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

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#### Introduction

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

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

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#### Methods

Eight healthy males (age 25.1$\pm $3.0 years; mass 71.7$\pm $3.6 kg; height 1.73$\pm $0.02 m) participated in this study. All subjects provided written informed 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 and is attached to the leg with wide Velcro stripes. Rubber springs provide the 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 device with no spring connected (Exo0), with device with springs that provide 70Nm at $90° $knee bend (Exo1), with springs that provide 105Nm (Exo2), last without device (No Exo2). The 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 in each condition. They were instructed to jump as high as possible and keep their hands crossed on the chest. The data was collected from the last five jumps. Between the jumps, the subjects rested for 1.5 minutes to prevent the effect of fatigue.

 Subject's motion was recorded using 14 cameras (Qualisys) and ground reaction forces were recorded using instrumented treadmill (Bertec). Invers dynamics was preformed using Visual 3D (C-Motion). Rectus Femoris (RF) and Gastrocnemius medialis (GM) muscles activity was measured using surface electromyography (Trigno, Delsys). Next, difference in center of mass height from detachment to maximum jump height and work performed at each joint from full bending to detachment was calculated using Matalb code (Math Works Inc).

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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 and is presented in Fig.1. Repeated measures analysis of variance (ANOVA) revealed that the average normalized difference in height for Exo2 was greater by 13$\pm $5% than Exo0 (P<0.001), and greater by 5 $\pm $ 0.1% than Exo1 (P=0.04). Exo2 was not 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 at all conditions (P>0.05). There was no difference in the 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 hip joints without the exoskeleton (No Exo and No Exo2) was lower than with the exoskeleton (P<0.05 for all the conditions). It might suggest that the subjects changed the way they jump, but still they did not fully utilize the exoskeleton work.In a 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 the interaction between the exoskeleton and the human and could improve the design of exoskeletons.

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