CRITICAL TIME-TO-CONTACT AFTER POSTURAL PERTURBATIONS

C.J. Hasson, C. Gariépy, G.E. Caldwell, R.E.A. Van Emmerik, and W.J. McDermott
University of Massachusetts, Amherst, MA, USA; E-mail: cjhasson@kin.umass.edu

INTRODUCTION

During quiet stance, stability requires keeping the body center of mass (CoM) above its base of support. An external force applied to the upper back will accelerate the CoM towards the front stability boundary. By developing ankle torque with the plantarflexor muscles, the ground reaction force center of pressure (CoP) moves in front of the CoM to stabilize and counteract the forward sway.

At a given instant, the projected time for the CoM or CoP to contact a stability boundary is known as *time-to-contact* (TtC). During quiet stance, mean TtC has been viewed as a global measure of overall stability, while minimum TtC values have been thought to represent points of instability (Van Wegen et al., 2002). During a perturbation with acceleration towards the anterior stability boundary, the CoM TtC indicates the degree of impending danger of falling forward (Riccio, 1993). If TtC becomes too small, the ankle musculature may have insufficient time to produce the angular impulse needed to reverse the CoM before it reaches the stability boundary.

In this study we examined CoM and CoP motion and TtC after external perturbations of increasing magnitude. We expected the minimum TtC for the CoM to decrease as the perturbing force increased, and sought to identify a critical TtC value associated with a subject's decision to step forward as the perturbation became unmanageable with ankle plantarflexor torque alone.

METHODS

A pendulum of constant mass instrumented for angular position and impact force was used to deliver perturbation impulses of known magnitude at 78% standing height (Fig. 1). Five subjects (27 ± 2 yrs, 77 ± 11 kg, 178 ± 6 cm) stood on a force plate while strapped to a lightweight wooden backboard that distributed the force of the impact and constrained motion to sagittal plane rotation about the ankle joint only. Subject and backboard kinematics were captured at 200 Hz with an 8-camera Qualysis system. Ground reaction forces (GRFs) were sampled at 1000 Hz.

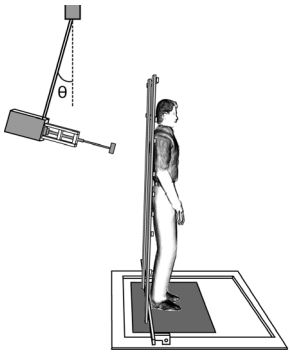

Fig 1. Apparatus.

In each trial, subjects were instructed to stand quietly, resist the perturbation, and return quickly to quiet stance. They were to step only when necessary to prevent a fall. Pendulum release occurred at a random time 2 to 5 s after a "ready" light. Subjects wore earphones with white noise to mask the pendulum release. A series of trials with increasing perturbations was performed, with an initial pendulum release angle (θ) of 10º (Fig. 1). The release angle was increased by 5º increments in subsequent trials until the subjects stepped. Perturbation magnitude was quantified by the peak pendulum angular velocity prior to impact (PP_{VEL}).

The CoP position was computed from low-pass filtered GRFs, and the CoM position from segmental kinematics. The CoM TtC to the anterior (toes) and posterior (heel) stability boundaries was calculated using methods developed by Slobounov et al. (1997). This required the solution of two quadratic equations of the form

$$\frac{1}{2}a\tau^2 + v\tau + (p - p_X) = 0$$

where p, v, and a are the positions, velocities, and accelerations of the CoM, p_x is the anterior-posterior (AP) location of the toe (or heel) markers, and τ is the TtC.

RESULTS AND DISCUSSION

In a typical perturbation response, the CoM accelerated towards the toes, followed by rapid forward motion of the CoP that placed it in front of the CoM (Fig. 2, Top).

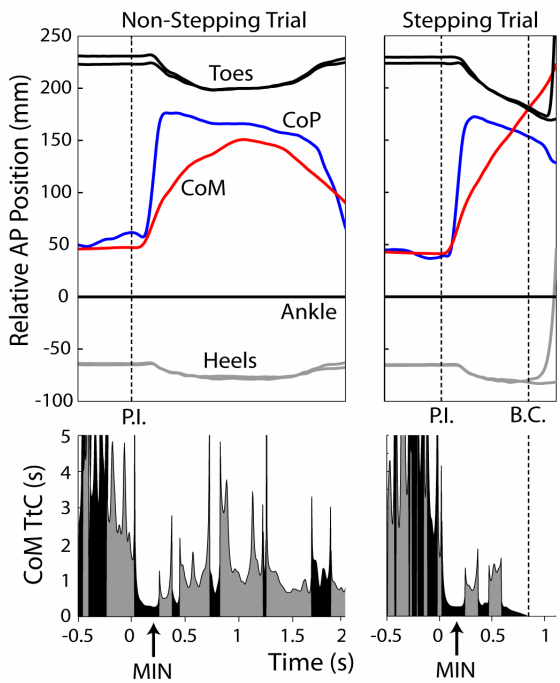

Fig. 2. Non-stepping (Left, PP_{VEL}=129°/s) and stepping (Right, PP_{VEL}=155°/s) trials for one subject. Top: AP displacement of the CoM, CoP, and toe/heel markers referenced to the ankle joint center. Bottom: CoM TtC; toe and heel trajectory contact indicated by black and grey shading, respectively. P.I.: Pendulum Impact; B.C.: Boundary Contact.

Except for the smallest perturbations, the CoP moved quickly to an initial position of 27 ± 7 mm (mean ± s.d.) from the toes. The time that the CoP remained in this forward position increased with perturbation level. In all trials, the minimum TtC occurred during the initial acceleration of the CoM towards the toes (MIN in Fig. 2, Bottom). As PP_{VEL} increased, the minimum TtC decreased (Fig. 3). As expected, more massive subjects required higher perturbation levels to elicit a step response than less massive subjects. In the stepping trials, the range of minimum TtC values was much smaller than the range of PP_{VEL} values (9.4% vs. 37.7% of total range; Fig. 3, brackets). Regardless of subject mass or absolute impact magnitude, there appeared to be a threshold TtC (~0.25 s) that dictated whether subjects stepped.

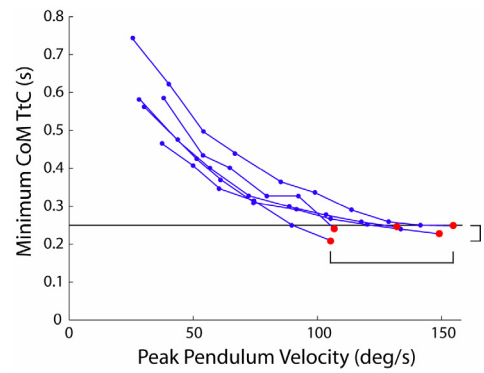

Fig. 3. Minimum CoM TtC as a function of peak pendulum angular velocity (PP_{VEL}) for 5 subjects. Last point (enlarged circle) in each line is the stepping trial. Horizontal line indicates possible threshold TtC of ~ 0.25 s. Brackets indicate range of TtC and PP_{VEL} for stepping trials.

CONCLUSIONS

During a perturbation, the body could use TtC information to predict whether it will be possible to reverse the CoM direction before a stability boundary is reached. It appears that the postural control system initiates a step response when TtC values fall below a critical threshold of ~0.25 s, invariant of body mass or perturbation magnitude.

REFERENCES

Riccio GE (1993) In: Variability and Motor Control (pp. 317-357), Human Kinetics.

Slobounov SM, et al. (1997) *J. Mot. Behav.*, **29**, 263-281.

Van Wegen EE, et al. (2002) *Hum. Mov. Sci.*, **21**, 61-84.

ACKNOWLEDGEMENTS

Funded by NIH grant R03AG026281-01A1.