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

Chang Liu
Department of Biomedical Engineering
University of Southern California
Los Angeles, USA
liuchang@usc.edu

Sungwoo Park, PhD
School of Engineering and Applied Sciences
Harvard Univeristy
Boston, USA
swpark@seas.harvard.edu

James Finley, PhD
Division of Biokinesiology and Physical Therapy
University of Southern California
Los Angeles, USA
jmfinley@usc.edu

***Abstract*— We determined if changing the reference axis for calculating angular momentum would affect interpretations of how humans control dynamic balance during perturbed walking. Peak angular momentum in response to perturbations was correlated with perturbation magnitude regardless of the choice of the reference axes. Our results also suggest that inverted pendulum models capture the dominant features of whole-body dynamics during both perturbed and unperturbed gait.**

I. Introduction

One of the common measures to quantify dynamic balance in human walking is whole-body angular momentum (WBAM). To compute angular momentum, one must specify a reference axis and momentum-based controllers for humanoid robots may use axes that project through either the center of mass (CoM) or the center of pressure [1]. However, researchers mostly use angular momentum about an axis projecting through the CoM to quantify human balance during walking [2]–[4]. Here, we asked if the choice of the reference axis influences the interpretation of dynamic balance control.

II. Methods

Four healthy young individuals walked on a dual-belt treadmill at their self-selected speed. Sudden treadmill perturbations with different magnitudes were remotely triggered at foot strike of the perturbed leg and the belt speed returned to the self-selected speed during swing. Full body kinematics were captured using a 10-camera Qualisys Oqus system (Qualysis, Sweden). From this data, we estimated whole-body angular momentum (WBAM) as the sum of all segmental angular momenta in the sagittal plane (Eqn.1).

$$\overrightarrow{WBAM_{ref}} = \sum_i [\, m_i (\vec{r}^{\,i}_{ref-i} \times \vec{v}^{\,i}_{ref-i}) + I^i \omega^i \,] \qquad (1)$$

Here, m_i is segmental mass, $\vec{r}^{\,i}_{ref-i}$ is a vector from the segment's center of mass to the reference axis, I is the segmental moment of inertia about its center of mass, ω is segmental angular velocity, and the index *i* corresponds to each individual limb segment. Two reference axes were used for computing WBAM: a mediolateral axis projecting through the CoM or through the leading edge of the base of support (BoS) as estimated by the first phalanx toe marker.

For both metrics, we used the maximum value of $WBAM_{COM}$ and $WBAM_{BoS}$ during single support of the perturbation step to quantify the effect of perturbations. Negative values represented forward rotation and positive values represented backward rotation. Each measure was normalized by weight, height, and walking speed [4][5].

We used a linear mixed effect model to investigate whether the maximum $WBAM_{COM}$ and $WBAM_{BoS}$ during the perturbation steps was associated with perturbation magnitude. Significance level was set at $p<0.05$.

III. Results

WBAM during the perturbation step deviated from the trajectory during the pre-perturbation step (Fig 1A & B). The maximum $WBAM_{COM}$ and $WBAM_{BoS}$ were both negatively correlated with perturbation size ($p<0.001$) (Fig 1C & 1D).

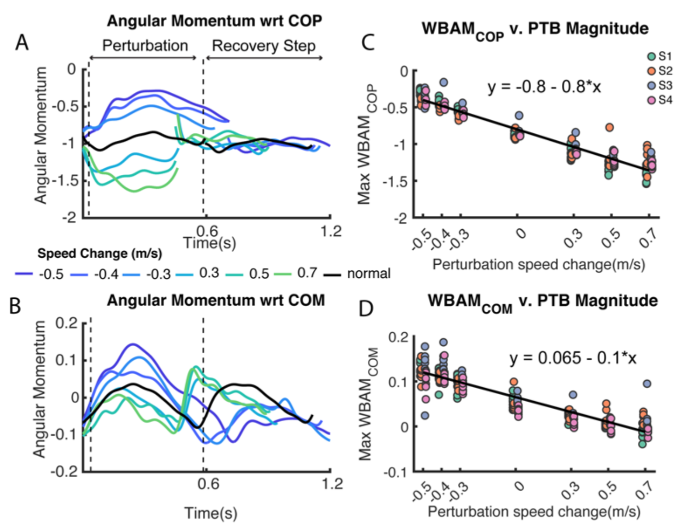

Figure 1 $WBAM_{BoS}$ (A) and $WBAM_{COM}$ (B) over time. Maximum $WBAM_{BoS}$ (C) and $WBAM_{COM}$ (D) were negatively correlated with perturbation size.

IV. Conclusion

Maximum whole-body angular momentum is negatively correlated with perturbation size regardless of the reference axis. In addition, $WBAM_{BoS}$ can be approximated by computing the angular momentum about the contact point with the ground using an inverted pendulum model, indicating large cancellation of segmental angular momenta.

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References

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