Analysis of Step Mechanics with Step Length Variation

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INTRODUCTION

- Humans or bipedal robots may be forced to use sub-optimal step lengths when adapting to constraints such as in obstacle avoidance, isolated foothold availability, or balance recovery.
- This study compared parameters from normal step length to those from increasing lengths to the point of failure.

What principles underlie motion at sub-optimal step lengths?

METHODS

- Ten each male and female subjects, 18-25 y.o.
- Normal step length measured. Subjects completed stepping motion at normal length plus successive 10% of height (Fig. 1).
- Whole-body kinematics, ground reaction forces, and lower extremity EMG recorded.
- MATLAB program [1] produced OpenSim [2] input.
- OpenSim model gait2354 scaled to match each subject's anthropometry.
- OpenSim was used for data analysis (Fig. 2):
  - Inverse kinematics algorithm solved for joint positions that best matched subject's motion.
  - Inverse dynamics algorithm solved equations of motion for joint reactions.

Figure 1. Instrumented participant at starting position.

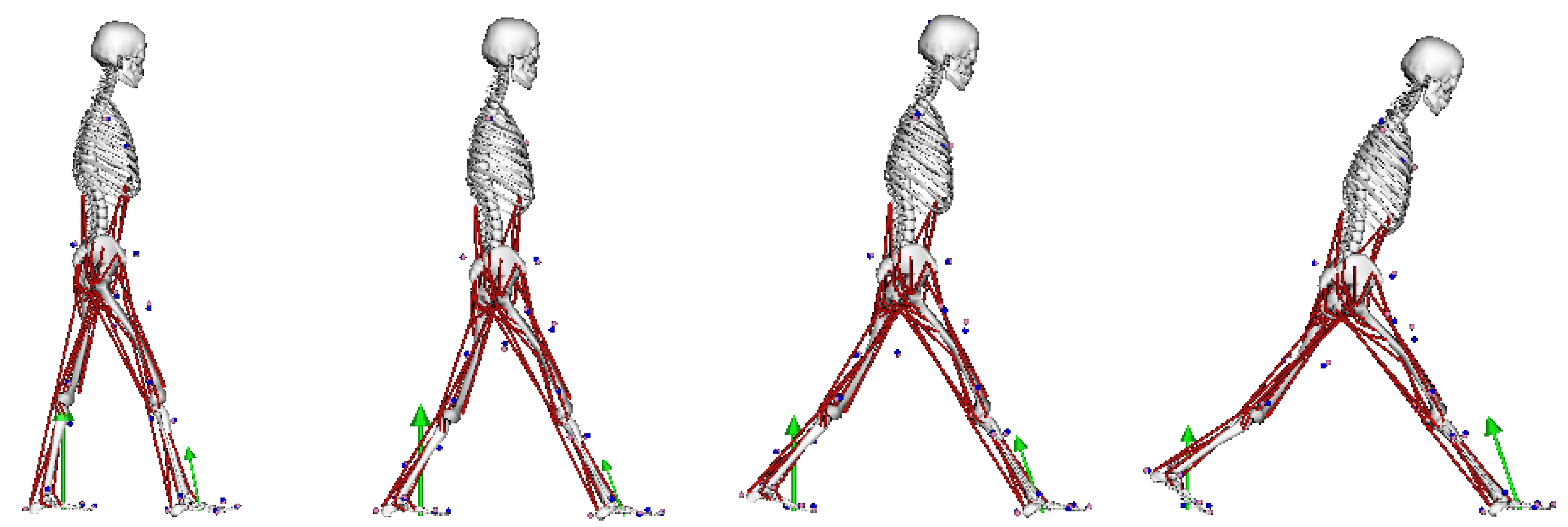

Figure 2. Simulation of subject position at the start of a right-foot-forward step for steps 0, 1, 2, and 3. Green arrows show center of pressure and the direction and magnitude of the ground reaction force.

RESULTS

- Only females included in current analysis (Figs. 3 & 4).

Hip:

- Peak front and back hip moments increased with step length.
- Back-hip flexural moment was larger than front extensional moment.

Knee:

- Peak knee moments were less than peak hip moments.
- Back knee moment was larger than front.
- Peak back and front knee moments increased with step length.

Ankle:

- Ankle moments had large variability, particularly in the front leg.
- Both front and back ankle moments were fairly constant across step lengths.
- Peak back ankle moment (0.9 N-m/kg) was twice as large as front.

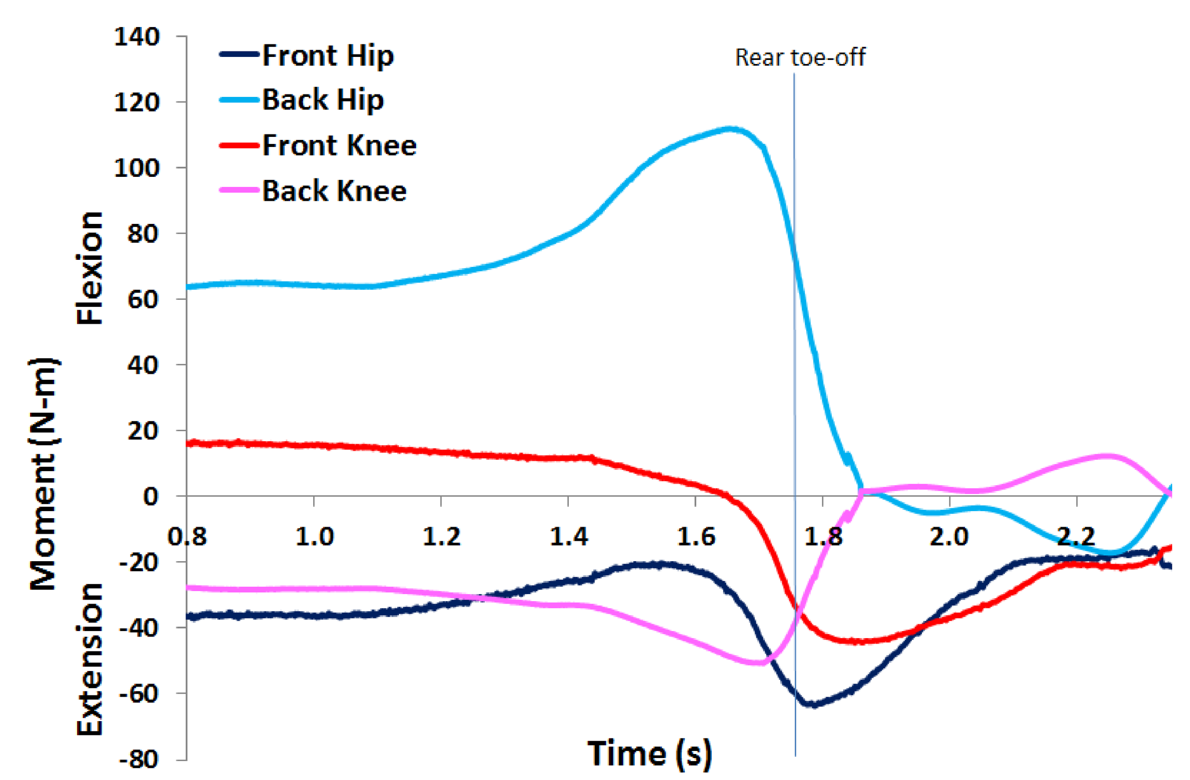

Figure 3. Typical moments from a single trial. Time is truncated when the rear foot begins weight-bearing on the front force plate.

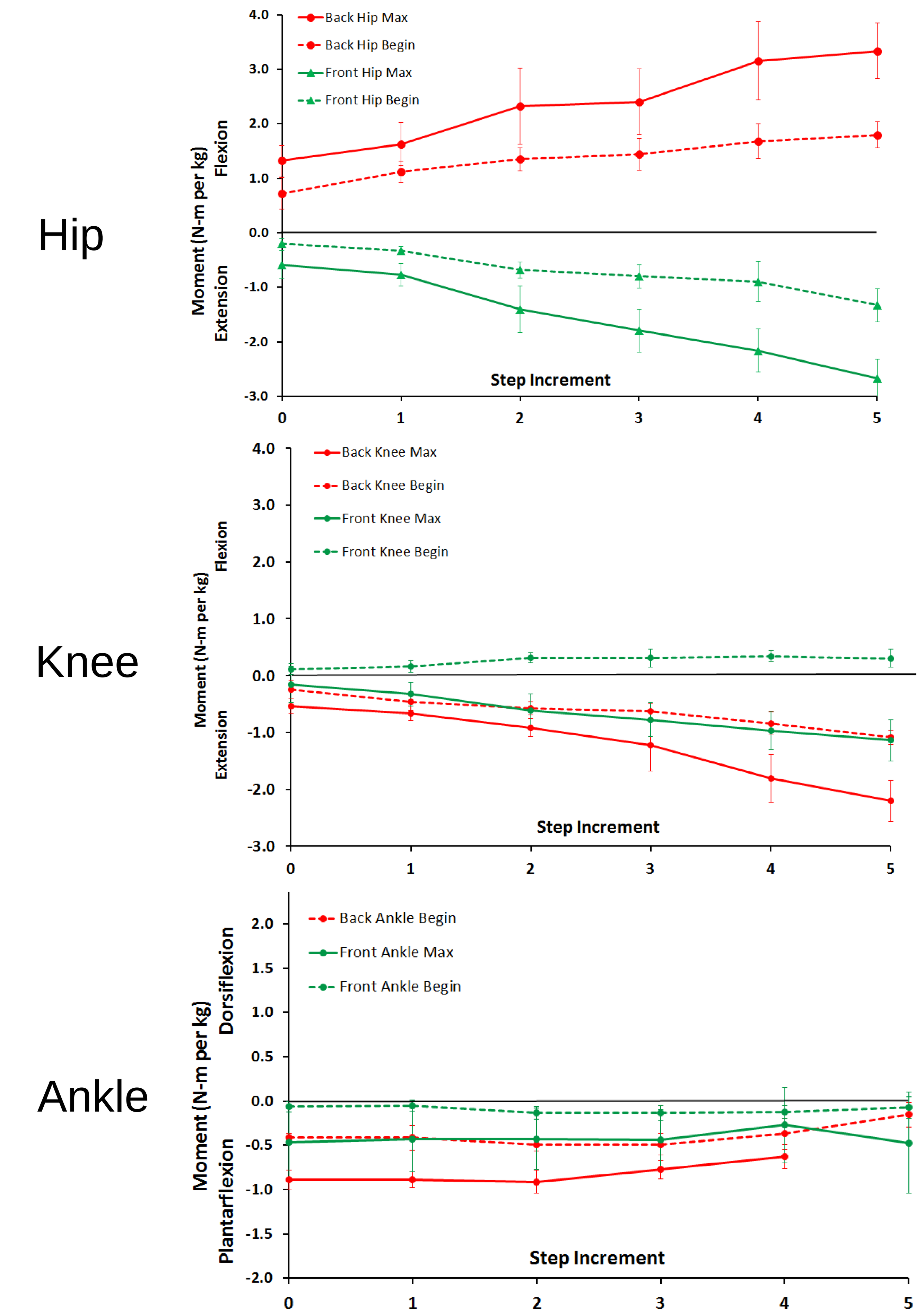

Figure 4. Maximum and beginning joint moments as a function of step increment (mean ± SD, n=9). All moments are plotted with flexion direction positive.

OPEN QUESTIONS

- What other variables are of interest for the robotics community? (e.g., joint forces, center-of-pressure, body center-of-mass location, individual muscle forces)
- Should the beginning moments be used to adjust the maximum moments?
- Is there a change in strategy as step length increases?
- What basic principles can be extracted from these results?

REFERENCES

[1] Kelly, John. Master's Thesis, North Carolina State University, 2008.
[2] Delp SL *et al*. *IEEE Trans Biomed Engr 54(11):* 1940-1950, 2007.