Postural Corrections in Response to Increasing Upper-Body Perturbations

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Introduction
The ability of individuals to respond to perturbations is an important component of overall postural stability.

A prevailing paradigm is to elicit a corrective response from a subject by rapidly moving the platform on which they stand.\(^1\)

However, during daily activities, a person is more likely to be perturbed by a bump or push to the upper body.

If pushed from behind, the body center of mass (CoM) will accelerate forwards toward the toes.

To prevent falling, increased ankle plantarflexor torque will move the ground reaction force (GRF) center of pressure (CoP) quickly ahead of the CoM to slow forward sway.

Our goal was to examine CoP and CoM motion during an ankle response to an upper-body perturbation, and to evaluate how these variables scale with perturbation level.

Methods

Subjects & Experimental Procedures
Eight young subjects (27 ± 3 yrs.) were struck in the upper back with a swinging pendulum, causing forward sway (Fig. 1, Left).

Subjects were to resist the perturbation via plantarflexor torque generation, and assume quiet stance as quickly as possible.

Kinematics and GRFs were measured with an 8-camera motion capture system and force plate.

Initially, the pendulum was released to swing through a 10º arc (θ) before impact. Pendulum motion was increased in 5º increments to amplify perturbation level; trials continued until the subjects stopped.

Data Analysis

Four anterior-posterior variables quantified the response (Fig. 1, Right):

- Maximum forward rate of change of the CoM (Max dCoM/dt) and CoP (Max dCoP/dt).
- Minimum CoM and CoP distance to toes (Min CoM Dit and Min CoP Dit, respectively).

The degree of postural challenge was computed as the peak pendulum velocity before impact divided by the subject’s mass.

The relationship between each of the postural variables and postural challenge was assessed by fitting linear and quadratic equations to the data, and computing the coefficients of determination (R\(^2\)).

Results

A typical perturbation response (see Fig. 1, Right for example):

- After impact, CoM accelerates forward towards toes - CoM lags CoP briefly, but then moves rapidly forward - CoP moves ahead of the CoM, slowing its forward motion - CoM starts moving backward towards heels; CoP follows

R\(^2\) values were high for all postural variables when plotted against postural challenge (Fig. 3)

In contrast to the other postural variables, Min CoP Dit was not well represented by a linear relationship. At higher postural challenge levels, the relation between the postural challenge and the Min CoP Dit changed in slope.

The time that the CoP remained in the extreme anterior position increased with perturbation level (see Fig. 2, Right).

Discussion

To maintain stability after a pendulum perturbation, plantarflexor torque must be generated to shift the CoP forwards and slow the forward motion of the CoM.

At lower postural challenges, subjects were able to develop sufficient stabilizing torque without moving their CoP to an extreme forward position. As postural challenge increased in this “low” range, the CoP moved proportionally closer to the toes.

However, at progressively higher levels, this relationship changed. An increase in postural challenge did not cause a proportional increase in CoP forward movement, presumably because subjects were approaching their functional stability boundary.

Changes in the mechanical properties of the plantarflexor muscles with disuse or aging may affect the rate of ankle torque development and the observed CoP strategy.\(^2\)

Large and rapid CoP movements during static postural tasks is often viewed as a sign of instability. On the other hand, such CoP movements are highly desirable when resisting a postural perturbation.

Conclusions

The forward distance the CoP can travel limits the magnitude of the stabilizing torque. Therefore, during challenging perturbations, it is imperative that the CoP be shifted to a forward position as quickly as possible to maximize the angular impulse acting to decelerate the forward motion of the CoM.

Large and rapid CoP movements are thus advantageous for recovery from postural perturbations.

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References
