased relative stability.

$$Sens = \frac{Js^2 - mgh}{Js^2 + bs + (k - mgh) + (K_p + K_d s)e^{-t}}$$

Table 2. Mean (SD) descriptive and spectral analysis sysID results.

| Parameter | YA | MA | OA | p-value* |
|----------------------------|-------------|-------------|-------------|----------|
| Peak Force (N) | 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 |
| K _p (N·m/rad) | 1035 (186) | 1172 (509) | 977 (433) | 0.54 |
| K _d (N·m·s/rad) | 367 (87) | 509 (362) | 422 (147) | 0.38 |
| τ (ms) | 136 (50) | 157 (140) | 109 (48) | 0.82 |
| k (N.m/rad) | 125 (116) | 377 (540) | 231 (294) | 0.31 |
| b (N.m.s/rad) | 41 (88) | 130 (269) | 15 (49) | 0.29 |
| MaxSens (dB) | 2.33 (0.39) | 2.26 (0.59) | 3.03 (0.77) | 0.014 |

SUMMARY

- Descriptive measures did not detect differences in sway response due to age.
- 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] R.J. Peterka. J Neurophysiol 88: 1097-1118, 2002. [4] V.M. Zatsiorsky and M. Duarte. Motor Control 4: 185-200, 2000.

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