Neural Control Versus Mechanically Intrinsic Control of Powered Ankle Exoskeletons

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Introduction

There are numerous ways to control an assistive robotic device; however, there is little consensus on which ways are better than others and why. From a broad perspective on the field of lower extremity assistive devices, controllers can be separated into two main categories: those driven by neural measurements and those driven by mechanically intrinsic measurements. Controllers driven by neural measurements use measures of electrical activity from the user's nervous system to directly drive control. These measures may be of the user's brain activity sensed using electroencephalogram (EEG) electrodes on the head or of the user's muscle activity sensed using electromyography (EMG) electrodes probed directly into the muscle or on the skin's surface [1, 3]. Controllers driven by mechanically intrinsic measurements use measurements taken from the device itself such as joint angles, actuation power output, or gait events to drive control. These signals are often used as phasing variables within a control scheme or as triggers for a timing-based controller [2].

Despite the prevalence of these two broad categories of controller design, to date, there exists no systematic and fair comparison of which may be better to use on a device and why. In the work presented here, we aimed to make a systematic comparison between proportional myoelectric control and timing-based mechanically intrinsic control of bilateral ankle exoskeletons (Fig. 1). In our experimental design we ensured that each controller had the same average actuation signal. The only difference in the two controllers was that one was driven directly by the users' muscle activity while the other was driven by measured gait events. We tested both controllers on a healthy subject population during steady-state treadmill walking. We calculated a number of physiological and biomechanical outcomes to compare these two controllers to one another.

Methods

We trained 8 healthy subjects over the course of three days to walk using pneumatically powered, bilateral ankle exoskeletons. The controller

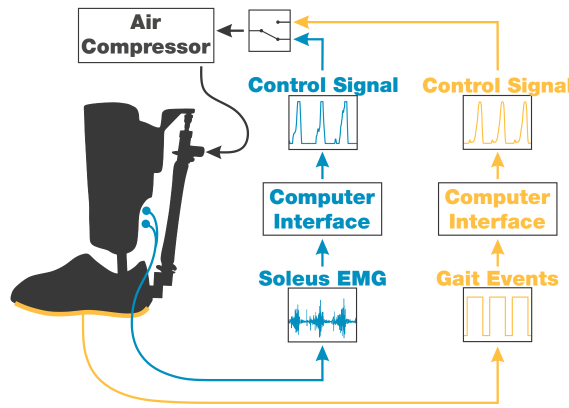

Figure 1: In this study we conducted a systematic comparison of proportional myoelectric controller (blue) and timing-based mechanically intrinsic controller (yellow) of bilateral ankle exoskeletons. By design, the two controllers had the same average control signal.

used for training was a dynamic gain proportional myoelectric controller driven by users' soleus activity [4]. Subjects then returned on a fourth day to complete a 10 minute unpowered walking bout followed by a walking bout using the same proportional myoelectric controller they trained with. We then created an actuation profile for a timing-based mechanically intrinsic controller directly from the average of control signals seen during the last 100 strides of use of the proportional myoelectric controller. By doing so, we ensured that the timing-based controller had the same exact subject-specific average actuation signal as the proportional myoelectric controller. The timing-based mechanically intrinsic controller was designed to trigger a playback of this average actuation signal upon heel strike detection. Subjects completed a 10 minute walking bout using this timing-based mechanically intrinsic controller and then repeated a final 10 minute walking bout with the proportional myoelectric controller. This repeated walking bout with the proportional myoelectric controller showed that no additional learning took place during the data collection. All comparisons presented here represent walking bouts of the the unpowered condition, the timing-based mechanically intrinsic control condition, and the final proportional myoelectric control condition.

During testing we recorded user's muscle activity, gait kinematics and dynamics, and metabolic work rate. All analysis was conducted using a repeated measures ANOVA analysis ($\alpha = 0.05$)

Results & Discussion

The proportional myoelectric controller resulted in a reduction in metabolic work rate relative to the unpowered walking bout of 0.73 ± 0.13 W kg^{-1} ($19.0 \pm 2.5\%$, mean $\pm$ 1 s.e.m.). The timing-based mechanically intrinsic controller resulted in a reduction in metabolic work rate relative to the unpowered walking bout of 0.73 ± 0.13 W kg^{-1} ($19.2 \pm 2.5\%$). There was no signifcant difference in the mean metabolic work rate between these two controllers ($p = 1.000$).

Despite there being no difference in metabolic work rate, there was a difference in soleus EMG activity (Fig. 2). The soleus rectified root mean square (r.m.s) EMG during walking with the timing-based mechanically intrinsic controller was on average 11.8% less than that when using the proportional myoelectric controller. These averages were note significantly different from zero ($p = 0.793$) due to two subjects in the group not exhibiting this same trend (one had no change between controllers while the other showed an opposite trend). Removing these two from the statistical analysis results in a $p = 0.067$. We believe additional testing with a larger subject pool would increase the statistical significance of this finding.

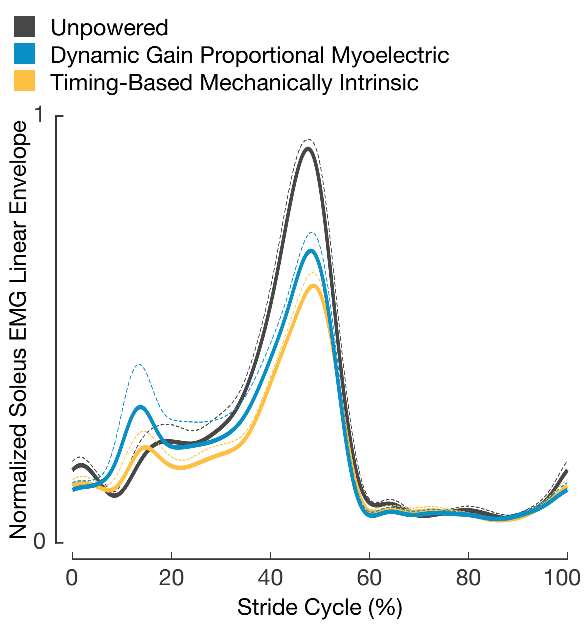

Figure 2: Average linear envelope soleus EMG activity from the three walking conditions across 8 subjects. The solid lines represent the mean and the dotted lines represent a single s.e.m. above the mean.

One major take away from the EMG results of this study is that it appears subjects are less engages on a muscle level when using the timing-based mechanically intrinsic controller than when using the proportional myoelectric controller. This intuitively makes sense as EMG activity is required for actuation to occur when using the proportional myoelectric controller. In contrast, the timing-based controller will actuate so long as a heel strike is detected. We believe this finding supports the theory of slacking [5], such that the human motor system continuously attempts to decrease its levels of muscle activation when movement error is small during repetitive motion. When using the timing-based mechanically intrinsic controller, subjects were able to slack more than when using the proportional myoelectric controller. If this hypothesis holds true, we would expect a controller driven by mechanically intrinsic measurements to result in a lower metabolic work rate than that of a controller driven by neural measurements. We believe we did not see any difference in metabolic work rate due to the fact that the soleus is a relatively small muscle. However, given that the proportional myoelectric controller resulted in more active muscle recruitment, the data suggest that this type of controller may be better suited for rehabilitation than a timing-based mechanically intrinsic controller.

References

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