Optimization of exoskeleton assistance: timing of actuation and exoskeleton power

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Introduction: Robotic devices, called exoskeletons, are being developed to improve walking metabolic economy of an able-bodied wearer. These devices can assist plantar flexion during walking by means of pneumatic muscles. The timing of actuation and the amount of exoskeleton power are key parameters for a maximum reduction in metabolic cost. A reduction below the cost of normal walking can be realised if timing of actuation occurs just before heel contact of opposite leg [1]. However, the effect of exoskeleton power has not been studied for bilateral exoskeleton walking. The goal of the present study was to optimize the actuation pattern of the exoskeletons to reduce the cost of legged locomotion.

Methods: 13 subjects walked in 12 powered conditions at 1.25 $m.s^{-1}$ wearing a powered ankle foot exoskeleton. The powered conditions varied in onset of actuation (31, 36, 41, 46% of stride cycle) and amount of exoskeleton power (low, medium and high). Each condition lasted 3 minutes in a habituation session and 4 minutes in the actual data collection one week later. Also, one unpowered (=without pneumatic muscle actuation) and one shod condition was done. Full body kinematics, exoskeleton kinetics, EMG, respiratory gas analysis and perception were measured.

Results: A U-shaped curve was observed for timing of actuation for low, medium and high amounts of power (fig1). The highest reduction in metabolic cost versus unpowered walking was 18% and was found in the 42% onset condition. The effect of varying exoskeleton power was less clear. For early timings an optimal exoskeleton power of 0.4 $W.kg^{-1}$ was found. Compared to normal walking this is an increase of positive ankle joint power with almost 30% [2]. However, no optimal exoskeleton power was found in later push-off timings. This could be due to the low amount of power that was reached in the late actuation timing conditions. Based on the 3D fit through all our data points it is suggested to actuate pneumatic muscles at ±41% of stride cycle and add an exoskeleton power of ±0.40 $W.kg^{-1}$. Compared to unpowered walking and walking with standard shoes, metabolic cost was reduced by ±18% and ±9% respectively.

Conclusion: For actuation timing we found an optimum around 42% of stride cycle and we suggest ±0.40 $W.kg^{-1}$ for exoskeleton power, in order to find the highest reduction in metabolic cost. However, it appears that the optimal value of power is greater than the range tested here, especially for later timings. Higher exoskeleton power should be tested to confirm these conclusions.

References:

[1] P. Malcolm, W. Derave, S. Galle, D. De Clercq. *PLoS One*, vol. 8, no. 2, p. e56137, Jan. 2013.

[2] D. J. Farris and G. S. Sawicki. *J. R. Soc. Interface*, vol. 9, no. 66, pp. 110–8, Jan. 2012.

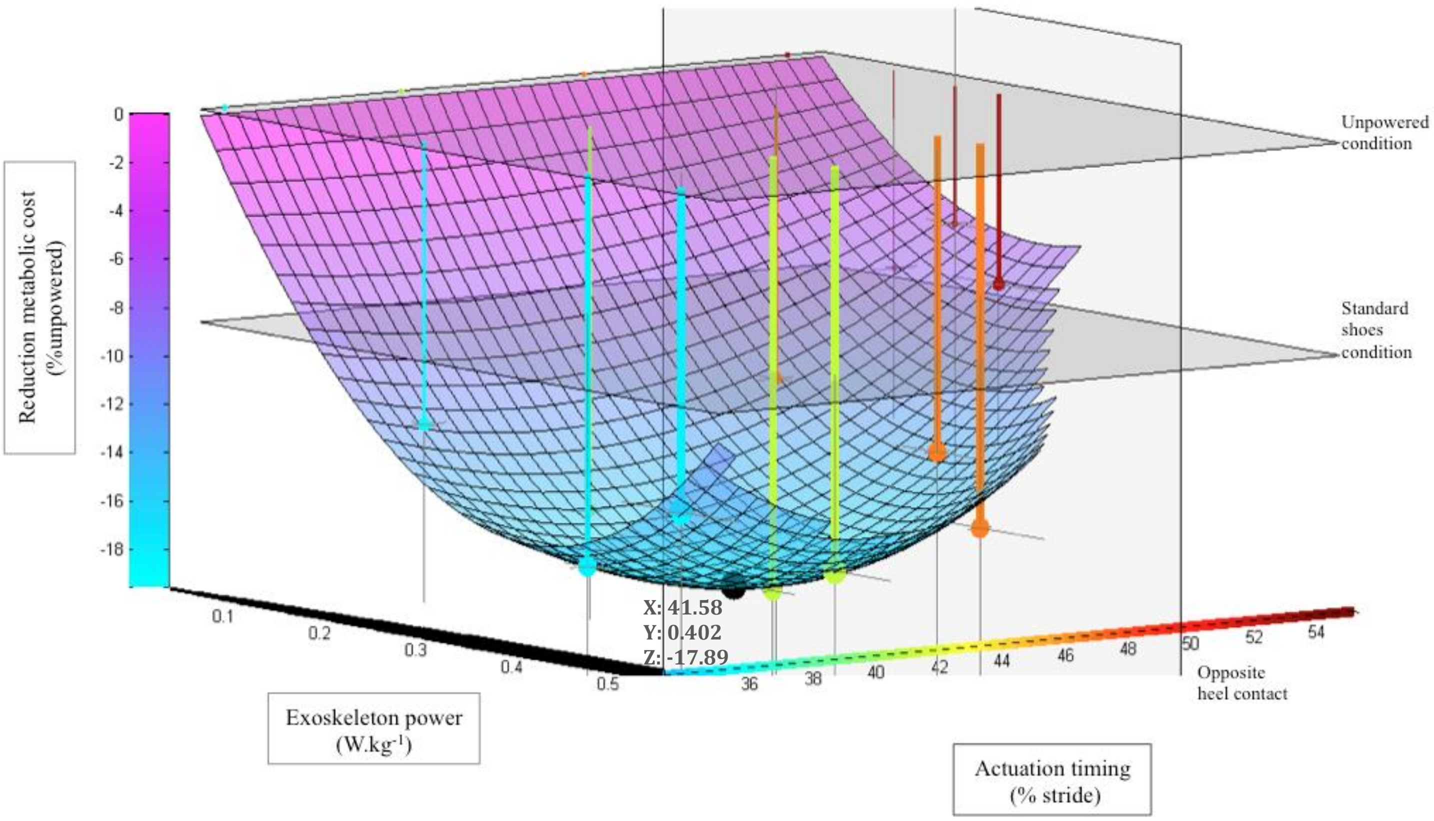

Fig. 1. Reduction in metabolic cost with variations in exoskeleton power and actuation timings.

A fit was made through 16 data points (12 powered conditions and 4 unpowered conditions for every timing). The dots on grid (end of colored vertical lines) indicate the 12 powered conditions. Colored dots indicate 4 different actuation timings and correspond with colors of actuation timing axis. Size of colored dots or vertical lines (lines are to make it more visible) indicate amount of exoskeleton power and correspond with size of black exoskeleton power axis. Upper and lower gray horizontal plane shows unpowered condition and standard shoes condition respectively. Black dot (●) indicates optimum based on 3D fit. X= actuation timing, Y= exoskeleton power, Z= reduction metabolic cost vs. unpowered.