Comparing the Energetic Effects of Different Energy Harvesting Profiles

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1. Motivation

One of the primary goals of exoskeletons is to assist humans in performing daily activities, such as walking, in efforts to decrease their metabolic cost. This goal has recently been achieved by an unpowered exoskeleton [1]. Through collecting energy during one phase of gait and reintroducing it to the user during another phase, the device effectively increased the walking efficiency of the user. This result demonstrated the possibility of decreasing the metabolic cost of walking without reliance on energy from an external power source. A remaining question is whether the metabolic cost of walking could be reduced, purely by harvesting energy from the user. Such a device could assist the user while simultaneously converting the harvested energy into electricity.

The lower limb-driven energy harvester (Figure: 1A) developed at Queen's University has been shown to decrease the metabolic cost of walking below that of walking while carrying the weight of the device, while simultaneously producing 5W of electrical power [2]. The ability of this device to assist the user in walking is likely due to the harvester aiding the user's muscles in producing a knee flexion moment during the terminal swing phase of gait [3]. This mechanism is similar to that of regenerative braking in the knee harvester [4].

Previously, this device produced electricity using a constant electrical resistance bank. This caused the moment applied by the harvester to the user's knee to be proportional to the motion profile inputted into the device (Figure 1B: blue). This loading profile is considered non-ideal with respect to providing proper assistance to the user, due to a portion of it falling outside of the natural net knee moment profile (Figure 1B: black). Therefore, instead of the device aiding the user in producing the natural knee flexion moment, it may have caused the user to generate an extension moment to overcome the mechanical resistance of the device. This may be the reason why the metabolic cost of walking while harvesting is higher than that of normal walking.

We hypothesize that a harvesting profile that mimics the user's natural net knee moment could better assist the user, and therefore lead to a larger metabolic decrease than a constant resistance profile. We also hypothesize that this profile could achieve a net metabolic benefit compared to normal walking.

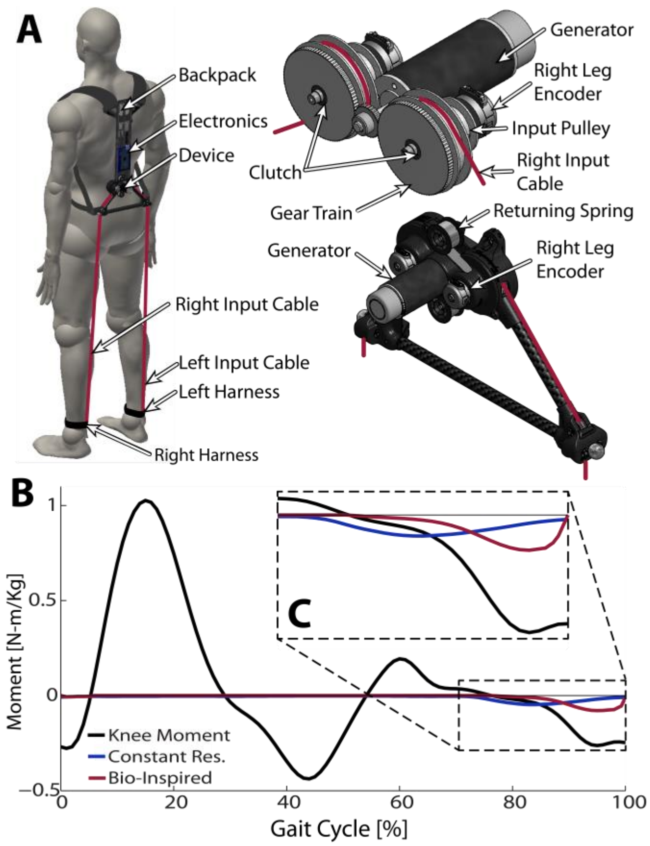

Figure 1: (A) Lower limb-driven energy harvester; **(B)** Net knee moment [N-m/kg] (black), moment applied to user via a constant resistances loading profile (blue), and theoretical moment from the proposed bio-inspired profile (red) during a gait cycle. **(C)** Enlarged view of (B) during the terminal swing phase.

2. Our Approach

In efforts to provide optimal assistance to the user, we have developed a novel bio-inspired harvesting profile that is proportional to the natural net knee moment profile (Figure 1B: red). A linear regulator was utilized to decouple the motion-load relationship and to implement this novel loading profile.

To test our hypotheses, preliminary human treadmill walking experiments were conducted. Energetic and bio-mechanical effects of the novel loading profile were compared to that of both the constant electrical resistance loading profile and normal walking. One day prior to testing, the participants performed five treadmill walking trials. The participants completed one ten-minute trial consisting of walking with the novel harvesting profile and four one-minute trials consisting of walking with four different constant resistances (1, 3, 5, 7Ω). These trials were used to identify a constant resistance that would result in harvesting the same amount of mechanical power between the constant resistance and the bio-inspired profile conditions. On test day, each participant performed four treadmill walking trials: 1) normal walking, walking without the device; 2) weighted, walking while carrying the device; 3) Constant, harvesting energy with a constant electrical resistance; and 4) bio-inspired, harvesting energy using the bio-inspired harvesting profile. Trials were completed in a randomized order.

3. Preliminary Results

Preliminary metabolic results from two participants suggest that it may indeed be possible to decrease the metabolic cost of walking, without reintroducing the harvested energy to the user (Figure 2A). These results are particularly interesting because, not only did both the novel loading profile and the constant resistance profiles lead to a metabolic benefit compared to normal walking, but the constant resistance loading profile was associated with a reduction in the metabolic cost of walking greater than that of the bio-inspired loading profile. Under the constant resistance and bio-inspired loading profile, the harvester produced 2.4W and 0.7W of electricity respectively.

Unfortunately, a direct comparison between the two harvesting profiles cannot be made due to differences in the amount of work performed at the user's knee by the device during the two trials (constant resistance: 0.027J/kg, bio-inspired: 0.02J/Kg). Therefore, it is not yet clear whether the differences in metabolic cost were related to the shape and timing of the profiles or to the magnitude of assistance provided to the user. Therefore, the constant resistance profile may have resulted in a lower metabolic cost of walking than the novel loading profile during the preliminary trials, because the device is aiding the muscles in performing more negative work under the constant resistance profile.

4. Future Work

In order to directly compare the effects of the different loading profiles, we are currently incorporating work regulation into the loading profile. This will enable our device to assist a specific amount of work at the user's knee, 0.03J/Kg per leg per gait cycle, during both of the harvesting profiles. This amount of negative work was selected because it was associated with the largest decrease in metabolic cost in previous walking trials [2]. Once the control system is implemented, treadmill walking experiments will be conducted to determine the effects of the two different loading profiles on the user.

5. Expected Outcomes

The regulation of work being assisted at the knee by the control system will allow for a direct comparison between the two different loading conditions. This comparison will provide a better understanding of the bio-mechanical and energetic effects of different assistive profiles. This study may also answer the question of whether a device can decrease the metabolic cost of walking below that of normal walking, while harvesting energy for electrical power production.

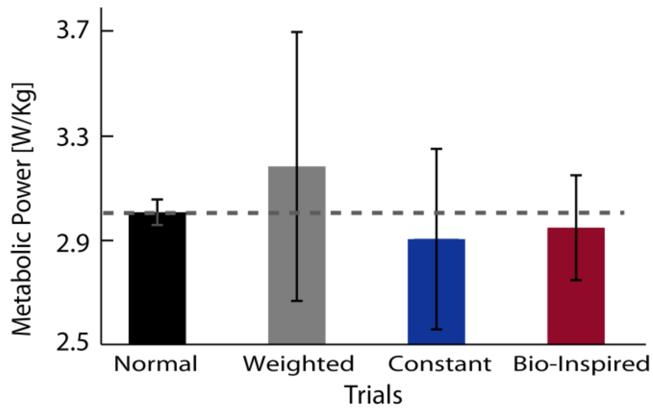

Figure 2: Preliminary metabolic power results [W/kg], for the four walking activities: Normal, walking without the device (black), Weighted, walking while carrying the device (grey), Constant, harvesting energy with a constant electrical resistance (blue), and Bio-Inspired, harvesting energy using the bio-inspired harvesting profile (red).

References

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