Can EMG accurately predict metabolically optimal step frequency

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Introduction

Measuring metabolic cost is time consuming and cumbersome for both experimenter and participant alike. Despite this drawback, metabolic cost is an important measure for biomechanical studies of locomotion and will continue to be used. Some have estimated metabolic cost using a wide array of measurements such as breathing rate, perspiration, and muscle activity[1]. Others used estimation techniques to approximate steady-state metabolic cost, shortening the duration of collection[2]. As muscles are the primary energy consumers during locomotion and EMG sensors are readily available, it follows that measuring muscle activity could be used to accurately estimate metabolic cost in real-time. One important aspect to metabolic estimation is whether the estimated values follow the same trends as originals (e.g. when walking at a constant speed there is a parabolic trend that determines the metabolically optimal and preferred step frequency (SF)). We hypothesize the metabolically optimal SF will be the same SF to minimize overall EMG activity.

Methods

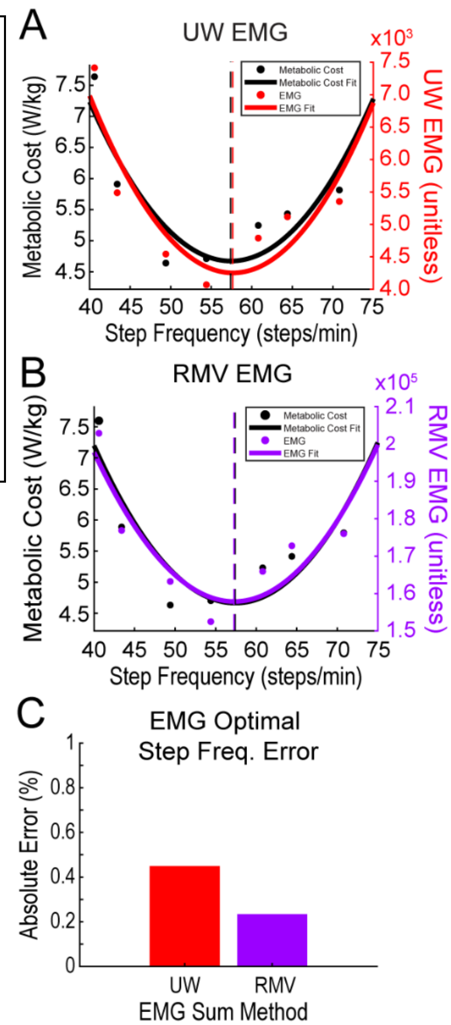
We measured EMG and metabolic cost of a healthy adult male while walking on a treadmill at 1.3 m/s. The participant walked for 15 minutes to habituate (preferred SF and ±20%), followed by a 35-minute randomized SF sweep between ±30% of preferred SF (7 trials total at 5 minutes each). SF was commanded using an audible metronome. Ground reaction forces (GRFs) were measured to quantify step durations and segment EMG data per gait cycle. The subject had 8 EMG sensors placed on the following leg muscles: Tibialis Anterior, Medial Gastrocnemius, Soleus, Vastus Medialis, Rectus Femoris, Bicep Femoris, Gluteus Medialis, Gluteus Maximus.

Muscle-specific EMG activity of each trial was quantified using 3 mathematical measures: integral (INT), sum square (SS), and waveform length (WL, i.e. geometric length) between 2.5 and 4.5 minutes. For each measurement, the muscle-specific EMG were summed using weights based on relative muscle volume (RMV) or without weights (unweighted; UW). A quadratic fit was made across trials for each EMG measure and the minimum was calculated. The SF where the minimum value occurred was compared to the metabolically optimal SF. EMG adaptation time (time it takes to reach steady-state, i.e. average of last minute of trial) was the first time when three consecutive steps of the EMG measure were within ± 2 std of the steady-state value.

Results and Conclusion

Using the UW sum method, SumSq had the least amount of error (0.5%). WL had the highest absolute error (3.4%). Using the RMV sum method, WL had the least amount of error (0.4%). SumSq had the most amount of error (3.2%). Based on these preliminary results, these EMG measures and metabolic cost reach their minimum at the same SF of 56 steps/min.

Figure 1: A) Steady-state metabolic cost and UW EMG sums across SFs with quadratic fits. B) Steady-state metabolic cost and RMV EMG sums across SFs with quadratic fits. C) Absolute error between the metabolically optimal SF and EMG optimal.



Significance

This data suggests that EMG has the potential to estimate metabolic cost in real-time while preserving key trends. EMG could be used as a substitute for metabolic measurement, decreasing experimental time and effort. Further, EMG can assist with the optimization of parameters for controls of exoskeletons, as metabolic cost is normally a performance/cost metric. In the future, we plan to investigate how quickly EMG reaches steady-state compared to metabolic cost, directly predict metabolic cost using EMG, and implement this method to optimize exoskeleton control.

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References

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