Medial-Lateral Oscillating Load Carriage on Gait Kinetics and Energetics

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1 Introduction

Altering mechanical compliance of a load carriage device in the vertical direction has shown to reduce metabolic cost and accelerative forces of carrying weight [1, 2]. Currently, modifications to load carriage compliance have been entirely targeted at vertical motion of the carried weight. We developed a backpack that allows a carried mass to oscillate in the medial-lateral direction. By choosing device parameters that elicit out-of-phase oscillations of the carried mass, with respect to the trunk of the user, we aim to reduce the accelerative forces of carrying weight similar to vertical oscillating load carriage devices.

2 The Device

The medial-lateral load carriage device suspends the carried weight using an inverted pendulum (Fig. 1). The inverted pendulum is then housed within a rectangular frame (weight = 2.2kg). The rectangular frame is mounted to a commercially available backpack frame (weight = 2.4kg) via a 6DOF load cell. Linear springs act at various lengths up the pendulum shaft, providing an equivalent torsional stiffness up to 250Nm/rad. The pendulum shaft is of variable length (12.5-40cm). Carried weight is simulated using cylindrical free weights in increments of 4.5kg.

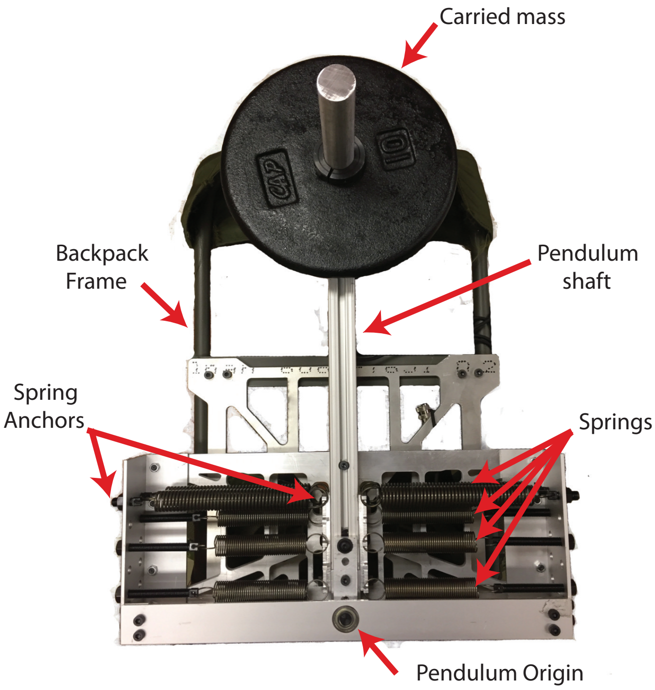

Figure 1: The medial-lateral load carriage device. Major components are labeled, with the exception of the 6DOF load cell mounted between the device frame and the backpack frame.

3 Methodology

During pilot testing, subjects consistently reduced their step width when walking with the device, confounding comparisons that could be made between fixed and oscillating conditions. Therefore, for our experiment, we held step width at (0%), below (-40%, -20%), and above (+20%, +40%) preferred levels of step width, using biofeedback. This allowed us to test why subjects may of chosen to reduce their step width while walking with the device. As well, systematically altering step width will indirectly vary oscillation amplitude of the carried mass. As the input to the system (amplitude of medial-lateral trunk displacement) increases with step width, the output oscillation amplitude of the carried mass is expected to increase as well.

During the experiment, subjects (n = 8) walked with the device, at all prescribed step widths, in unlocked (oscillating) and locked (fixed) backpack conditions. Device oscillatory response was measured using motion capture. The interaction force and moments between the device and user were measured using the 6DOF load cell. The metabolic power of walking was measured using a portable respirometry unit. Lastly, lower-limb joint power and work was estimated using motion capture and an instrumented treadmill.

4 Results

By selecting spring configurations that resulted in a device natural frequency less then the trunk's forcing frequency, the carried mass oscillated out-of-phase with respect to if the mass was rigidly fixed (Fig. 2). It can also be seen that as step width increased, the amplitude of lateral oscillations increased for unlocked conditions.

Out-of-phase oscillations of the carried mass led to a reduc-

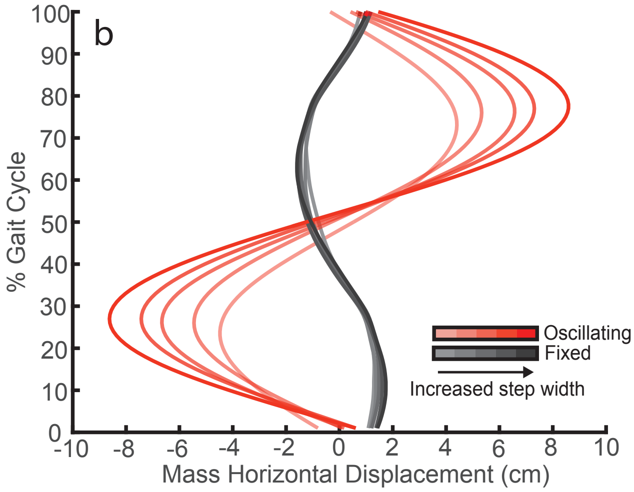

Figure 2: The carried mass' relative lateral displacement from the pendulum origin over a stride. Trajectories under the oscillating conditions are shown as red, where as grey conditions are fixed. Increased line transparency indicates a decrease in step width.

tion in the device interaction forces in the horizontal and vertical direction. However, the frontal plane interaction moment increased during oscillating conditions, compared to fixed. In addition, the increase in frontal plane interaction moment was also found to become larger with greater oscillation amplitude. The metabolic power required to walk with the device increased for oscillating conditions, compared to fixed. The only exception being the most narrow step width (-40% preferred step width), where no significant changes in metabolic power between backpack conditions was observed. The increase in metabolic power was accompanied by an increase in peak power and hip work performed during stance.

5 Discussion and Future Work

Although the device was able to reduce peak interaction forces, the metabolic power required to walk with the device generally increased during oscillating conditions. However, there was no significant difference in metabolic power between backpack conditions at the most narrow step width condition (-40% preferred step width). A possible explanation may be that greater mass oscillation amplitude has negative consequences for the energetics of gait.

For the Dynamic Walking Conference, we anticipate having collected several subjects walking with the device with a new energy harvesting module attached. We aim to present some of the preliminary findings of this device at the conference. With the energy harvesting module, we aim to generate electricity from the relative motion of the carried mass during oscillating conditions. The damping induced by energy harvesting will also allow us to reduce lateral oscillation amplitude and vary the phase angle of oscillations.

References

[1] L. C. Rome, L. Flynn, T.D. Yoo, "Biomechanics: Rubber bands reduce the cost of carrying loads," Nature, 2006, 444:1023-1024.

[2] E.R. Castillo, G. M. Lieberman, L. S. McCarty, D. E. Lieberman, "Effects of pole compliance and step frequency on the biomechanics and economy of pole carrying during human walking," Journal of Applied Physiology, 2014, 117:507-517.