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Research Brief

# Passively-powered knee exoskeleton to reduce human effort during manual lifting



Manual lifting is an indispensable activity in many occupations such as manufacturing, construction, and agriculture. The task involves moving loads upwards or downwards without mechanical assistance [1]. As a result of manual lifting or lowering, workers around the globe are experiencing a variety of musculoskeletal disorders (WRMSD). According to The Health and Occupation Research network in General Practice (THOR-GP) in the United Kingdom, approximately one-third of the WRMSD are caused by heavy and light lifting, carrying, pushing, or pulling work [2]. In addition, the reports indicate that lower-limb injuries account for 25% of the overall WRMSD reported annually. These disorders or injuries to manual workers can result in loss of productivity. On the other hand, manual worker's performance is also affected by the repetitive and tiring nature of the lifting task. In that context, we have developed a unique wearable technology for assisting or complementing the manual worker to reduce effort and improve comfort during squat lifting.

The passively-powered knee exoskeleton can be worn on the lower limb to assist knee flexion and extension during squatting tasks (see Figure 1(A)). Accordingly, this power-assist wearable device is energetically autonomous, meaning it requires no external energy source to power up the joints. It is also included with a unique body-powered soft actuation system made of springs to store lost potential energy as strain energy. The passive actuation system is responsible for capturing and releasing biomechanical energy from the knee during the descending and ascending phases of the squat cycle (see Figure 1(B)). Furthermore, the lightweight and compliant mechanical structure ensures the ergonomic operation of the device, hence improving physical comfort of the wearer. The target of the design was to reduce muscular activities in the lower limb and prevent muscle fatigue during repetitive squatting tasks. Moreover, the device is also capable of reducing joint forces and metabolic energy consumption during manual lifting.

The proposed device consists of a system of helical elastic springs bilaterally located on the shank for capturing/storing waste biomechanical energy at the knee, a cable and pulley system to transmit power from and to the knee, a pulley locking/unlocking mechanism to achieve passive control of the device operation (see Figure 2). The locking/unlocking mechanism serves two functions. It

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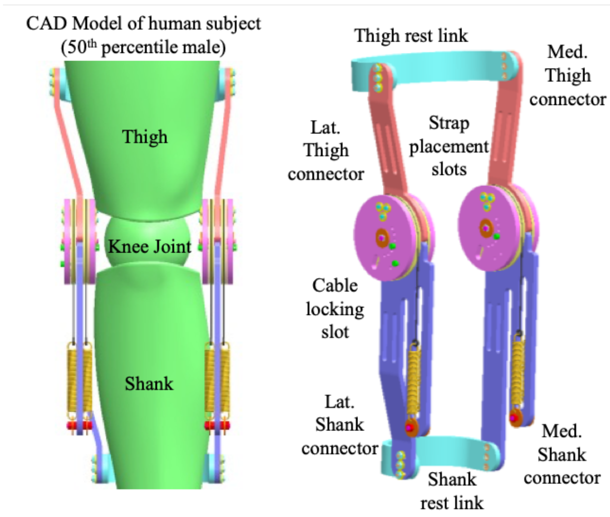
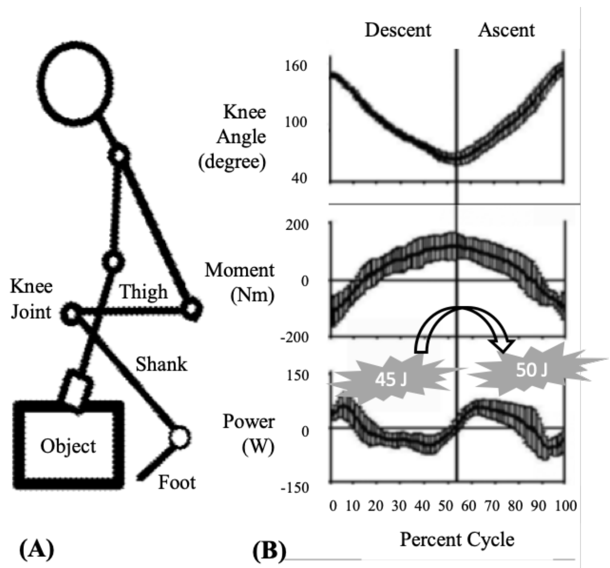
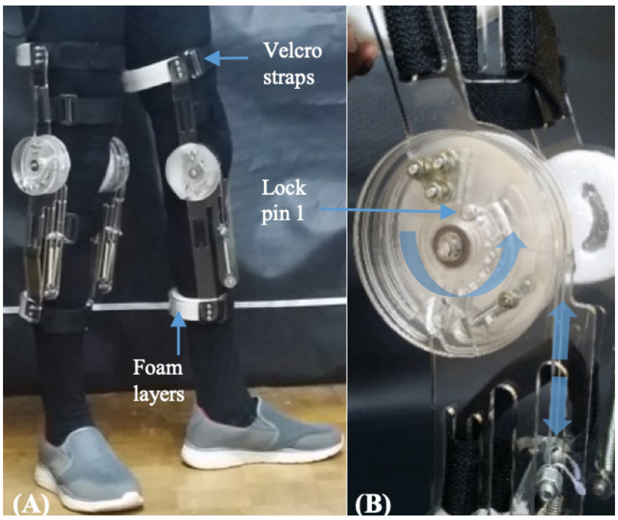
ensures no restrictions are posed by the springs during walking and applies a pre-tension on springs to prevent slacking of the Bowden cable using a return spring. However, when the wearer performs a squatting task, the springs engage/disengage energy springs when the knee flexes over a preset angle (i.e., 60 degrees). The energy dissipated and generated at the knee joint during decent and ascent phases from biomechanical studies were recorded as 45 J and 50 J respectively for an average human [3]. Accordingly, the selected energy springs can collectively capture and return approximately 20% of biomechanical energy at the knee.

The overall mass of the fabricated prototype of the knee exoskeleton (see Figure 3(A & B)) is approximately 900 g per unit. The lightweight mechanical system was manufactured using Acrylic and the structural integrity was verified using finite element simulations.

The functional performance of the proposed device was evaluated on 10 test subjects by measuring and analyzing surface electromyography (sEMG)



signals of rectus femoris (RF) muscles during the squatting cycle. The mean root-mean-square (RMS) feature of the sEMG signals was then used to compare muscle power changes during squat lifting with and without wearing the passively-powered exoskeleton. Experiment results confirm a significant reduction of RMS sEMG activity when the exoskeleton provided power assistance. Moreover, the peak muscle activity reduction during the squat cycle was found to be 30-40%, and as per the 'Cohen's d' formula the effect size was determined to be 'large'. In other words, the findings indicate a large difference between the means of the muscle signals when compared to the variability. Interestingly, the results remained consistent even when the number of squat cycles increased delaying the fatiguing effects of the muscles. Thus, the proposed knee exoskeleton with the passive powering system can be identified as an effective tool for reducing human effort and can be readily employed in industrial applications where repetitive squatting tasks are performed. For example, the device can be readily used to provide assistance to manual workers for lifting moderate to heavy loads (i.e., crates with bottles, vegetables, fruits, etc.) at warehouses.

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