Assessing the Performance of a Lower-Limb Energy Harvesting Device

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1 Introduction

With the rise in popularity of mobile devices, our dependence on portable electricity has led to exploration to increase battery capacity. Batteries however are limited by the amount of energy stored per unit mass. Research in energy harvesting has shown that useable amounts of energy can be captured from human movement during daily activities [1, 2]. A biomechanical energy harvester was developed that can produce over 10 Watts of electrical power from lower limb movement. To date, the harvester's performance has been assessed through a performance factor, the total cost of harvest (TCOH) [3], while walking on a treadmill. The TCOH is the ratio of the metabolic power increase from normal walking without carrying the harvester to the amount of electrical power produced.

Instead, a new method of assessing device performance is proposed; we wish to find the metabolic cost of transport (COT) in both overground and treadmill walking conditions at an overground self-selected speed. Additionally, electromyography (EMG) will be used to assess changes in muscular activation over different walking conditions.

2 The Device

The new lower-limb harvester uses a concept of regenerative breaking, similar to that of cars, to target a region of negative work during the end of swing phase during walking. It integrates the out-of-phase motion of both lower limbs in to a single device located near the centre of mass of user, reducing the cost of carrying the weight of the device.

The device entails a harvesting unit and a pair of foot harnesses (Figure 1.A). The harvesting unit is mounted to the bottom of a backpack frame. Two individual cables, attached to the foot harness at each ankle joint, are fed from and retracted into the harvesting unit (Figure 1.B). A gear train amplifies the cable linear displacement and integrates motion of each limb into a single rotational motion. This rotation drives an electric generator, converting mechanical energy to electrical energy.

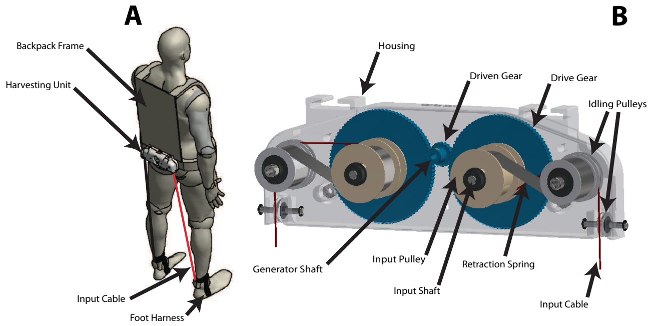

Figure 1: (A) The harvester system worn by a user. (B) The harvesting unit with front cover removed.

3 Methodology

Our study will look at the cost of transport while walking on a treadmill and overground. After an acclimatization period of walking with the harvester is completed, the subject will walk four randomized walking conditions for 10 minutes each. The four conditions are as follows: overground normal walking, overground harvesting, treadmill normal walking, and treadmill harvesting.

During treadmill conditions, 10 subjects will walk at the overground self selected speed previously determined. A unique speed will be found for both harvesting and normal walking conditions. Overground walking will be conducted on a 60m indoor track.

During the four conditions, the metabolic energy expenditure will be found using a respirometer measuring O^2 intake and CO^2 production. Metabolic energy will be normalized to both subject's weight and distance travelled to find the cost of transport (COT). EMG of knee flexors/extensors and ankle plantar flexors will be recorded using sEMG.

4 Initial Results

Two comparisons will be made over the four walking conditions. First, treadmill walking COT will be compared to overground walking COT. Secondly, we wish to study differences in COT between harvester and normal walking, in both treadmill and overground walking. Preliminary results for three subjects are shown in Figure 2. In the first three subjects, COT

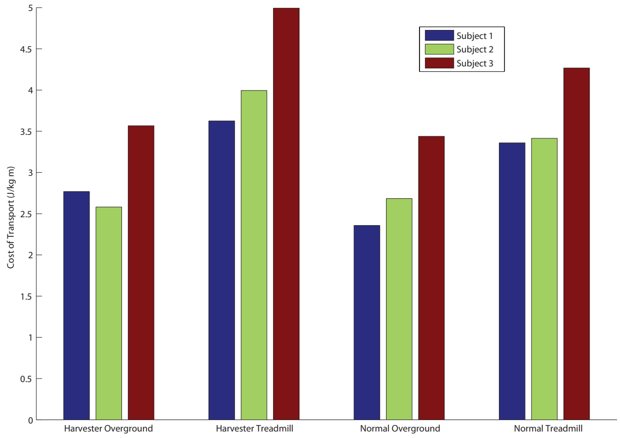

Figure 2: Preliminary data showing the cost of transport (COT) for three subjects over the four walking conditions.

is reduced during overground walking compared to treadmill walking. Additionally, we see that when walking with the harvester on the treadmill, COT is increased compared to normal walking on the treadmill. However, in overground walking, the COT for subject's 2 and 3 for walking with the harvester are closer in value to normal walking.

Sample EMG data for subject 1 is shown in Figure 3. A single knee flexor and extensor muscle is shown. EMG data will be used to determine underlying mechanisms responsible for metabolic differences across conditions.

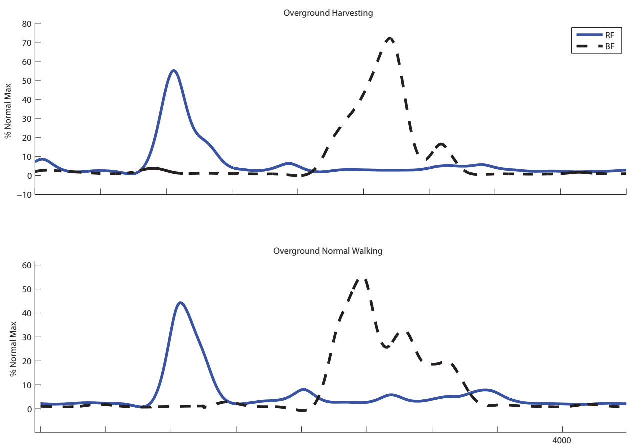

Figure 3: Preliminary data showing EMG response for the biceps femoris (BF) and rectus femoris (RF) for both harvester and normal walking conditions overground.

5 Best Possible Outcome

Our initial hypothesis is that the COT will be reduced from treadmill to overground walking for both normal and harvesting conditions. Additionally, we hope to see the the COT of walking with the harvester to be similar to that of normal walking when done overground. This would imply energy is being generated at no additional metabolic expenditure for the user.

Our hypothesis is that instabilities during gait, caused more frequently during harvester walking due to an externally applied force, will be dealt with more energetically efficiently while walking overground then compared to on a treadmill. We do not know the exact mechanisms responsible, however treadmill walking introduces an additional constraint during gait: a reduction in a degree of freedom. The harvester will additionally reduce another degree of freedom. The idea being more metabolic energy will be used by the user to overcome two reductions of degrees of freedom, instead of dealing with solely one. Further analysis of EMG experimental results and gait parameters such as step frequency will hopefully reveal underlying mechanisms responsible for such changes in metabolic data.

References

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