Angular Momentum Synergies in the Sagittal Plane during Walking

[1]Thomas Robert, [2]Bradford C. Bennett, and [2]Mark F. Abel
[1] université de Lyon, Lyon, France; INRETS, LBMC UMR_T 9406, F-69675, Bron.
[2] University of Virginia, Charlottesville, VA 22903, United States;
Corresponding author: thomas.robert@inrets.fr

INTRODUCTION

It has been observed that during walking the Whole Body Angular Momentum (WBAM) demonstrates a very reproducible pattern from stride to stride [1, 2]. This has been viewed as a sign that the CNS cares about controlling the WBAM [1]. However, the way this control is performed is not clear, and more particularly the way the CNS deals with the redundancy of the body segments to produce a given WBAM value.
An interesting way to study this question is the notion of multi-segmental synergies, and the framework of the Uncontrolled Manifold Hypothesis [3]. Within this framework, the control is viewed as a two level hierarchy: at the lower level, the individual variables are grouped into Elemental Variables (EV) based on their co-variation. At the upper level, the neural controller forms in the space of elemental variables a sub-space, named Uncontrolled Manifold (UCM), corresponding to a desired value (time profile) of an important Performance Variable (PV). By confining the elemental variables to that sub-space, the controller guaranties a constant value of the PV. Moreover, if most of the trial-to-trial variance is confined to the UCM, a conclusion can be drawn on a synergy among the elemental variables stabilizing the performance variable (i.e., decreasing its variability across trials).
Within this framework, this study aims at investigating: 1/ the presence or the absence of synergies among the individual segment angular momenta (SAM) to produce repeatable WBAM; 2/ the evolution of these synergies along the stride. Results of this study will provide insight into the control of human walking.

METHODS

Seven male subjects (mean age 31 year old, mean height 1.80 meter, mean weight 76.1 kg), without any known neurophysiological disorders, were asked to walk over a treadmill at their own CWS for about 10 minutes. 3D trajectories of 38 markers attached to the subject were recorded for at least 5 series of 10 consecutive strides. A 17 segment models was adjusted to subject's anthropometry using the GeBOD database and the 3D kinematics (joint angles) were computed from the marker trajectories using the LifeMod plugin. The individual segment angular momenta (SAM) and the whole body angular momentum (WBAM), all relative to the whole body center of mass, were then computed for the 3 dimensions of the reference space and normalized by the mass, height and CWS of the subject [1]. Data for each stride (from left heel strikes to left heel strikes) were time normalized over a 100% time window. Further analyses were performed independently for the three planes. Only results for the sagittal plane will be presented here.
The SAM were submitted to a principal component analysis (PCA) and the 5 first PCs, which accounted for at least 95 % of the variance, were kept for further analyses. The magnitudes of these PCs were considered as the elemental variables (EV) of the UCM analysis.
The linear relation between the WBAM and the EV was expressed by a Jacobian matrix, whose null space, the Uncontrolled Manifold (UCM), was computed. The stride to stride variance of the EV was computed, projected onto the UCM and its orthogonal subspace, and normalized by these subspace dimension (4 and 1 respectively). It resulted in 2 components: V_{UCM} (note that this component does not affect the WBAM) and V_{ORT}. An index of synergy (ΔV) was computed as the difference between these 2 components, normalized by the total variance of the EV (normalized by the number of EV, 5). This index was used to quantify the strength of the synergies among the SAM stabilizing the WBAM.

RESULTS AND DISCUSSION

Whole body angular momentum patterns and results of the PCA were typical from those already published [1, 2], confirming that segments can be grouped in a small number of independent components. Figure 1 shows the time profile of the index of synergy for the sagittal plane averaged across subject. On overall ΔV was positive ($p<0.05$). Moreover, one can remark the increase of ΔV between the double support and swing phase ($p<0.05$).

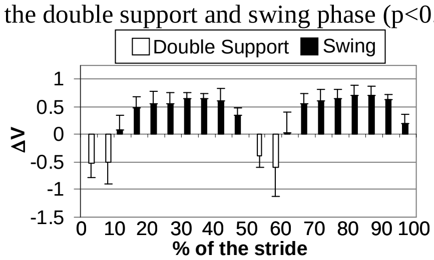

Figure 1: Time profile of the index of synergy averaged across subjects (± one standard deviation).

These results confirm that the WBAM is a variable of importance for the CNS. Moreover, the control of the WBAM differs between the gait phases: positive values of ΔV during double support reveal that synergies among the SAM are used to make the WBAM reproducible from stride to stride. On the opposite, during the double support phase ($\Delta V<0$) the CNS tends to adjust the WBAM from stride to stride. These observations have implications in terms of bipedal waking control and can be more particularly linked with the ZMP control methods.

REFERENCES

1. Herr H and Popovic M. *J Exp Biol* **211**, 467– 481, 2008.
2. Russell S. Dissertation, University of Virginia, 2008.
3. Latash ML et al. *Motor Control* **11**, 275–307, 2007.