Whole-body dynamics in response to unpredictable and adapted drop-like gait perturbations

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Summary

Neuromechanical mechanisms that control whole-body behaviour during unpredictable without experience and predictable with experience drop-like gait perturbations were investigated in 18 participants. We found rapid changes, ~75 ms after plate drop, in the joint kinematics and activation patterns of the perturbed leg, which prioritised managing the absorption of total centre-of-mass (CoM) energy at the expense of whole-body angular momentum during the unpredictable perturbations. Predictive modulations of leg posture, joint kinematics and muscle activation of the perturbed and contralateral leg regulated mechanisms that manage both total CoM energy and whole-body angular momentum in the adapted perturbations.

Introduction

Mechanical preflexes, sensory feedback and feedforward commands are mechanisms that control the stability of biological systems during locomotion [1]. Our purpose was to investigate negotiation control strategies during unpredictable and adaptive drop-like gait perturbations. In particular, how the neuromotor system regulates whole-body angular momentum and total CoM energy to maintain dynamic balance, and how leg posture, joint kinematics and muscle activation patterns are adapted with learning after experience of the drop-like perturbation.

Methods

An 18 m customised gangway with a hidden electronically triggered drop-plate was used to introduce unpredictable without experience and predictable with experience drop-like gait perturbations (15 cm drop). In eighteen (5F/13M) participants, whole-body kinematics were recorded using an infrared motion capture system with 19 cameras operating at 250 Hz, and electromyographic activity (EMG) of 7 lower leg muscles was measured bilaterally (2000 Hz). Whole-body angular momentum was studied in the frontal plane. The EMGs were normalised to maximal isometric voluntary contraction and the first-order differential equation proposed by Zajac [2] was used to assess muscle activation.

Results and Discussion

We found an increase ($p<0.05$) in the peak-to-peak range of whole-body angular momentum and increased changes in total CoM energy compared to level walking, with the highest values in the unpredictable condition, indicating an increased challenge to body stability (Figure 1). Kinematics and activation patterns showed no differences ($p>0.05$) in the unpredictable perturbations until the plate dropped, i.e. no anticipatory adjustments (Figures 1 and 2). There was a reactive rapid increase in muscle activation of the perturbed leg after the drop plate (~75ms delay) and large muscle activation in the first part of stance during unpredictable perturbations (Figure 2).

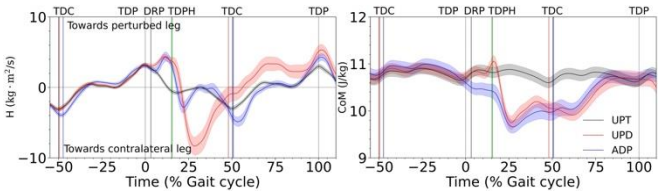

Figure 1. Whole-body angular momentum (H) and total CoM energy. TDC: touchdown contralateral leg, TDP: touchdown perturbed leg, DRP: plate drop, TDPH: touchdown perturbed leg in hole, UPT: unperturbed walking, UPD: unpredictable perturbations, ADP: adapted perturbations (n=18).

Predictive adjustments in leg posture, joint kinematics and muscle activation patterns in the perturbed and contralateral leg during the adapted perturbations reduced the challenge of managing whole-body angular momentum and total CoM energy (Figures 1 and 2).

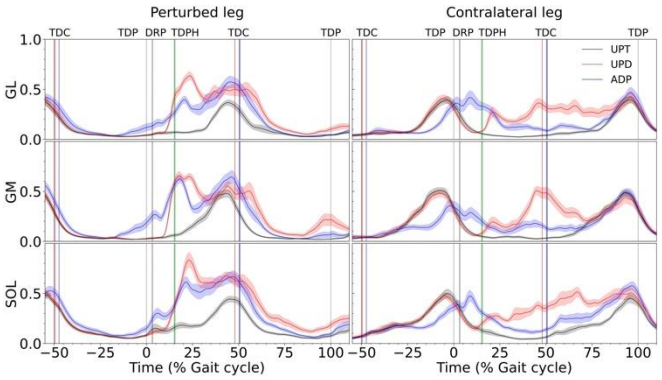

Figure 2. Activation patterns of the soleus (SOL), gastrocnemius medialis (GM) and lateralis (GL) muscles. TDC: touchdown contra-lateral leg, TDP: touchdown perturbed leg, DRP: plate drop, TDPH: touchdown perturbed leg in hole, UPT: unperturbed walking, UPD: unpredictable perturbations, ADP: adapted perturbations (n=18).

Conclusions

The rapid increase and high muscle activation after the drop plate suggests a prioritisation in the regulation of total CoM energy at the expense of whole-body angular momentum during unpredictable perturbations. Predictive adjustments in the adapted drop-like perturbations reveal scaled feedforward regulation of mechanisms controlling both total CoM energy and whole-body angular momentum.

References

[1] Dickinson, M.H. et al. (2000). *Science*, **288:** 100-106.
[2] Zajac F.E. 1989. *Crit Rev Biomed Eng*, **17:** 359-411.