Is a Passive Perturbation Device Assisting Medial-Lateral Balance During Walking?

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1 Introduction

Active stabilization of motion in the frontal plane is believed to be governed by a metabolic trade-off between centre of mass (COM) step-to-step transition work and required active movement of the legs to adjust for medio-lateral foot placement [1, 2]. Mathematical modelling suggests that improvements in frontal plane stability can come from providing external lateral stabilization [2, 3]. Two studies [2, 4] have shown that metabolic reductions up to 6% can be achieved by providing external stabilization through elastic elements applying a restorative force to the centreline of progression. We have developed a device that intends to similarly provide varying medial-lateral load response using a completely onboard system. The device suspends the weight normally carried in a backpack and allows it to oscillate in the medial-lateral direction. By tuning the passive suspension elements we allow the mass carried in the pack to oscillate out of phase with COM horizontal excursions, providing a restorative force to the centreline corresponding with leading leg negative work contributions in redirecting the COM during step-to-step transitions. Our hypothesis is that a restorative force will act as lateral stabilization, reducing both step width and step width variability as shown in [2, 4], leading to a reduction in mechanical work required to redirect the COM.

2 The Device

The device, shown in Figure 1, suspends the mass carried in a pack (simulated as a proof mass) using an inverted pendulum of varying length (10-40 cm). Linear springs act at different insertion lengths (2-10 cm) up the pendulum shaft allowing for varying spring constant configurations (1-280 Nm/rad). The device weighs 2.2 kg and is connected to a backpack frame through a 6DOF load cell (Mini-45, ATI Industrial Automation, Apex, NC)(frame = 2.4 kg, load cell = 92 g) (Figure 1.B).

3 Methodology

The system is modelled as a 1DOF inverted pendulum with base excitation due to harmonic motion of the user's trunk. Using the model, system parameters are then found that tune system suspension, giving desired horizontal motion of the proof mass. By choosing parameters that result in a system natural frequency lower then the horizontal forcing frequency of the subject, the resultant motion of the mass will be out of phase with the horizontal oscillations of the user's trunk. Parameters are then further tuned to control mass horizontal amplitude across a desired range .

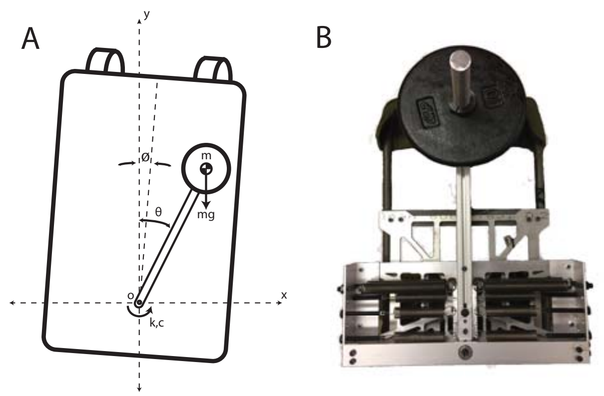

Figure 1: (A) A simplified model of the device as an inverted pendulum suspending a carried mass. (B) The fabricated device with 4.53kg proof mass.

Human experimentation will involve 10 subjects (n = 10) walking with the device in a locked and unlocked position. Subjects will first complete a 25 minute acclimatization period with the device 24-48 hours prior to testing. On the day of experimentation, subjects will walk a total of 6, 5 min trials, carrying a mass of 4.53kg. Walking conditions will be randomized and are as follows: device locked resulting in no pendulum motion and 5 unlocked trials of varying mass oscillation amplitude (2-10 cm). Subjects will walk on a split-belt AMTI Force-Sensing Tandem Treadmill (AMTI Inc., MA) while recording 3D joint kinematics and kinetics of the foot, shank and thigh using a seven-camera motion capture system (Oqus, Qualysis, Sweden). COM horizontal excursions and variability, along with step width and variability will be measured using force treadmill data sampled at 1000 Hz. Device force, work and work rate contributions will be recorded using a potentiometer on the drive shaft and a 6DOF load cell mounted between the device and the backpack frame.

Figure 2: The device, without mass or springs, mounted to the testing apparatus.

4 Initial Results

Device performance testing was conducted under a free vibration response to initial conditions. Testing was performed in the apparatus shown in Figure 2. The model predicted system parameters that resulted in a natural frequency within 2.54 $\pm$ 2.38 % of the desired natural frequency over six varying mass and pendulum length conditions. Human experimentation outlined in the methodology section is underway.

5 Best Possible Outcome

With human experimentation to be completed by the conference, we have outlined the best possible outcomes of the proposed study. First, verifying mass horizontal amplitude is within a desired limit of the model's predicted horizontal amplitude. Secondly, that the inertial force of the proof mass assists the leading leg during weight acceptance by reducing step-to-step transition work in the medial-lateral plane. This we hypothesize, based on the results of [2, 4], will lead to a reduction in horizontal COM excursions, step width, and step width variability. Lastly, we aim to find a relationship between the aforementioned parameters and the amount of assistance provided. We aim to address this by varying the amplitude of the horizontal mass and relating it to the observed changes in kinematic and kinetic behaviour.

References

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