Identifying the best two-joint combination of hip, knee, and ankle exoskeleton assistance

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I. Introduction

Advancements in exoskeleton assistance optimization have brought about improved reductions in the metabolic cost of walking for both single- and multi-joint assistance. However, direct comparisons of metabolic reduction efficacy between different assisted joint pairs remain to be made. Here, we optimize and assess the three combinations of two-joint assistance (hip-knee, knee-ankle, and hip-ankle) to better understand how these variations on two-joint assistance affect biomechanical outcomes such as metabolic cost, muscle activation, and joint kinematics.

II. Methods

Using the hip-knee-ankle exoskeleton emulator described in [1], assistance was optimized for each of the two-joint combinations. We used human-in-the-loop optimization to find assistance that minimized the measured metabolic cost of walking at 1.25 m/s, similar to [2]. After arriving at optimized parameters, a validation experiment was conducted where the participant walked in optimized assistance, zero-torque, and no exoskeleton conditions. Data collected in validation experiments included applied torque, indirect calorimetry, electromyography, and joint kinematics. This protocol has been completed by one participant thus far; we expect to have results for two additional subjects.

III. Results & Discussion

The greatest metabolic reduction was achieved by hip-ankle assistance (42% relative to no torque condition), followed by knee-ankle (35%) and hip-knee (34%) (Figure 1). As expected, these values are greater than the best single-joint assistance metabolic reduction (ankles-only, 30%) and less than the reduction realized by three-joint assistance (50%) [3]. Optimized torque profiles varied with configuration; for example, hip extension torque magnitude was larger in the hip-knee configuration than in the hip-ankle configuration. This shows that optimal assistance depends on exoskeleton configuration. Small changes were observed in joint kinematics and muscle activation in different assistance conditions, indicating that the user was adapting their gait to different types of assistance. These changes in biomechanics may help illustrate why different assistance conditions are able to achieve different metabolic reductions.

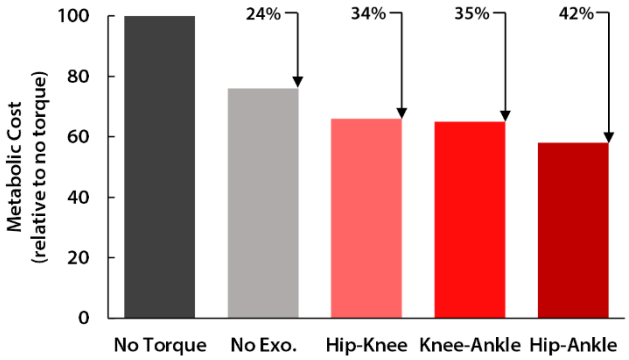

Figure 1. Metabolic reduction of 2-joint assistance conditions (n=1). Percent reductions are relative to no exoskeleton condition.

IV. Conclusion

For maximally reducing the metabolic cost of unloaded walking on a flat surface, we find that hip-ankle assistance is the optimal joint assistance pair. These findings should be weighed in combination with other factors such as cost and weight when optimizing exoskeleton design. Future studies could examine how changes in the walking task, such as walking up a grade or carrying a load, affect these results.

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