From Humans to Robots and Back:
Role of Arm Movement in Medio-lateral Balance Control

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The Action Lab

AIM OF STUDY

In passive dynamic walking, it has been argued that bipedal walking is intrinsically unstable in the medio-lateral (ML) direction [1], [2]. Thus, body movements, and in particular arm movements, need to be actively controlled to maintain upright balance. Despite this important role in maintaining ML stability, arm movements have found relatively little consideration. **With the goal of developing control policies in humanoid robot locomotion, this study investigated how humans control their arms to maintain stability in the ML direction.**

Prior studies suggest that whole body angular momentum is a critical controlled variable in normal human locomotion [3], [4]. They observed that whole body angular momentum is small, despite substantial momenta from individual body segments [3]. Particularly in steady state walking, the contribution of the arms to whole body angular momentum in the medio-lateral direction is minimal [3], [4]. **To further understand the role of arm movements in stabilization, this study examined 3D body kinematics of humans walking on a narrow beam, where the instability in the ML direction was increased compared to overground walking.**

EXPERIMENTAL TASK

EXPERIMENT ONE

Sixteen healthy individuals participated in this experiment. In each trial, the subject walked along the narrow beam (3.4cm wide, 5m long) at a self-selected speed. A trial was deemed successful, if the participant remained on the beam for its entire length. Participants perfomed as many trials as necessary to complete 20 successful trials.

EXPERIMENT TWO

After experiment one, nine participants completed another set of 20 successful trials while their elbow and wrist joints were fixated by rigid tubes. An additional set of 20 successful trials with no constraints was then conducted to test for after effects.

CONTROL	CONSTRAINED	CONTROL
20 successful trials	20 successful trials	20 successful trials

HYPOTHESES

H1) When walking on a balance beam, the arms play a significant role in their contribution to whole body angular momentum in the ML direction.

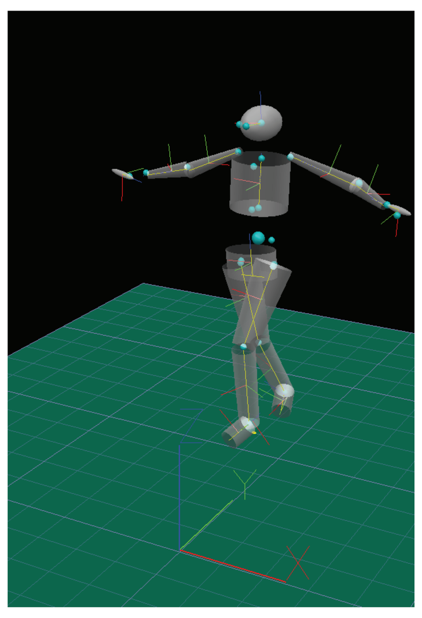
H2) Reducing controllable degrees of freedom (DOF) in the arms is detrimental to task performance.

DEPENDENT MEASURES

TASK PERFORMANCE

Number of failed attempts served as the measure of overall task performance.

ANGULAR MOMENTUM ABOUT BODY CENTER OF MASS



Motion of 15-segment rigid body model was fit to the 3D motion capture data

Angular momenta about the y-axis (frontal plane) around the body's COM were calculated for each segment i

$$L_i = r_i \times m_i v_i + I_i w_i$$

- L_i segment's angular momemtum about body's COM
- $I_i w_i$ angular momentum of the segment about its own COM
- r_i distance from body center of mass to the segment's center of mass
- m_i mass of the segment
- v_i translational velocity

Whole body angular momentum was calculated as the sum of individual segment angular momenta about the body's COM

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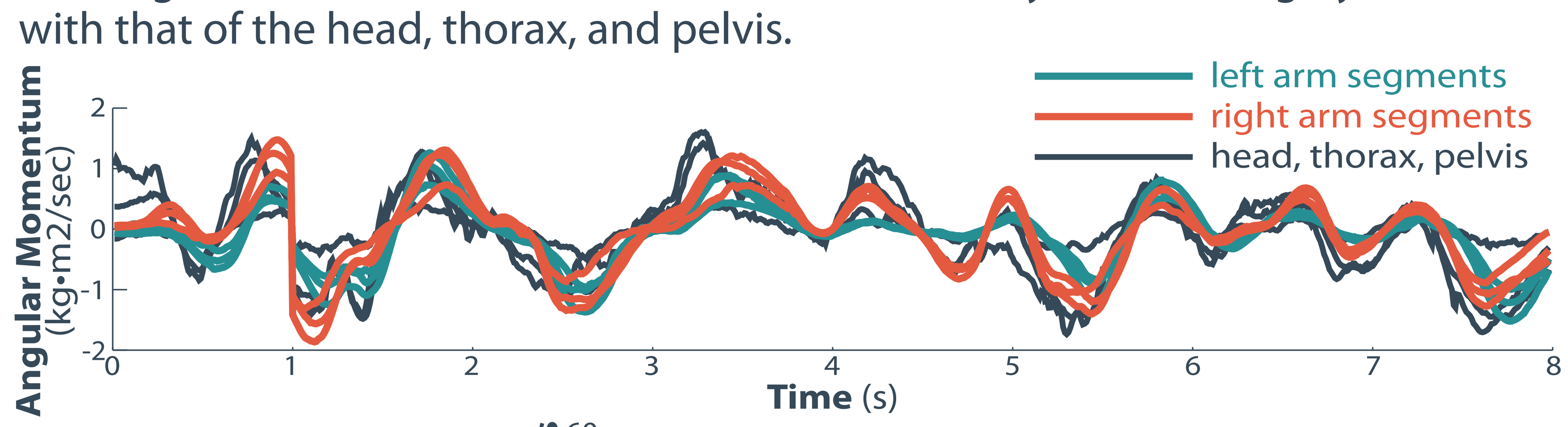
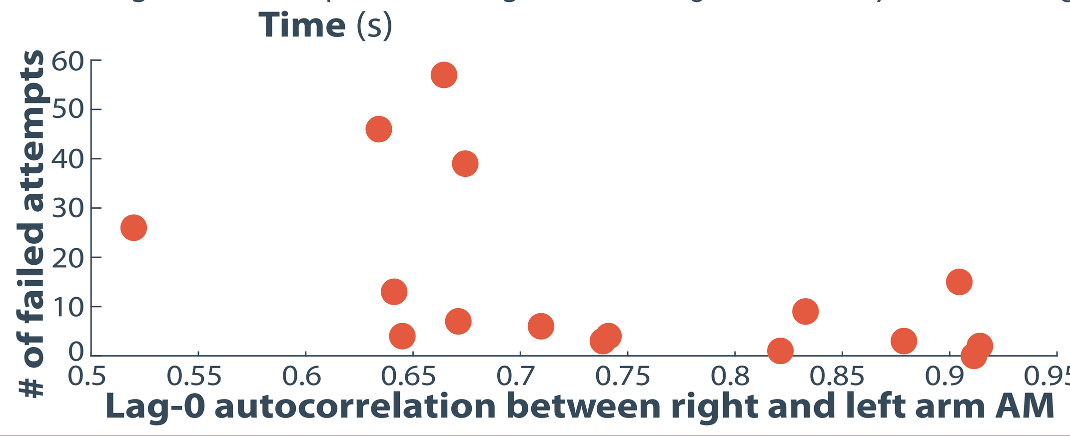
RESULTS: EXPERIMENT ONE

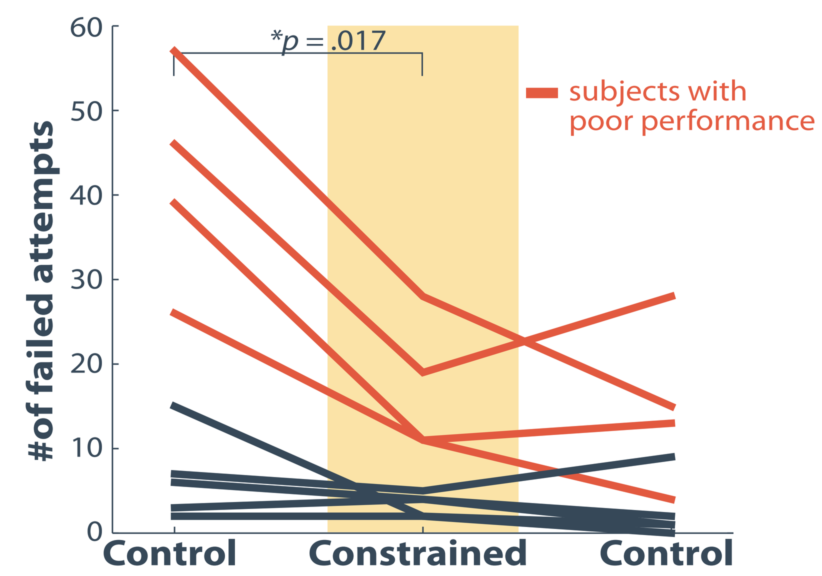
The angular momentum of the arms about the body's COM is highly correlated with that of the head, thorax, and pelvis.



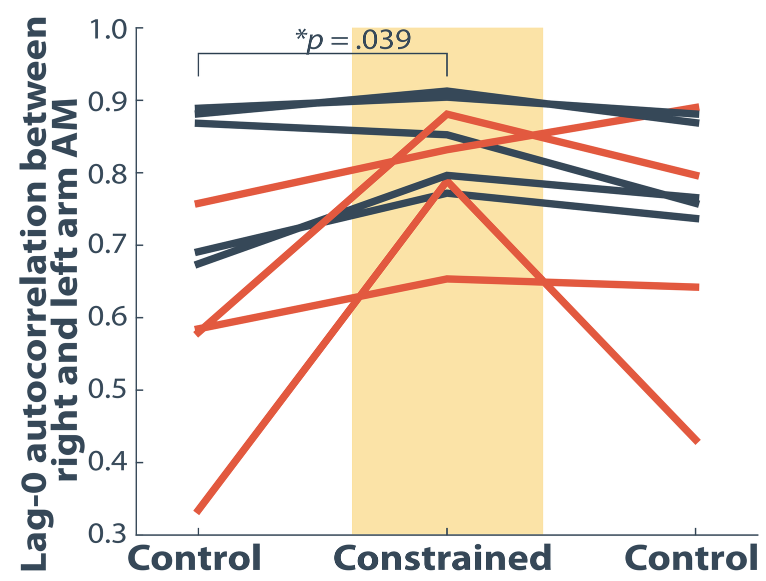
Those subjects with higher correlation between the right and left arm angular momentum about the body's COM had better task performance, $r(14) = -.52$, $p = .039$.



RESULTS: EXPERIMENT TWO



Constraining the arms did **NOT** debilitate performance as predicted. Instead, performance was significantly increased, although learning may have contributed to this effect.



Constraining the arms increased the correlation between the right and left arm angular momentum about the body's COM.

CONCLUSIONS

Subjects with higher correlation between right and left arms had better performance on the balance beam task.

- Contrary to hypothesis 2, reducing DOF in the arms was not detrimental to performance. Instead, it increased coordination between right and left arms. Although further work is needed to delineate this effect from a learning effect.
- We speculate that reducing DOF in the arms simplified control by minimizing interaction torques.

The segments in the upper body appear to contribute to angular momentum about the y-axis in the same manner. Thus it may be possible to simplify control of angular momentum in humanoids within this plane.

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