Cost of Transport and Muscle Activity as a Function of Walking Efficiency at Variable Speed.

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Abstract

Previous studies have mostly relied on surface EMG signal amplitude to understand the correlation between muscle activity and metabolic rate during walking at various speeds. However, these studies have failed to establish a relationship between EMG signal frequency and gait efficiency (i.e., cost of transport (COT)). The frequency of the EMG signal is an important measure as it provides a better understanding of the motor unit recruitment range.

The goal of our project is to examine the correlation between human metabolic rate and muscle activity, with a particular focus on the frequency of the EMG signals during walking at different speeds. As a result, the findings of this study will be valuable in rehabilitating individuals who suffer from gait-related disorders.

We recruited ten participants for our study. Each participant's preferred walking speed was identified using a 10 meters walk test, and seven speeds were determined from their average walking speed to test the effect of variable walking speed on muscle activations. We recorded EMG activity from gastrocnemius and tibialis anterior. We also recorded metabolic efficiency to estimate COT. To establish a relationship between EMG signal frequency and gait efficiency two forms of analysis were used in frequency domain, a pulse width analysis and area under curve analysis.

We found a U trend with the COT analysis which showed that the average walking speed of each participant was their most efficient walking speed, whereas faster and slower walking is metabolically inefficient. Additionally, in terms of the EMG frequency of the signal, we also found six out of eight participants has greater power spectral density (estimated from the area under the curve) for the tibialis anterior compared to gastrocnemius at slower walking speed, followed by a decrease at faster speeds. The gastrocnemius showed an increased the speeds of each participant increased.

Introduction

- **Problems with walking efficiency**
  - Decreased mobility results in reduced walking efficiency (1)
  - 15% of people suffer from gait related disorders that reduces walking efficiency (4).
  - Abnormalities in posture, Aging, neurological conditions (sensory or motor) injury results in reduced efficiency (1), (2)
- **Population with reduced walking efficiency**
  - Elderly
  - Stroke patients
  - Amputees
  - Spinal Cord Injury
  - Cerebral Palsy
- **Measures to quantify walking efficiency**
  - Biomechanical efficiency quotient (4)
  - Metabolic cost of transport
- **Importance of studying muscles related to those measures**
  - Motor control & pattern development of walking gait
  - Muscles are what metabolizes and utilizes oxygen during walking and so by studying them we can attempt to understand a relationship between metabolic efficiency and muscle activity.
- **Literature gaps within the research**
  - To the best of our knowledge, no research has presented a relationship between metabolic efficiency and muscle activity in the frequency domain.
  - It will help us to understand how gait efficiency changes with an estimated muscle activation frequency.
- **What we have done to fill this gap**
  - We have used both COT measure and power spectral density of acquired EMG analysis at different speeds to find a relationship correlation in terms of walking speed efficiency.
- **How our study is going to help clinical population**
  - Tuning of a muscle to a specific frequency with a stimulator or therapy can be beneficial.

Methodology

- **Participant Recruitment**
  - We recruited ten participants. The demographic data is below.
  - No clinical population was recruited.
  - We received their signed consent as per the IRB protocol, Northwestern College.

Demographic	Average/Ratio	STD (+/-)
Age (yr)	28.44	10.11
Sex (m/f)	4:5 (F:M)	
Height (cm)	178.48	6.75
Weight (kg)	81.77	12.93
Avg Walking Speed (mph)	3.32	0.39

- **10 Meter Walk Test**
  - This test measured participants average walking speed
  - 3 trials, walking 10 meters each time
  - Time recorded in seconds
  - 10/avg time = average walking speed (m/s)
  - Converted to mph
  - 7 speeds are determined based on the average walking speed (+/- 0.5mph)
- **EMG Recording and Muscle Palpation**
  - EMG sensors were placed on the tibialis anterior and gastrocnemius of the dominant leg
  - EMG sensors record the frequency of muscle activity during movement.
- **V_EO_2 and V_ECO_2 data recording**
  - These variables were measured to find COT.
  - Data of oxygen consumption & carbon dioxide production was measured via open circuit spirometry.
  - Participants wore a mask connected to a metabolic cart to measure V_EO_2 and V_ECO_2

Figure 1: Displays participant performing exercise protocol with open circuit spirometry and EMG sensors.

Methodology

- **Experimental Protocol and Procedure**
  - A warm-up on the treadmill was conducted for each participant
  - Participants walked for 4 min at each speed (based on avg) starting with the lowest and increasing by 0.5mph for each new speed
  - EMG was also recorded within the 4 min at each speed.
  - In-between each speed participants rested for at least 1 min to limit any fatigue
  - RPE was taken at in 4th minute of each speed
  - Upon completion, participants cooled down at a slow pace
- **Data Analysis**
  - EMG = E, T = Time, Steady State = V_EO_2
  - COT = V_EO_2/Speed
  - Power Spectral Density = $S(f) = \lim_{T\to\infty}\frac{1}{T}\left(\widehat{E_T}(f)\right)^2$

Results

- **Cost of transport at variable speed**

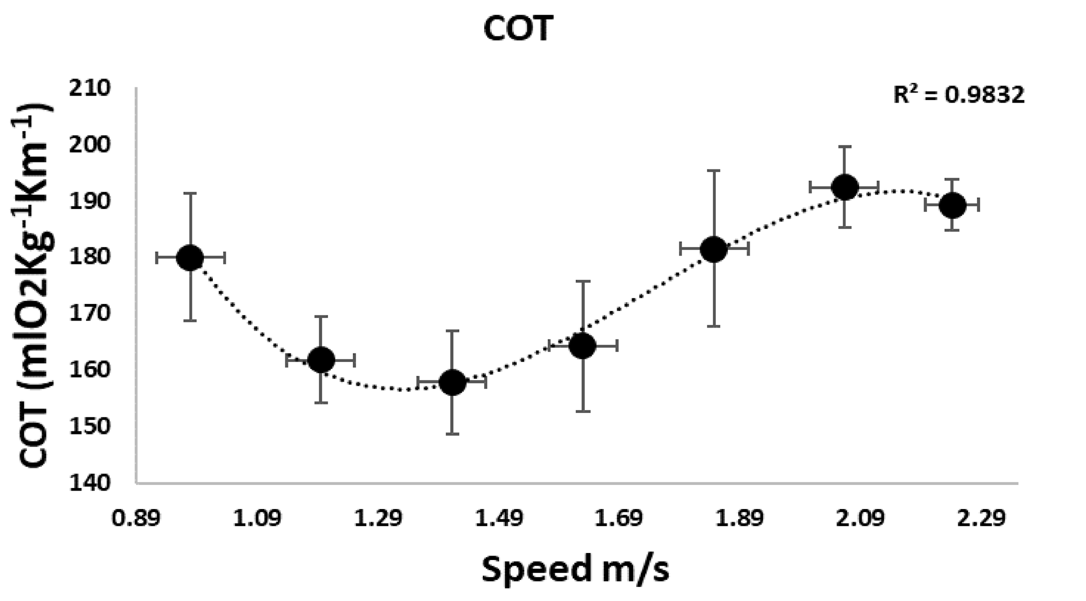

Figure 2: Relationship between cost of transport and walking speed at various levels. The x axis shows speed in meters per second and the y axis shows the cost of transport. The dots represents the averaged values across participants. The standard deviation across the participants is displayed as vertical (COT) and horizontal (Speed) error bars. The U curve shows that walking at an average speed is metabolically more efficiency compared to faster and slower walking.

- **Change in muscle activation frequency at variable speed in the frequency domain (power spectral**

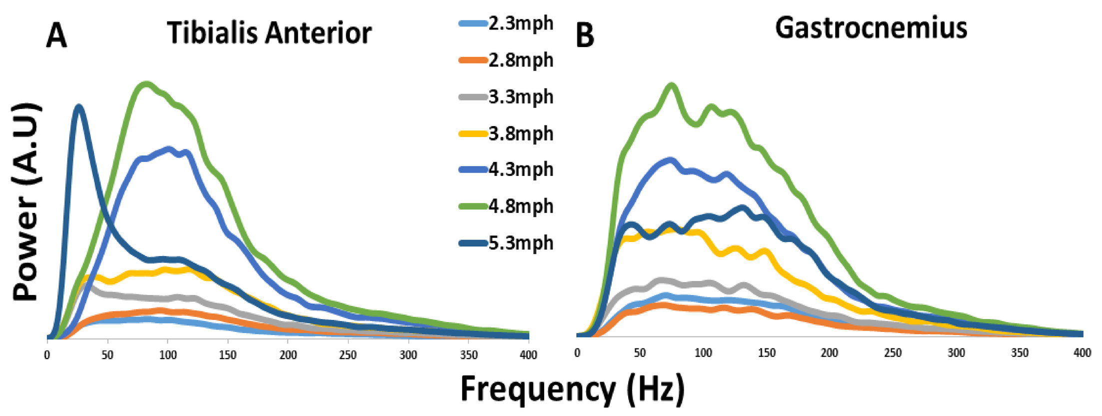

Figure 3: A) displays power spectral density of TA. B) display show power spectral density for gastrocnemius. They x axis is frequency in Hz. The y axis is power in arbitrary units (au). The power spectral density is a method that describes the power content of a signal in frequency domain. The Power spectral density for these muscles is computer over a range of walking speed.

Results

- **The relationship between power spectrum and variable walking speed.**

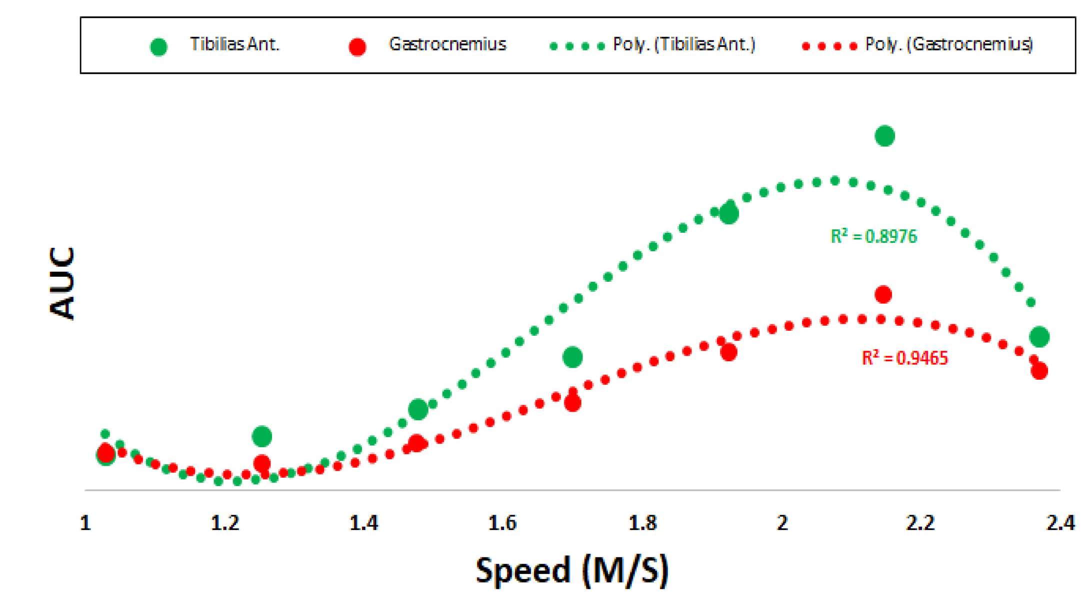

Figure 4: Curvilinear relationship between area under the curve (AUC) and speed. The figure shows the power and frequency for tibialis anterior and gastrocnemius increments, and then reduces at a faster walking speed. Moreover, the tibialis anterior power and frequency is relatively higher compared to gastrocnemius at faster walking speed.

Conclusion and Discussion

For every participant in our study, we found that their average walking speed was their most metabolically efficient. In figure 2, you can see that the third speed level which was the average walking speed of all participants is the most metabolically efficient. Additionally, in figure 4, in terms of the EMG frequency of the signal, the power spectral density (estimated from the area under the curve) for the tibialis anterior and the gastrocnemius muscles display that both muscles experienced a curvilinear increase. Meaning that as the speed increased by 0.5 mph after every 4 minutes of exercise, the frequency of the muscle activation also increased. In the last speed, we can see that the AUC decreases and this is because the participant changed their gait and began to cross a point where they exhibit a running pattern.

To summarize, we have found that the average walking speed of an individual is most metabolically efficient for them. And within the average walking speed, the muscle activation frequency of the plantar flexor and dorsi flexor also increases suggesting larger motor unit recruitment.

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