**Evaluation of a Passive Knee Exoskeleton for Vertical Jumping**

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#### Introduction

An exoskeleton is a wearable device, designed to enhance physical abilities during human activities. Several exoskeletons have succeeded in assisting walking [1], running [2] and hopping [3]. The goal of these exoskeletons is to reduce the effort expended during aerobic tasks (i.e. the metabolic rate). However, exoskeletons which assist during anaerobic tasks (specifically, vertical jumping) have not yet been thoroughly researched. During the countermovement of vertical jumping, there is a negative work phase in the knee, followed by positive joint work. Therefore, a passive exoskeleton (based on a spring) can assist knees during a jumping activity.

 In this study, we built a passive knee exoskeleton for vertical jumping, and performed an experiment to gain knowledge on exoskeleton-human interaction.

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#### Methods

Eight healthy males (age: 25.1$\pm $3.0 years; mass: 71.7$\pm $3.6 kg; and height: 1.73$\pm $0.02 m) participated in this study. All subjects provided informed written consent before participating in the study The study was approved by Ben-Gurion University’s Human Research Institutional Review Board.

 The passive knee exoskeleton consists of aluminium frames, attached to the leg with wide Velcro stripes. Rubber springs provide assistance torque. The overall device mass is 1.5 kg, for each leg. The subjects performed vertical jumps under five conditions: without the device (No Exo); with the device but with no spring connected (Exo0) with the device and with springs that provide 70 Nm at a $90° $knee bend (Exo1); with springs that provide 105 Nm (Exo2); and without the device again (No Exo2). The performance order of the conditions with the device was randomized for each subject. The subjects followed a warm-up routine, and then performed eight vertical jumps under each condition. They were instructed to jump as high as possible, and to keep their hands crossed on their chest. Data was collected from the last five jumps. The subjects rested for 1.5 minutes between jumps, to prevent the effect of fatigue.

 The subjects’ motion was recorded using 14 cameras (Qualisys), and ground reaction forces were recorded using an instrumented treadmill (Bertec). Invers dynamics was performed using Visual 3D (C-Motion). Rectus Femoris (RF) and Gastrocnemius medialis (GM) muscle activity was measured using surface electromyography (Trigno, Delsys). Next, MATLAB code (Math Works Inc) was used to calculate the difference in the center of mass height (from detachment to maximum jump height) and work performed at each joint (from full bending to detachment).

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Results and Discussion

The average height difference from detachment to maximum jump height, for each of the conditions, was normalized by the average height difference gained in No Exo condition, as presented in Fig. 1. Repeated measured analysis of variance (ANOVA) revealed that the average normalized difference in height for Exo2 was greater by 13$\pm $5% than for Exo0 (P<0.001), and greater by 5 $\pm $ 0.1% than for Exo1 (P=0.04). Exo2 was no different from No Exo (P=0.69).

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**Figure 1:** The average height difference from detachment to maximum jump height, normalized by the No Exoskeleton (No Exo) condition

 There was no difference between the maximum amplitude of EMG in RF and GM, under all conditions (P>0.05).There was no difference in average ankle joint work between all five conditions. The average total work at the knee joints (i.e. the biological knee work and exoskeleton work) with No Exo2 was greater than all the conditions with the exoskeleton (P<0.01). The work at the hip joints without the exoskeleton (No Exo and No Exo2) was lower than with the exoskeleton (P<0.05, for all the conditions). This might suggest that the subjects changed the way they jump, but that they still did not fully utilize the exoskeleton.In future research, we will train the subjects to better utilize the exoskeleton, by storing more energy in the springs.

**Table 1**: The average work done by each joint (J)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Condition\ Joint | Ankle | Knee- total | Knee bio | Exo | Hip | All 3 joints |
| No Exo | 128.6 | 220.3 | 220.3 | - | 195.2 | 544.1 |
| Exo0 | 129.6 | 192.3 | 192.3 | - | 242.1 | 563.9 |
| Exo1 | 139.7 | 206.6 | 104.3 | 102.2 | 242.6 | 588.8 |
| Exo2 | 141.1 | 192.1 | 51.3 | 140.9 | 247.8 | 581.0 |
| No Exo2 | 123.8 | 239.5 | 239.5 | - | 176.5 | 539.8 |

**Significance**

The results contribute to a better understanding of the interaction between an exoskeleton and the human body, and could improve the design of exoskeletons in future.

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