Does the Reference Axis for Computing Angular Momentum Affect Interpretations of Balance Control?

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Introduction

- One common measure of dynamic balance in human walking is whole-body angular momentum (WBAM) computed about a specified reference axis.

- Biomechanists primarily compute WBAM about an axis projecting through the center of mass to quantify balance control during walking [1]–[3].

- However, momentum-based controllers for humanoid robots may use axes that project through the center of pressure [4].

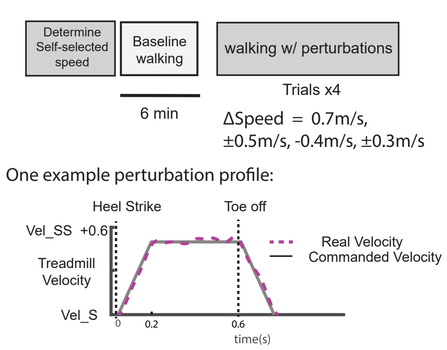
- Here, we asked if the choice of the reference axis influences our interpretations about how people regain balance and coordinate body segments following external perturbations.

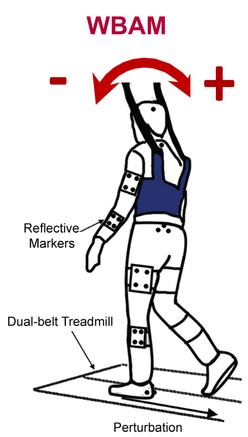
Methods

Participant characteristics:

- Four participants (4F, 27 ± 2yrs old, right leg dominat, self-selected speed=1.15 ± 0.1m/s)

Experiment protocol and setup





We applied 12 perturbations of each magnitude at either side.

Whole-body Angular Momentum (WBAM)

$$\overrightarrow{WBAM_{ref}} = \sum_i \frac{\left[m_i \left(\vec{r}^{\,i}_{ref-i} \times \vec{v}^{\,i}_{ref-i} \right) + I^i \omega^i \right]}{\mathrm{MVH}}$$

H: COM height, M: Subject mass, V: Self-selected walking speed, m: Segmental mass, r: Distance from segment to the reference axis, v: Velocity of the segment with respect to the reference axis; I: Segmental moment of inertia.

References axis for computing WBAM:

- A mediolateral axis projecting through 1) the CoM or 2) the leading edge of the base of support (BoS) as estimated by a marker on the first phalanx. Both axes were defined as positive to the person's right.

Kinematics:

- Full-body markers position collected by motion capture system.
- Created a full-body model using Visual 3D.

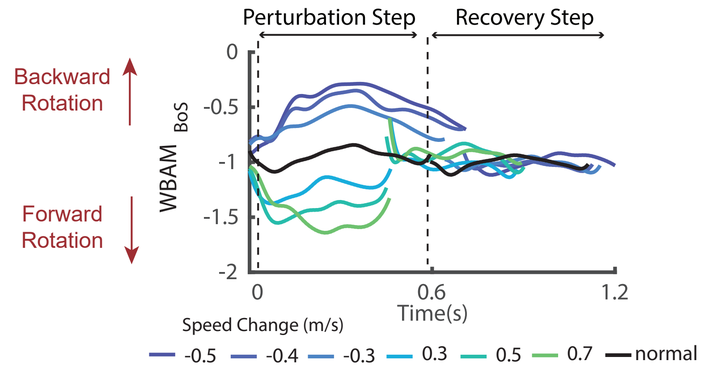
Methods

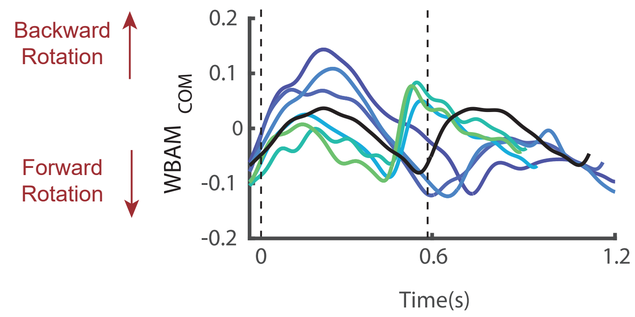
Statistical Analysis:

We used a linear mixed effect model to determine if the maximum $WBAM_{COM}$ and $WBAM_{BoS}$ during the perturbation was associated with perturbation magnitude.

Results

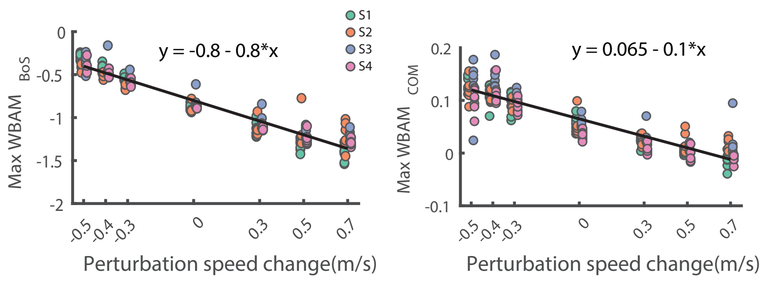
1. Perturbations induced changes in angular momentum over multiple steps.





- $WBAM_{BoS}$ magnitude was higher than $WBAM_{COM}$ as a result of the larger distance between most segments and the reference axis.

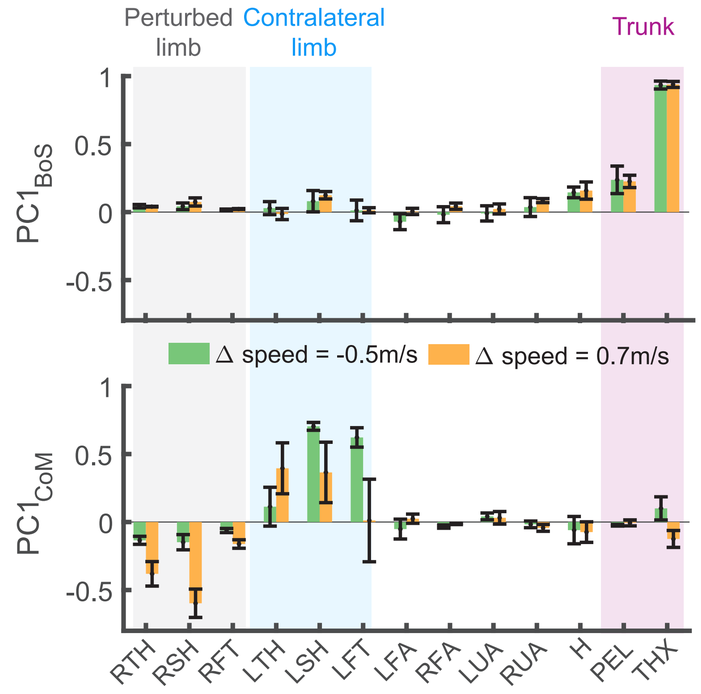
2. Peak WBAM was negatively correlated with the change in speed regardless of the reference axis.



- The maximum $WBAM_{COM}$ and $WBAM_{BoS}$ during the perturbation steps were both negatively correlated with the change in speed ($p < 0.001$)

Results

3. Segmental coordination patterns differed based on the reference axis chosen for WBAM during the perturbed steps..



- On average, $2PCs_{BoS}$ and $3PCs_{CoM}$ were necessary to explain more than 90% of variance. $PC1_{BoS}$ explained higher variance (78 ± 11%) than $PC1_{CoM}$ (61 ± 6%) for all perturbation levels.
- Changes in angular momenta in trunk and lower extremities had the largest loadings for PC1 referenced to BoS and COM, respectively.
- For $PC1_{COM}$, changes in segmental angular momenta of the perturbed limb were counteracted by the contralateral limb during perturbation responses.

Conclusions

- Maximum WBAM was negatively correlated with the change in speed during walking on the treadmill regardless of the reference axis.
- CoM dynamics is the dominating factor in computing $WBAM_{BoS}$ while computing WBAM relative to CoM neglects that dynamics.

References

[1] H. M. Herr and M. Popovic, J. Exp. Biol.211, 467-81 (2008)
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[3] C. Liu et al. Front. Hum. Neurosci. 12. 251 (2018)
[4] S.-H. Lee et al., Angular Momentum Based Balance Control (2018).

Acknowledgement

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