CORRELATION OF COMFORT, METABOLIC COST & MUSCLE ACTIVATION FOR AN ANKLE EXOSKELETON

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Introduction

Ankle exoskeletons have been used to reduce metabolic cost (MC) assuming that minimal MC produces the optimal gait[1]. Other factors, such as muscle activation or user comfort, may also be important. These factors may[2,3] or may not[4] be correlated. This abstract tests the hypothesis that muscle activation and metabolic cost are negatively correlated with an individual's perceived comfort while walking in an ankle exoskeleton.

Methods

2 young adult subjects (1M, 1F) walked at a slow speed on a treadmill while wearing a pneumatically powered ankle exoskeleton on each leg. Subject 1 completed 25 trials while subject 2 completed 30. For each 3 min trial, a different set of exoskeleton control parameters were used to alter perceived comfort. EMG signals were collected from the rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), and soleus (SOL). Muscle activation was quantified by finding the RMS[5] of each stance phase then normalizing the average by the maximum voluntary isometric contraction. MC was determined using indirect calorimetry and the modeling method in Selinger et al[6]. After each trial, the subjects electronically reported their comfort via a modified 100mm visual analog scale[7].

To determine if correlations exist between comfort (response) vs muscle activation or MC (predictors), univariate linear regression models were created. 95% confidence intervals (CI) were calculated for the linear term. A model was created for each subjects' left and right muscles and MC due to distinct clusters.

Results and Discussion

While subjects' comfort, muscle activation, and MC all varied, correlations were generally weak ($R^2 < 0.25$), except for subject 2's left SOL ($R^2 = 0.71$). For the muscles spanning the knee (RF, BF), there was a single statistically significant CI (Table 1), though it was not clear that this was meaningful. Overall, for this ankle exoskeleton, the knee muscles were not related to comfort. Similar to the knee muscles, the TA for both subjects and subject 1's SOL was not particularly related to comfort. Conversely, subject 2's SOL for both the left and right leg had statistically significant correlations with comfort. Thus, decreased SOL activity may increase comfort for some subjects. Nevertheless, based on the majority of the results, our hypothesis that muscle activation is negatively correlated with comfort is rejected.

When comparing comfort and MC, subject 1 had no correlation while subject 2 had a statistically significant positive correlation. In previous research, the relationship between comfort and MC varied by subject and study[2,4]. Even in the study that showed negative correlations between MC and comfort, this was not true for all subjects[2]. Our study also suggests that the relationship between comfort and MC differs between subjects. Therefore, our results reject our hypothesis that comfort is negatively correlated to MC.

If a larger range of exoskeleton parameters were tested, this could produce more exaggerated changes in muscle activation and MC. In turn, this may yield stronger correlations with comfort. It is also likely that subjects were not able to fully adapt in the 3 min time span; full adaptation is likely to take at least 30 min per exoskeleton condition[5]. When subjects are adapting to novel gait conditions, some research has indicated that MC is deprioritized[8]. Thus, much longer experimental trials may yield different correlations between MC and comfort compared to short trials.

Significance

Exoskeletons have the ability to enhance user ability or help in rehabilitation. To develop devices that subjects would be willing to use, it may be important to understand how comfort and physiological signals relate. If easily measured physiological signals are highly correlated with comfort, then these quantifiable signals could serve as a proxy for comfort. In turn, these signals could be used to design controllers that optimize comfort. However, the preliminary results show that neither MC nor muscle activation are strongly correlated with comfort.

Acknowledgments

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References

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Table 1: Slopes with associated 95% confidence intervals for regression models. Statistically significant slopes are in bold.

	RF		BF		TA		SOL		MC
Subject	Left	Right	Left	Right	Left	Right	Left	Right	
1	177±2594	2316±2656	221±408	4±50	89±126	76±202	198±241	16±156	1.22±12.34
2	230±610	-1331±2887	**143±128**	2±76	-107±228	-1±92	**-413±105**	**-284±211**	**3.30±3.23**