Balance recovery in the double support phase during perturbed walking

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Background & Aim

- Exoskeletons have a very slow walking speed.
- Slow walking increases duration of the double support phase (DSP).
- Crucial to control balance when both feet are on the ground.
- The centre of pressure (CoP) describes the control of the centre of mass (CoM) movement [1].

How do modulations of the CoP trajectory contribute to the control of the CoM during the double support phase?

Methods

Experimental data

- 10 subjects walking at 1.25 ms^{-1} [2]
- Pelvis perturbations at toe-off right
- Magnitude 4, 8, 12 ,16 % of body weight

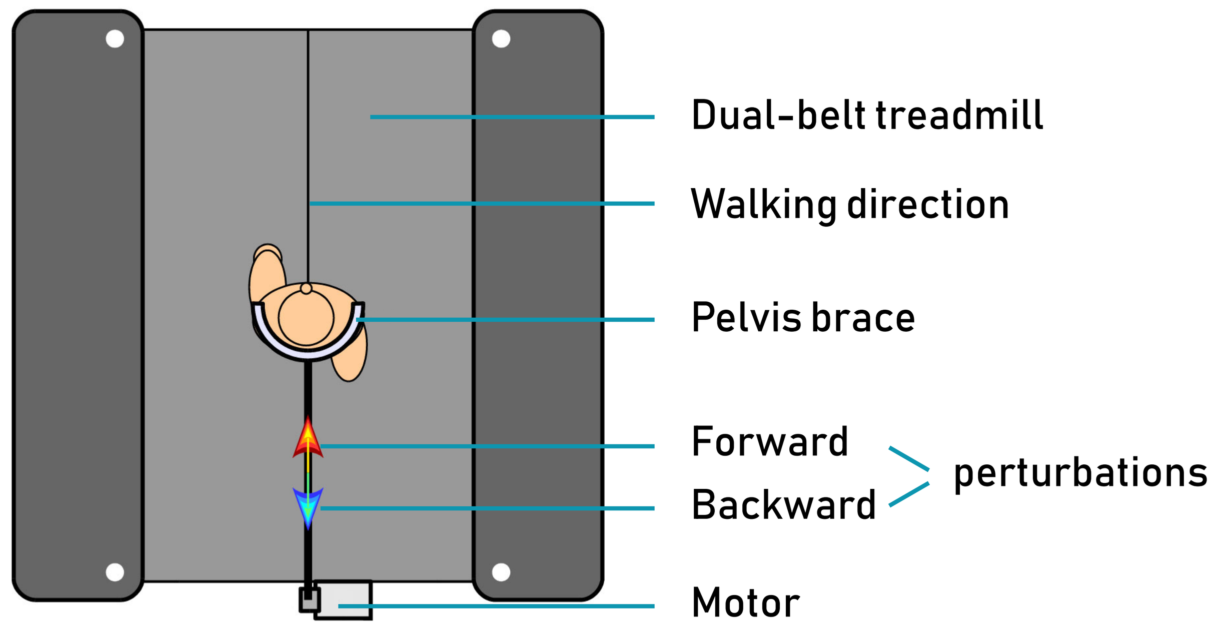


Figure 1: Experimental setup. [2]

Modelled data

Simple inverted pendulum model [3]:
- Input: Generated CoP trajectories
- Output: CoM position and velocity

Δ CoM velocity = end - begin velocity of the DSP

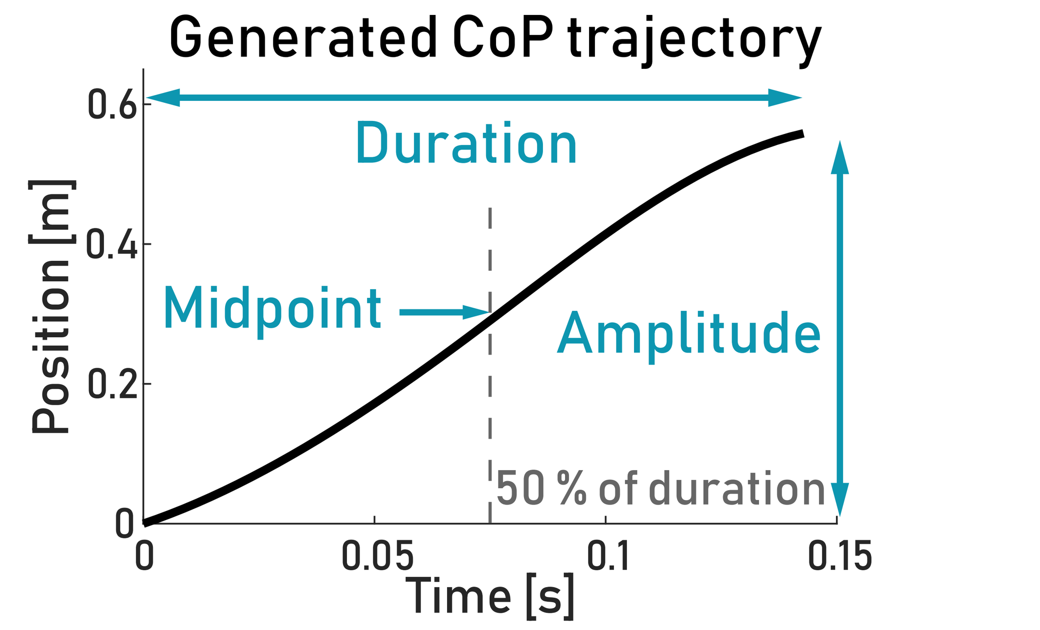


Figure 2: Parameterised CoP trajectories, based on spline.

Results

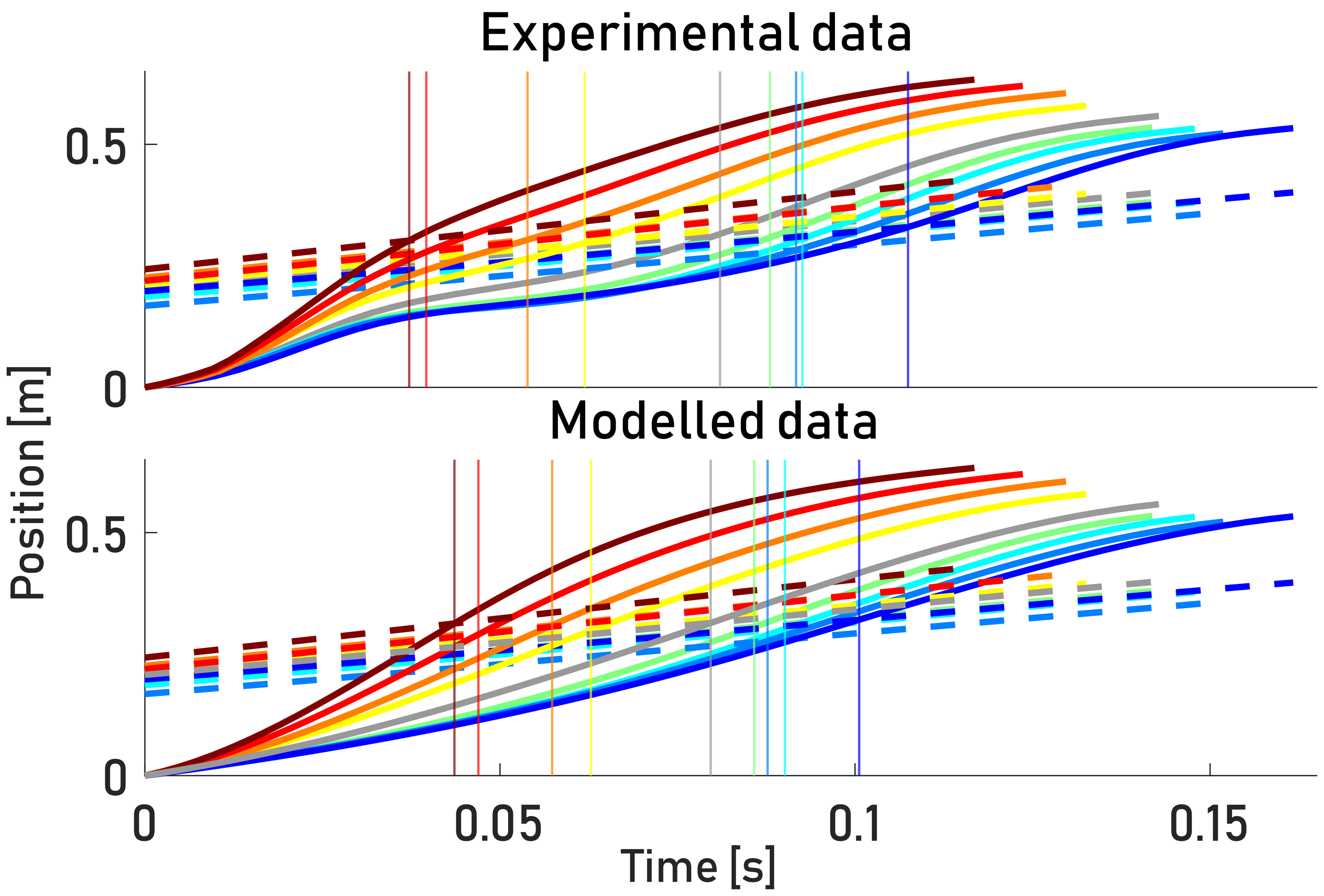
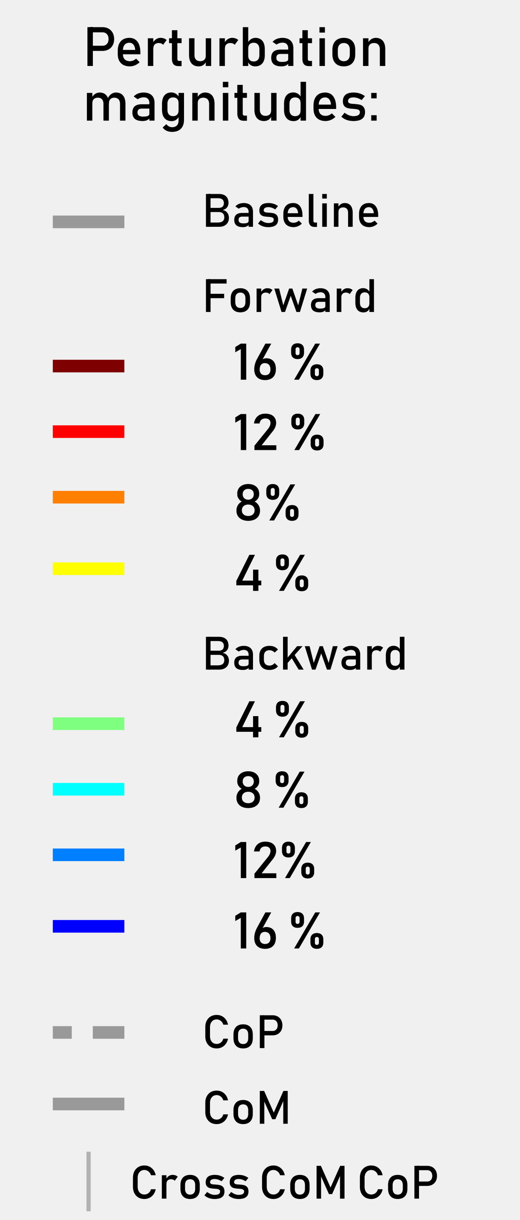


Figure 3: Top) Experimental CoP and CoM trajectories for different perturbation magnitudes. Bottom) Generated CoP trajectories based on values from experimental data and modelled CoM trajectories.



All data is presented in the sagittal plane.

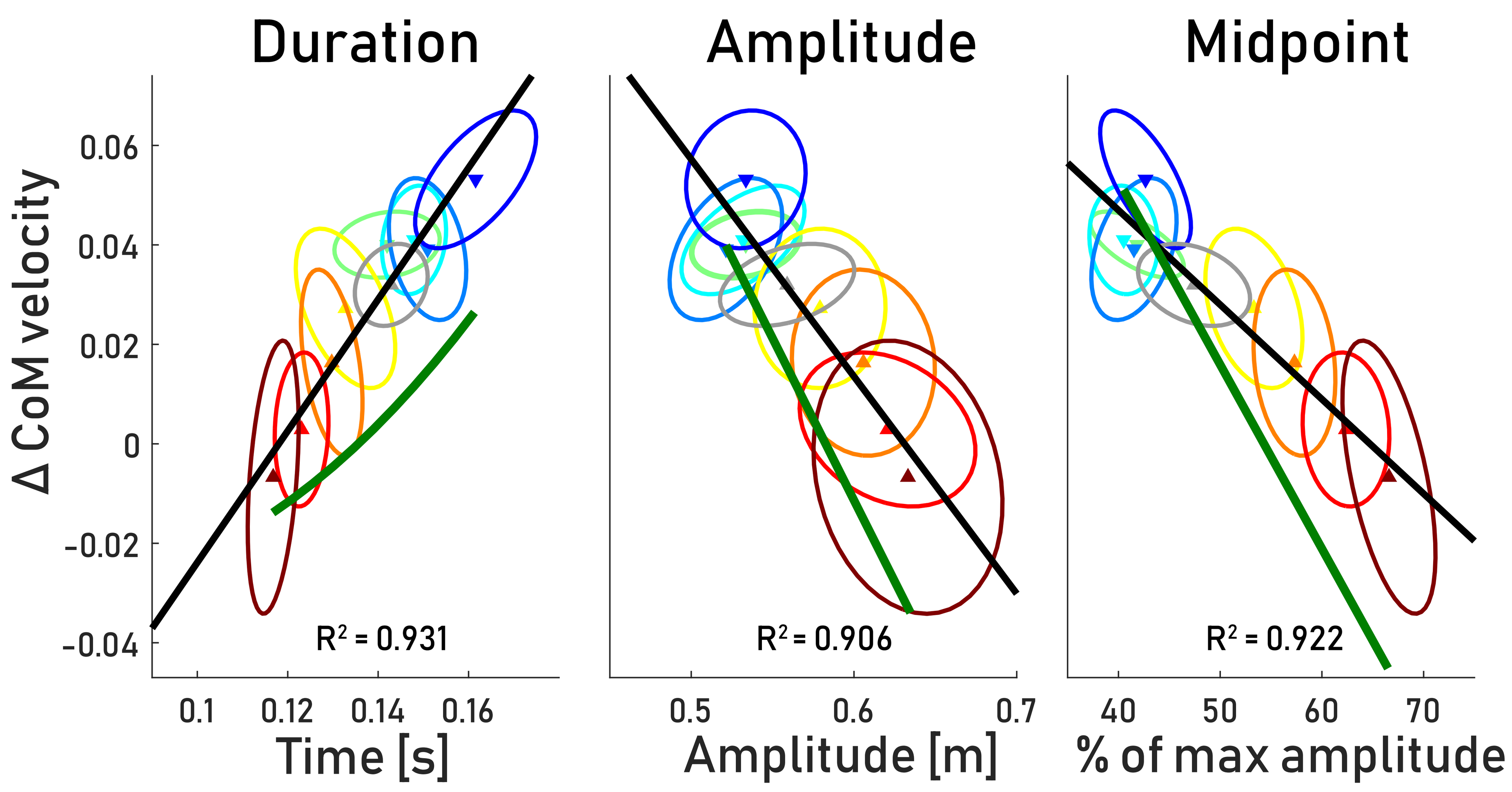


Figure 4: Relationships between CoP parameters and Δ CoM velocity for experimental (triangles with ellipses [mean ± std] and LLSQ fit [black line and R^2 value]) and modelled data (green line).

- Minimal difference between the end CoM position of the experimental and modelled data: 0.1 – 0.4 mm
- Systematically lower Δ CoM velocities for modelled data: 0.1 – 95 mm/s

Experimental data

- Linear relationships between the Δ CoM velocity and all CoP parameters.

Modelled data

- Directions of relationships correspond with experimental data.
- Systematically lower Δ CoM velocity compared to experimental data.

Conclusion

- A simple inverted pendulum model is able to model representative CoM trajectories during the DSP, from a generated input CoP trajectory using only three CoP parameters.
- Subjects used all the CoP parameters, the duration, amplitude and midpoint, to control the CoM velocity after a perturbation.
- Earlier or later loading the leading leg helped in controlling the CoM velocity, and was even more effective than changing the duration or amplitude.

References

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[2] M. Vlutters, E. H. F. van Asseldonk, and H. van der Kooij, "Center of mass velocity-based predictions in balance recovery following pelvis perturbations during human walking," J. Exp. Biol., vol. 219, no. 10, pp. 1514–1523, 2016.
[3] Y. Jian, D. Winter, M. Ishac, and L. Gilchrist, "Trajectory of the body COG and COP during initiation and termination of gait," Gait Posture, vol. 1, no. 1, pp. 9–22, 1993.

Wearable Robotics

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