Passive inter-joint gait assisting exoskeleton suit

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Summary

Recent breakthrough in passive gait assisting exoskeletons have shown a reduction in of user effort below that of normal walking by assisting the ankle joint. Assisting multiple joints intuitively suggests that further reduction in user effort can be achieved. However, previous attempts in developing passive inter-joint exoskeletons have not yet been successful. The energetic pathways for an inter-joint approach to passive exoskeletons is currently unclear. This study attempts to expand our understanding of passive inter-joint assistance for gait assisting exoskeletons. Three configurations of a passive inter-joint gait assisting exoskeleton system are explored in this study.

Introduction

Recent developments in passive gait assisting exoskeletons has demonstrated a reduction in the net metabolic rate during normal treadmill walking of 7% (Collins et al., 2015), and the device focuses on only a single joint (ankle). The approach taken in the current study is to employ a passive inter-joint assistance approach whereby no external source of power or work in added to the human biological system and the only available method is to transfer energy between the joints for gait assistance. While the concept of passive inter-joint assisting devices has previously been proposed for both prosthetic and exoskeletons alike (Unal et al., 2010; van den Bogert, 2003; van Dijk et al., 2011), there are still many unknowns on the effects of gait assisting exoskeletons on human gait and a successful reduction in subject metabolic effort has yet to be demonstrated using a passive inter-joint approach.

The aim of this study is to evaluate the efficacy of an inter-joint exoskeleton suit at varying degrees of joint assistance. Our hypothesis follows the notion of superposition, whereby assisting more joints will result in large reductions in the metabolic rate. While this hypothesis appears to be intuitively simply, there exists many challenges such as an effective human device interface. In this study we will experimentally compare the results between three device configurations using only a passive approach: a) ankle-knee joint assistance, b) hip assistance and c) combined assistance.

Device

The exoskeleton suit is comprised of adjustable nylon webbing straps. Each configuration a) ankle-knee, b) hip, c) combined, is achieved by adding or removing the respective lower limb component shown in Fig. 1. The basic function of the device aims to convert negative joint work during certain periods of gait cycle into elastic potential energy and assists in performing positive joint work, with the exception of the knee joint. At the knee joint, the current configuration of the device assists in reducing the negative work at the knee joint by assisting the knee during terminal swing.

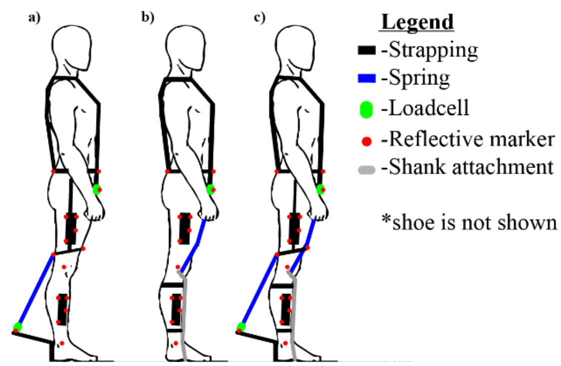

Fig. 1: Three configurations of the passive inter-joint gait assisting exoskeleton suit. (a) Ankle-knee, (b) Hip-only, (c). Combined. The spring elements in blue do not indicate they are the same types of physical springs.

Approach

Eight healthy male subjects will be recruited for this study. All subjects will walk on a force instrumented treadmill (Tandem Force Treadmill, AMTI) for 8mins at 1.25m/s for three randomized walking conditions i) normal, ii) weighted and iii) device engaged. In walking condition ii) the subjects will don the entire device without spring elements while in condition iii) the spring elements are connected. Condition iii) is repeated for each configuration of the device a) ankle-knee, b) hip, c) combined. The metabolic rate for each trial is estimated during the last two minutes of each trial using $V0_2$ and VCO_2 measurements from the COSMED K4b2 and the Brockway equation (Brockway, 1987). Motion capture data is obtained using a 7 Oqus Camera setup and all data synchronization is provided by Qualysis QTM. Kinetic and kinematic data from a minimum of 10 consecutive gait cycle within the last two minutes of each trial is averaged to coincide with the metabolic data. The inverse dynamic method is employed to estimate kinetic and kinematic results. Force plate and motion capture data are filtered using a zero-phase, 4th order Butterworth with a cut-off of 25Hz and 12Hz, respectively. Gait cycle segmentation is identified using the ground reaction force data. Inertial parameters of the lower limb segments are estimated with regression equations (Vaughan et al., 1999). Device contribution to joint kinetics is calculated by subtracting the biological contribution from the net joint value. The subjects will use a standard running shoe (New Balance, 880-v3) individually sized for all trial conditions. A custom shoe insole is used to interface with the foot and replaces the stock insole of the running shoe for conditions ii) and iii). Spring forces are measured using miniature load cells mounted in series with each respective spring, Fig. 1. The magnitude of assistance is controlled between subjects by setting spring force to within 1N while in a calibration pose.

Discussion

Preliminary results of a previous prototype in the ankle-knee configuration (Fig. 2) demonstrates that the device allowed the subject to maintain normal ankle and knee joint power profiles. We expect reductions in both positive and negative biological joint power as the net profile is a summation of the device and biological contributions. The only period which observed an increase of joint power was terminal swing at the knee joint, Fig. 2.

Expected Outcome

Both hip and ankle are approximately equal contributors of positive work to the limb during normal gait within the corresponding walking speed while the knee joint performs the majority of negative work (Farris and Sawicki, 2012). This suggests that the ankle-knee assistance configuration will outperform the hip-only configuration in reducing the participants' metabolic rate since it assists both the ankle in performing positive work and the knee in performing negative work while the hip-only configuration only assists the hip in performing positive joint work during hip flexion. The combined device configuration is expected to outperform the other two configurations as it assists the entire limb at all three joint levels.

Preliminary Results

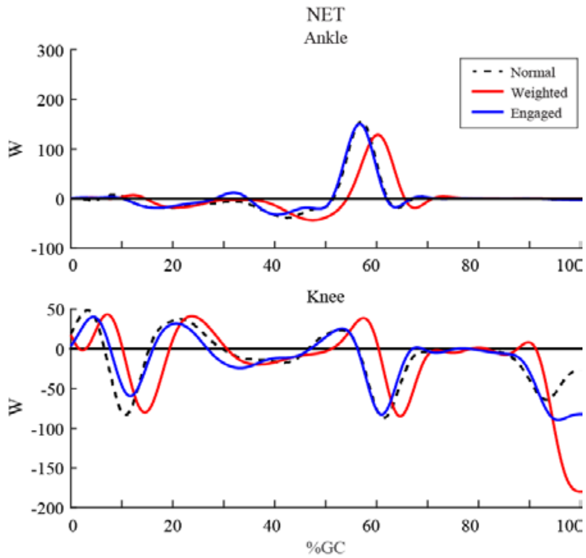

Fig. 2: Preliminary results for a single subject using a previous prototype in the ankle-knee configuration. The "temporal shift" in the Weighted condition is probably caused by the inertia of the shoe insert which may delay push-off progression and increase in negative knee joint power during terminal swing.

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