THE RELATIONSHIP BETWEEN GLUTEUS MAXIMUS ACTIVATION AND RUNNING ECONOMY IN RECREATIONAL DISTANCE RUNNERS

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A Thesis Presented to

The Faculty of California State Polytechnic University, Humboldt

In Partial Fulfillment of the Requirements for the Degree

Master of Science in Kinesiology

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May 2023

ABSTRACT

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Within the running community, there are strategies that a trainer will utilize to improve the performance of an athlete. One of these strategies suggests that an increase in activation of the Gluteus Maximus (GM) muscle will result in an increase in the efficiency of runners. The primary purpose of this study is to examine the relationship between GM activation and running economy (RE).

Methods: Three female and seven male recreational runners (27±8 yrs) from California Polytechnic State University, Humboldt and the local community. A Pearson product-correlation was used to determine the strength of the relationship between Gluteus Maximus activation and running economy. Runners (27±8 yrs) ran on a treadmill at 11 km/hr and running economy was quantified as metabolic power (Watt/kg) using indirect calorimetry (ParvoMedic). Muscle activation (2000 Hz; Delsys Trigno) of the Rectus Femoris (RF), Biceps Femoris (BF), Soleus (SOL), Tibialis Anterior (TA) muscles were collected in the last two minutes of each six-minute trial.

Results/Discussion: There was no significant relation between GM activation and metabolic cost at 11km/hr ($r=-0.08$, $p=.817$, Figure 1). When examining secondary lower extremity muscles, none of the muscles had a correlation with metabolic cost (Table 1).

Similar studies examining metabolic cost and muscle activation found similar trends in which GM was reported to be one of the lower activating muscles at slower speeds. This lack of a relationship between muscle activation and running metabolic cost may be related to the contributing roles of these muscles while running.

Conclusion: GM activation does not correlate with metabolic cost at intermediate running speeds. The results of this study will be beneficial to coaches and athletes in developing a training program to improve running performance.

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INTRODUCTION

The popularity of running as a form of exercise and competition has grown tremendously over the last fifty years (van Gent et al., 2007). In 2019 alone, 17.6 million people registered for organized races in the U.S (Running USA, 2020). With this popularity, there has been an increased interest in running technique and its relation to performance. Improving an athlete's running economy (RE) is affiliated with improvements to distance running performance (Saunders et al., 2004). Altering running mechanics such as stride length/frequency or changing the relative contribution of specific muscle activity may lead to improvements in RE (Anderson, 1996). There are methods that a trainer will utilize to alter technique to improve performance. However, many of these methods lack evidence showing that the change in running technique is responsible for increasing the athlete's performance. One technique believed to improve running performance is to increase Gluteus Maximus (GM) muscle activation to improve running economy. To date, no study has examined the relationship between the GM muscle activation and RE. Thus, the purpose of this study was to examine the relationship between GM activation and RE.

Fundamentals of Running Gait Cycle

Running is a cyclic motion where one complete cycle is known as the gait cycle. The running gait cycle can be defined as the interval from which a foot contacts the ground (foot strike-FS) until the subsequent ipsilateral FS. The gait cycle can be broken down into two different primary phases: the stance and swing phases. The stance phase is the time interval from FS (0%) until the foot leaves the ground (Toe off - TO) (Õunpuu, 1994). The stance phase can be broken down further into subphases, the braking and propulsion phases. The braking phase, also known as the absorption phase, occurs during the first half of the stance phase, from FS to midstance (MS). During this phase, there is a deceleration of the center of mass. In the propulsion phase, the center of mass accelerates and is propelled forward from MS to TO (Novacheck, 1998). When combined, the entire period when the foot is on the ground is known as ‘contact time’. The swing phase in running is the interval in which the foot is off the ground from TO until the ipsilateral foot contacts the ground again. The period in which the foot is in the air is known as swing time (Thordarson, 1997). The distance traveled during the gait cycle is known as stride length (meters) and the number of strides in each amount of time is known as stride frequency (strides per second, Hz) (Novacheck, 1998). As speeds begin to change so do the timing of these gait events, specifically TO. For example, as speeds increase from 19.3 km/hr to 27.7 km/hr, the time of TO becomes shorter, reducing stance phase from 31% to 22% of the gait cycle (Mann & Hagy, 1980).

Factors Influencing Running Performance

Running performance is influenced by both physiological and biomechanical factors. Physiologically, it is generally agreed that performance is strongly influenced by blood lactate threshold, $\dot{V}O_{2max}$ and RE. While $\dot{V}O_{2max}$ has been the standard for measuring cardiovascular fitness and is used most widely as a predictor of performance, more contemporary research suggests that RE is a more accurate predictor for distance running performance (Conley & Krahenbuhl, 1980). For biomechanists, what is most interesting is that RE has been shown to be influenced by running technique and associated biomechanical factors including the vertical motion of the body across a gait cycle, stride length (meters), and stride frequency (strides per second) (Tartaruga et al., 2012).

Physiological Factors

According to Brandon (1995), physiological factors such as $\dot{V}O_{2max}$, lactate or anaerobic threshold, and RE are shown to have a high correlation with running performance. $\dot{V}O_{2max}$ is identified as the integrative ability of the energy systems to transport oxygen to active muscles where energy, in the form of adenosine triphosphate (ATP), can be utilized for muscle contractions. A higher $\dot{V}O_{2max}$ value is indicative of a more elite runner; however, a runner with a higher lactate threshold is capable of better performance over a runner who has a higher $\dot{V}O_{2max}$ but a lower lactate threshold (Brandon, 1995). Lactate threshold has been defined as the exercise intensity where an excess of lactate has begun accumulating during submaximal oxygen uptake. A runner who has a low blood lactate level at exercise intensities near $\dot{V}O_{2max}$ can utilize a large percentage of their aerobic capability (Costill et al., 1973). Another factor associated with endurance running performance is muscle fiber composition. It has been identified that distance runners and endurance athletes have a larger percentage of slow twitch muscle fibers than participants in strength events (Costill et al., 1976). Foster et al. (1977) found that there is only a moderately strong relationship between a runner's performance and their muscle fiber composition. It is suggested that muscle fiber type is more related to one's suitability to a particular event (Foster et al., 1977). For example, a distance runner who competes in more aerobic events is more likely to use more slow muscle fiber types compared to a sprinter which uses more fast muscle fiber type. A runner's fitness and speed can influence the different substrate and metabolic systems (Aerobic vs Anaerobic) that provide the energy. One system utilizes substantial oxygen in the generation of metabolic energy for running exercise (aerobic) while the other does not but is used for primarily faster and less sustainable running such as sprinting. Energy expenditure (EE) as related to substrate utilization are reflected by the respiratory-exchange ratio (RER) during running and when determining running economy via metabolic cost it is important to understand how these systems influence the measurement. Generally speaking, when the RER is below 1.0, it may be assumed that the aerobic metabolic system is providing the majority of energy for running and thus oxygen consumption as measured by indirect calorimetry can be used to estimate metabolic energy consumption and running economy.

Biomechanical Factors

To better understand how biomechanical factors influence running economy, researchers have described running using a spring-mass model. The spring-mass model describes the body during running as a mass oscillating up and down on each stance leg which acts as a spring (Figure 1). In this model, the leg supporting the body weight compresses during the first half of the stance phase (breaking phase) and there is an increase in elastic potential energy stored in the musculo-tendon tissue of the leg muscles (Farley et al., 1993). As the motion continues forward that spring is released in the 2nd half of the stance phase (propulsion phase) and the potential energy is converted into kinetic energy propelling the individual forward and upward (Dalleau et al., 1998). This spring-like behavior of the body helps to conserve mechanical energy and thus reduce the metabolic cost of running (improve running economy). By altering running mechanics such as stride frequency and stride length, the spring-mass behavior of the body is directly affected and in turn, so is running economy; 28% and 23% of the variability in metabolic cost can be accounted for by stride frequency and stride length when running at a constant speed (Tartaruga et al., 2012).

Another key biomechanical variable associated with energy consumption in running is ground contact time. According to the cost of generating force hypothesis, ground contact time is inversely related to metabolic cost (Roberts et al., 1998) and contact time accounts for as much as 78% of the variability in metabolic cost of running at a constant speed in the range of 8-14 km/hr (Kipp et al., 2018). In congruence with the cost of generating force hypothesis and the spring-mass model of running, numerous studies demonstrate that as speeds increase, the amount of muscular force required to propel the body forward also increases during the braking and propulsion phases (Kyröläinen et al., 2001).

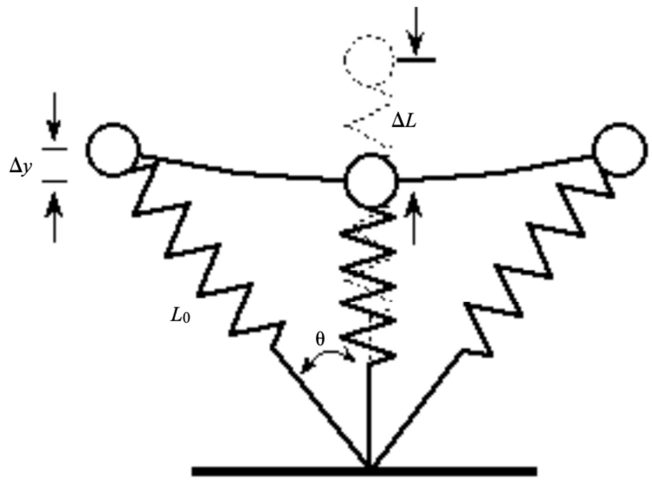

Figure 1. A depiction of the spring-mass model, where the center of mass is compressed to store energy and this energy is converted to kinetic energy (Farley et al., 1993).

Muscle Activation in Running

Muscle activation varies across the different running phases. These muscles have different roles and are activated primarily in different phases. The upper extremity muscle groups with higher muscle activation are the muscles at the shoulder and elbow, specifically the deltoids, biceps, and triceps (Hinrichs, 1990). These muscles showed moderate to stronger activity as speeds increased. According to Hinrichs (1990), the function of these muscles during running is to stabilize the body with upper body angular momentum to counteract the angular momentum of the lower body. The most active lower extremity muscles used in distance running include the tibialis anterior, triceps surae (gastrocnemius and soleus), quadriceps, hamstrings, and hip extensors (including gluteus maximus) (Novacheck, 1998). At the ankle, the gastrocnemius and soleus are active from just prior to FS to late stance phase as they contribute to forward propulsion (Sasaki & Neptune, 2006). Identified by Novacheck (1998), the anterior tibialis dorsiflexes the ankle to provide clearance in the swing phase and prepares the foot for FS. The quadriceps (e.g. rectus femoris, vastus lateralis, vastus medialis, vastus intermedius) are active in late swing phase to help prepare the limb for FS and later at mid-stance to slow the motion of the knee. Hamstrings (Biceps femoris, Semimembranosus, Semitendonosis) act to extend the hip and slow the momentum of the tibia in the second half of the swing through mid-stance. The onset of GM activation occurs just before FS with an increase in activation in the second half of the stance phase to aid in the acceleration of the body forward and upward (Lieberman et al., 2006).

The average activation of the GM while running at speeds between 12.7 km/hr and 14.0 km/hr is 55.9±29.2% of maximum voluntary isometric contraction (MVC) for women and 35.9±13.7% of MVC for men (Willson et al., 2012). The GM has been shown to play an important role in weight support, propulsion and trunk control during bipedal locomotion, and these functions of the GM are a hallmark of ancient humans' transition to bipedal locomotion from a quadrupedal locomotion used by apes (Bartlett et al., 2014). Lieberman et al. showed that the GM played an important role in stabilizing the trunk during bipedal running (Lieberman et al., 2006). Despite evidence that increased GM activation helps to stabilize the trunk in running, there is little evidence that trunk stabilization is related to running economy. In fact, only one study was observed that showed trunk stabilization exercises improved trunk stability but did not improve running economy (Stanton et al., 2004). Thus, it remains unclear whether increased GM muscle activation during running is associated with improved running economy.

Purpose Statement

The primary purpose of this study was to examine the relationship between GM activation and RE. A secondary purpose of this study was to examine the relationship between leg muscle activation and RE. In relation to the primary question, it is hypothesized that there is no significant relation between GM activation and RE. It is also hypothesized that there is no significant relation between leg muscle activation (RF, BF, SOL, TA) and RE.

METHODS

Participants

Three female and seven male participants (27±8 yrs) free of any cardiovascular, neurological diseases, or orthopedic disorders for a minimum of 6 months participated in the study. All participants self-identified as a recreational runner, defined as participating in at least 20–60 minutes of moderate to vigorous intensity running, three to five days per week (Medicine, 2014). Moderate intensity is typically defined as 3–6 METS (e.g. slow running/jogging) whereas vigorous activities are over 6 METS (e.g. running). Participants ran an average of 28±29 miles per week. Participants were recruited from California State Polytechnic University, Humboldt and the local Humboldt County community. All subjects provided written informed consent prior to participation. This study was approved by the Human Subjects Review Board at California State Polytechnic University, Humboldt.

Experimental Design

This study consisted of one testing session in which participants ran at four speeds (8, 9, 10, and 11 km/hr) in which running economy, and leg muscle activation were measured. Prior to these experimental trials, anthropometrics, isometric maximum voluntary contraction (MVC) of leg muscles and standing resting metabolic cost were measured for each participant.

Experimental Session

Prior to data collection, subjects were instructed to wear cool, tight-fitting clothing and their own lightweight running shoes and were instructed not to consume any food or drink, other than water, 90 minutes before the testing session. They were asked to refrain from caffeine and vigorous physical activity for 24 hours before each session and to wear the same pair of running shoes they would normally run in. The testing session began with measuring the subject's anthropometrics (e.g. height, weight, and leg length). Using standard procedures (Contreras et al., 2015), participants then performed three MVC trials for each of five leg muscles of the right leg. Participants were instructed to maintain standard position for each MVC (Table 1). The timing of each MVC was determined by a verbal count given by an experimenter during which the subject grades the contraction force from zero to maximum in ~3 seconds and maintains this force for ~3 seconds. Subjects observed their performance on a digital display and were exhorted to maximize the force during each MVC trial. Subjects were given a rest period of at least 2 minutes between each MVC.

Table 1. Description of body position and action of maximum voluntary isometric contractions (MVC).

Muscle	Position	Action	Resistance	Reference
Gluteus Maximus	Prone with knee flexed at 90°	Hip extension	Distal end of the thigh	(Waldhelm, 2016)
Biceps Femoris	Prone with knee flexed at 70°	Knee extension	Distal end of the shank	(Sedighi et al., 2019)
Rectus Femoris	Seated with knee at 90°	Knee extension	Distal end of the shank	(Sedighi et al., 2019)
Tibialis Anterior	Seated with knee flexed at 90° and ankle plantar flexed at 30°	Dorsiflexion	Dorsal aspect of the forefoot	(Connelly et al., 1999)
Soleus	Prone with knee flexed at 90°	Plantarflexion	Plantar aspect of the forefoot	(Waldhelm, 2016)

Following the MVC trials and ~5-minute rest period, resting metabolic rate was measured as each subject stood quietly for 6 minutes (Weyand et al., 2009). Prior to collecting running trials, participants "warm up" for a minimum of five minutes by running at a self-selected "easy" speed on a motorized treadmill (Trackmaster TMX425C, Full Vision Inc., Newton, KS). For the experimental running trials, participants ran in order from slowest to fastest, at each of four speeds (8, 9, 10, and 11 km/hr) for 6 minutes separated by a minimum of 5 minutes of rest (V. Mendonca et al., 2020). During each running trial, respiratory exchange ratio (RER) via indirect calorimetry was monitored to ensure energy expenditure contributions from the anaerobic system were minimized (RER <0.95). In the last two minutes of each trial, steady state O_2 consumption and CO_2 production was recorded. Steady state was defined as an increase of <100 mlO_2 per min over the final 2 minutes of each stage. In the case for which the difference was >100 ml, the stage continued in 30 seconds increment until a 2-minute steady-state period was confirmed. EMG and lower body kinematics were collected for 10 consecutive strides within the final 2 minutes of each trial.

Metabolic Cost

Metabolic costs as a measure of running economy for running trials were determined using open circuit indirect calorimetry (TrueOne 2400, ParvoMedics, Sandy, UT). Oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were measured. Average gross metabolic rate per kilogram body mass (Watts/kg) was calculated using the average steady-state $\dot{V}O_2$ and $\dot{V}CO_2$ for the last 2 minutes of each 6-minute running economy trial (Brockway, 1987). Resting metabolic rate was subtracted from gross metabolic rate for running to calculate net metabolic power (Watts/kg) for running.

Electromyography (EMG)

Surface electromyography (EMG) signals were recorded using the standard procedures of the International Society for Electrophysiology and Kinesiology (Meyer, 1999). Specifically, site locations were shaved, cleaned and lightly abraded to improve signal to noise ratio prior to placing the electrodes. Bipolar, surface electrodes (Ag/AgCl 10 mm IED, Trigno Delsys) were placed on the Gluteus Maximus (GM), Biceps Femoris (BF), Rectus Femoris (RF), Tibialis Anterior (TA) and Soleus (Sol) according to SENIAM guidelines (Hermens et al., 2000). Electrode positions and signal quality were verified by visually inspecting the EMG signals while participants activated each muscle. EMG signals were collected at 2000 Hz and pre-amplified with a gain of 1700 (input impedance>100MΩ, common mode rejection ratio>110 dB at 60 Hz). Electrode impedance was verified to be less than 5000 Ω and the crosstalk between muscles was negligible.

Following data collection, Visual 3D software (C-Motion, Germantown, MD) was used for EMG analysis. Specifically, raw EMG signals for all MVC and running trials were bandpass filtered using a 6^{th} order zero lag Butterworth filter to retain frequencies between 20 and 450 Hz. The filtered EMG signals were full wave rectified to calculate the root mean square (40 ms moving window) EMG amplitudes (EMG_{RMS}).

Within each experimental session, the time of peak EMG_{RMS} activation was determined for each MVC trial of each muscle tested. MVC magnitude was then quantified for each muscle as the mean EMG_{RMS} activation level (mV) for a 25 ms window at the time of peak activation. Average peak EMG_{RMS} activation was then calculated for each muscle as the mean across all three MVC trials of each muscle.

For all the running trials, each muscle EMG signal was normalized to its average peak MVC EMG_{RMS} amplitude (Hanon et al., 2005). The normalized EMG signals were then integrated using the *trapezoidal method* to determine integrated Electromyography (iEMG) (Smoliga et al., 2010). The iEMG signals were synchronized to the gait cycle using the foot strikes and toe offs identified (Oliveira et al., 2016). The iEMG was calculated for 10 consecutive strides (20 steps) during the last minute of each trial. The iEMG of each muscle was determined over the entire stride, stance phase, and swing phase.

Statistics

The relation between muscle activation of the GM, RF, BF, SOL, TA and net metabolic power (i.e. running economy) was investigated. Pearson product-correlations were used to determine the strength of the relationship between RF, BF, SOL, TA activation and running economy at 11 km/hr. To address the relationship between muscle activation, a secondary set of Pearson Product-Correlations was used to measure these relationships. The strength of the relationship is evaluated using a scale: $r = 0$, none; $0 < r < 0.3$, weak; $0.3 < r < 0.5$, moderate; and $r > 0.5$, strong. For all statistical analyses, significance was set at $p<.05$. Statistical analyses were completed using SPSS software (ver. 27.0, SPSS, Inc., Armonk, NY, USA).

RESULTS

Muscle Activation

Across the range of moderate speeds tested, leg muscle activation did not change significantly (Table 2). GM activation increased less than 1% ($p=.929$) with an increase in treadmill speed from 8 km/hr to 11km/hr and BF activation only increased by 8% ($p=.962$). In contrast but still not statistically significant, RF activation demonstrated the largest change, increasing 25% from 8 km/hr to 11km/hr ($p=.340$). In the lower leg, TA activation increased by 3.6% ($p=.864$) while the SOL decreased by 13% ($p=.437$).

Table 2. Descriptive statistics on net metabolic cost and muscle activation across speeds 8-11km/hr (n=10)

	8 km/hr	9 km/hr	10 km/hr	11 km/hr
Net Metabolic Cost (Watts/kg)	7.53 ± 0.67	8.19 ± 0.56	9.37 ± 0.71	10.12 ± 1.17
RER ($\dot{V}CO_2/\dot{V}O_2$)	0.86 ± 0.03	0.86 ± 0.03	0.87 ± 0.04	0.87 ± 0.04
Integrated Gluteus Maximus (%MVC)	4.24 ± 3.44	4.20 ± 3.87	4.58 ± 4.35	4.27 ± 3.03
Integrated Biceps Femoris (%MVC)	5.05 ± 2.23	4.68 ± 2.03	4.84 ± 2.11	5.05 ± 2.65
Integrated Rectus Femoris (%MVC)	3.15 ± 1.79	3.25 ± 2.18	4.04 ± 2.77	4.04 ± 3.20
Integrated Tibialis Anterior (%MVC)	5.84 ± 2.82	6.04 ± 3.05	6.08 ± 2.62	6.05 ± 2.46
Integrated Soleus (%MVC)	12.55 ± 3.89	11.91 ± 4.67	11.50 ± 4.14	10.95 ± 6.22

Metabolic Cost

The net metabolic cost of running increased linearly with running speed ($r=0.791$, $p<.001$). Specifically, net metabolic cost increased by 34% from 8 km/hr to 11km/hr. Analysis further revealed that across this range of speeds, RER ($\dot{V}CO_2$, /$\dot{V}O_2$) for all trials were <0.95 suggesting that all subjects utilized aerobic metabolism as a primary source for metabolic energy for running (Table 2).

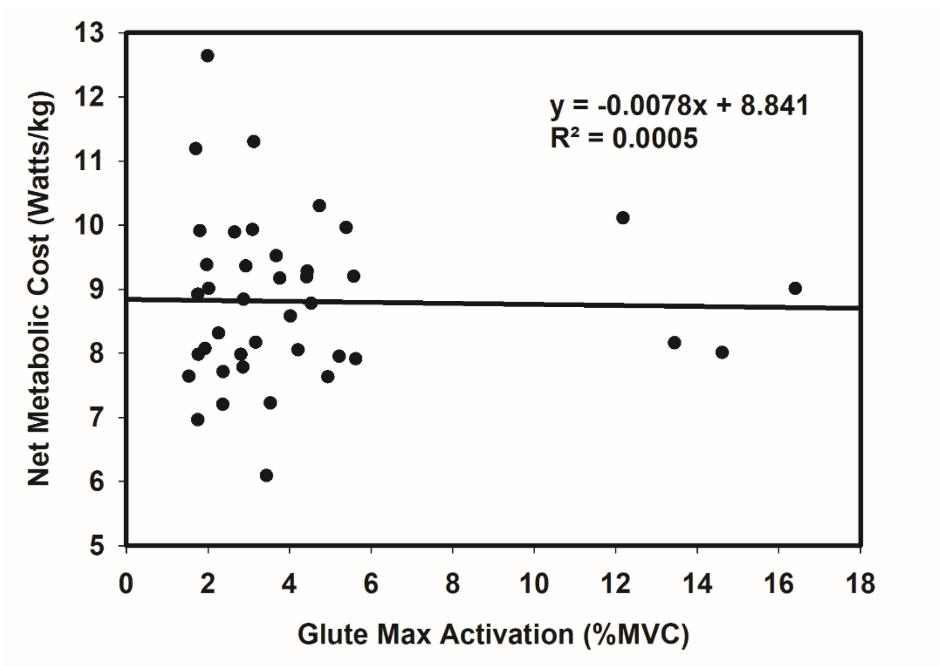

Figure 2. The relationship between gluteus maximus activation and net metabolic cost across speeds 8-11km/hr. (n=10)

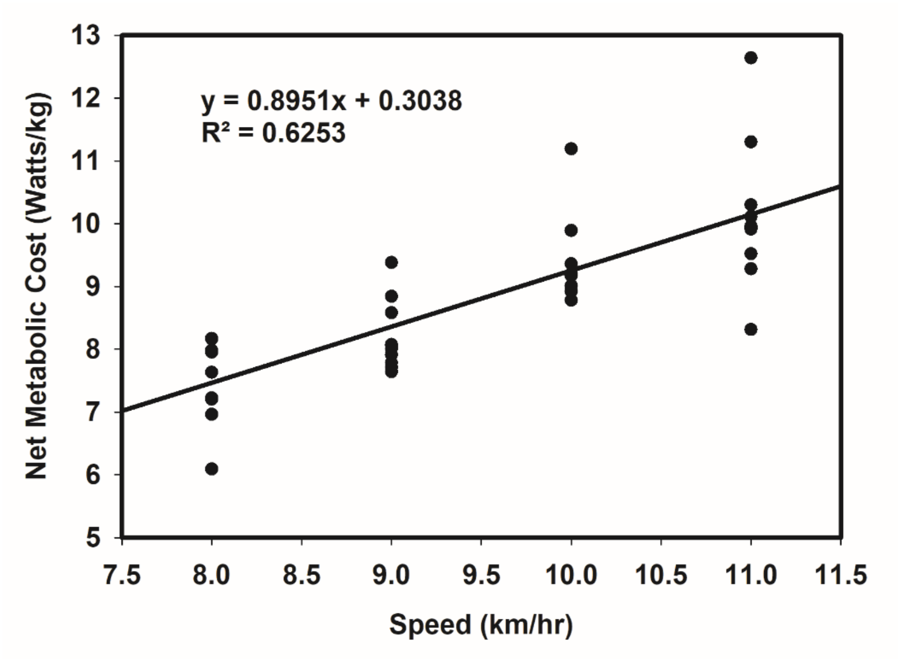

Figure 3. The relationship between running speed and net metabolic cost. (n=10) p<0.001

Correlation Between Muscle Activation and Metabolic Cost

To control for speed acting as a covariate, the correlation between GM and metabolic cost was conducted at 11 km/hr only where GM is most likely to have its greatest activation levels. Despite having no outliers and a normal distribution, GM activation (M=4.27 ± 3.03) was not correlated to metabolic cost (M= 10.13 ± 1.17 Watts/kg) among distance runners at 11 km/hr (r=-0.08, p=0.817; Table 3). Across the entire range of speeds tested, we observed no significant relation between GM activation and net metabolic cost (r=0.02, Figure 2) despite the strong correlation between running speed and metabolic cost (r=0.791, p=<.001). Although insignificant, BF activation was positively related to metabolic cost (r=0.59, p=.071). The remaining leg muscle activations had no correlation with metabolic cost at 11 km/hr (Table 3).

Table 3. Correlation matrix between muscle activation (integrated EMG) and net metabolic cost at 11km/hr.

Variable	*n*	*M*	*SD*	1	2	3	4	5	6
1. Net Metabolic Cost (Watts/kg)	10	10.13	1.17	-					
2. Biceps Femoris (%MVC)	10	5.05%	2.65%	0.59	-				
3. Gluteus Maximus (%MVC)	10	4.27%	3.03%	-0.08	-0.29	-			
4. Rectus Femoris (%MVC)	10	4.04%	3.20%	0.08	-0.14	0.29	-		
5. Soleus (%MVC)	10	10.95%	6.23%	-0.17	-0.21	-0.10	0.02	-	
6. Tibialis Anterior (%MVC)	10	6.05%	2.47%	0.12	-0.36	-0.13	0.41	0.31	-

DISCUSSION

The primary purpose of this research project was to examine the relationship between GM activation and metabolic cost in recreational distance runners. While running at moderate speeds between 8-11 km/hr, GM activation was not correlated with metabolic cost.

As a secondary question the relationship between four other lower extremity muscles and metabolic cost was examined. Similar to GM activation, no significant relations were observed between leg muscle activation and metabolic cost while running at speeds between 8-11 km/hr.

Metabolic Cost

The relationship between running speed and net metabolic cost observed in the present study are well aligned with the results of prior studies. In this study, runners averaged 10.12 ± 1.17 Watts/kg net metabolic cost for 11 km/hr (Table 2). Another study utilizing recreational runners observed a similar net metabolic cost running at a speed of 3 m/s (10.8 km/hr) (Grabowski & Kram, 2008). Moreover, the observation that metabolic cost is positively correlated with running speed (r=0.791) (Figure 3) coincides with previous research where a strong linear relationship is observed (r=0.999) (Batliner et al., 2017). Because of this linear relationship, speed acting as a covariate on metabolic cost was controlled as the relation between muscle activation and net metabolic cost at 11 km/hr was analyzed.

Muscle Activation

GM activation was found to be one of the lower activating muscles compared to the other lower extremity muscles that were collected for this study. This is consistent with other studies where the GM was found to be the lowest activator of the lower extremity muscles collected during level running (Yokozawa et al., 2007). Yokozawa et al. (2007) reported no significant differences in leg muscle activation at both slow and moderate running speeds (11.9 km/hr and 15.1 km/hr). These findings are consistent with this study, where no significant relation between muscle activation and metabolic cost was observed at 11km/hr. Yokozawa et al. (2007) also observed similar trends in activation levels of all lower extremity muscles such as the BF, SOL, and TA. Interestingly, the lowest activation observed was in the RF muscle, whereas Yokozawa et al. (2007) showed RF activation as having one of the greatest activation levels at similar moderate speeds. This may be explained by the different methods of normalization used for the study. While it is standard practice, using peak or MVC normalizations may not accurately represent the activation of the muscles because they only represent the amplitude or the time of muscle activation.

Gender Differences

There were no significant relationships between metabolic cost and gender, this is consistent with literature dictating that gender has no difference in aerobic demand (Morgan et al., 1989). The TA ($p=.009$) was the only muscle to have significantly different muscle activations between males (7.2 ±1.7%) and females (3.3 ±1.6%). No other muscles showed significant differences between muscle activation and gender however, one study has found significant differences between glute max activation running at intermediate running speeds (Willson et al., 2012). In this study, females (6.3±5%) averaged a higher GM activation compared to males (3.4±1.5%) while running at 11km/hr.

Gluteus Maximus and Metabolic Cost

In the present study, no relation between GM activation and metabolic cost was observed at all speeds. When accounting for speed as a covariate, this lack of a relationship persisted (r=-0.08). The lack of a relation between GM activation and metabolic cost may be related to the relatively smaller role the GM muscle plays in running at slow to moderate speeds. Literature suggests that lower extremity muscles utilize oxygen to activate and stabilize joints and control movement patterns (Moore, 2016) therefore, increasing RE. The expectancy for a relationship was sought due to the GM being a hip stabilizer and hip extensor while running. However, the GM is not the primary muscle to be activated during hip extension. This role belongs to the hamstrings, specifically the biceps femoris and semimembranosus muscles (Montgomery et al., 1994). Furthermore, the adductor magnus and tensor fascia latae are other primary muscles involved in hip stabilization while running. In addition, the GM is activated more at higher speeds (Kyröläinen et al., 2001) and could potentially play a larger role in hip stabilization at these faster speeds. However, the GM was found to have low activation among recreational runners at moderate speeds of 8-11 km/hr. Because of the low muscle activation, the GM utilized less oxygen and thus had no discernable relation to RE.

Muscle Activation and Metabolic Cost

Although insignificant, the BF was found to have the strongest relationship to metabolic cost (r=0.59). This is consistent with a study that determined the hamstring muscles' role to drive the body forward while running, and that the hamstring muscle activation had a linear relationship with oxygen consumption (Moore, 2016). The low sample size in this study could have an effect on the relationship between BF activation and metabolic cost. If more subjects were studied there may have been a stronger relationship. In the present study, no significant relation was observed between RF activation during the stance phase of running and metabolic cost (r=0.08). In contrast, one prior study suggests a moderate relationship (r=.346) between RF activity in the swing phase of running and RE and suggests that this relationship is due to the RF muscle playing a primary role in knee extension during this phase (Tartaruga et al., 2012). Because this current study only observed these muscles in the stance phase of running, this relationship was not observed. SOL muscle activation and metabolic cost shared a low relationship (r=-0.17). Although insignificant, this relationship may suggest that increasing SOL activation can be beneficial to metabolic cost. Through active shortening, the SOL muscle can produce work and transfer this to the tendon as strain energy. One other prior study found similar results when a 14-week soleus muscle-tendon training intervention led to a reduced metabolic cost (Bohm et al., 2021). As explained by Alexander et al, (1991) less work must be done by active muscle concentric shortening as tendons are better able to utilize stored elastic energy. TA and metabolic cost also shared a low relationship with one another (r=0.12). The TA is responsible for dorsiflexing the ankle while in the swing phase and preparing the foot for foot strike. However, as running speed increases TA muscle activity is found to decrease due to the association of decreased dorsiflexion at fast speeds (Moore et al., 2014). While some muscles showed a stronger relationship than others to metabolic cost during running, it is important to note there were no significant relations observed between these muscles and RE.

Strengths

This study utilized both male and female subjects. There is not a significant difference between males and females for the aerobic demand of submaximal running relative to their total body mass (Morgan et al., 1989). In the literature review, only one study was found to demonstrate a sex difference in GM activation while running. That study found that females tend to have more peak GM activation and more average GM activity while running than males (Willson et al., 2012). In this present study, participants consisted of 3 females and 7 males. An analysis comparing glute max activation between females and males shows no significant difference. However, because of the limited sample of runners, an observed gender-related difference is unlikely and should be further explored in a study with a much larger number of participants.

When analyzing RE, many studies only report the rate of oxygen consumption. This follows the definition of RE by analyzing the rate of oxygen consumption at a submaximal speed, however in this study a calculation of RE was utilized that takes into account the rate of oxygen consumption and the rate of carbon dioxide produced (Brockway, 1987). Brockway (1987) demonstrated that this calculation gives a more accurate representation of metabolic cost as compared to calculations that only use oxygen consumption although the differences are very small.

Limitations

A potential limitation of this study was that the running speeds may not have been fast enough to observe a relationship between GM activation and metabolic cost. One study looking at GM activation while running found a significant increase in GM amplitude when comparing their slowest and fastest speeds (Kyröläinen et al., 2001). These speeds were 11.7 km/hr and 18.9 km/hr. The slowest speed utilized in that study exceeds the fastest speed of 11 km/hr in this current study. When determining the speeds, runners were expected to be able to run at steady state with RER <1.0 for up to five minutes and primarily utilizing the aerobic metabolic pathway in order to use indirect calorimetry as a valid measurement tool of metabolic cost. A study by Black et al., restricted recreational runners to a maximal speed of 12 km/hr to maintain an RER of < 1.00 as faster speeds exceeded this RER (Black et al., 2018). Additionally, trials were not counterbalanced to accommodate the effect of increasing speed on metabolic cost. Although all speeds utilized were submaximal and participants were given ample time to recover, the order in which participants completed the trials may have had an effect on fatigue.

Another potential limitation of this study is that EMG data was normalized to each muscle's MVC. Although all participants were given exactly the same instructions and same level of encouragement during the MVC trials, it is possible that some participants were unable to achieve a true "maximal" contraction and thus biased the normalized EMG amplitude data. Moreover, one study looking at changes in muscle activity while running determined that isometric MVCs may not be the best indicator of full activation potential (Kyröläinen et al., 2005). Specifically, Kyröläinen et al. (2005) showed that subjects were able to activate beyond their maximal voluntary contraction while running. Despite this potential limitation, the use of MVC as a means of normalizing EMG data is still considered a valid and reliable method when all procedures are performed consistently across all participants.

Another limitation for this study was the impact COVID-19 had on participant recruitment. Distancing regulations caused a significant reduction in research subjects that were willing to participate in this study. An initial power analysis indicated a sample size of at least 50 participants to detect a significant effect size with 80% power and a significance level of 0.05. However, due to the impact of COVID only 10 participants were recruited for this study. A post-hoc power analysis using G power revealed that this study had a power of 4% to detect the relationship observed between GM activation and metabolic cost. Because this is lower than the recommended power of 80%, this suggests this study is underpowered and not able to detect a significant relationship between GM activation and metabolic cost at 11km/hr. To fully assess this relation of GM activation and metabolic cost, future studies should plan to use a broader range of running speeds including faster speeds and a substantially larger number of participants.

CONCLUSION

Contrary to prior beliefs, GM activation does not correlate with the RE at intermediate running speeds. Therefore, differences in GM activation among runners likely does not have a large impact on relative running performance at these moderate speeds. Based on these limited results, training of the GM should not be considered as a key factor when focusing on improving metabolic performance at moderate running speeds.

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APPENDIX

Cal Poly Humboldt Biomechanics Lab

Medical History Questionnaire

Subject ID:________________ Contact Phone or email:__________________

Age ____ Gender ____

YES NO In the past five years have you had:

☐ ☐ 1. Shortness of breath or difficulty breathing at rest or with mild exertion
☐ ☐ 2. Dizziness or fainting
☐ ☐ 3. Heart palpitations (forceful or rapid beating of heart)
☐ ☐ 4. Pain, burning, or cramping in leg with walking
☐ ☐ 5. Unusual fatigue with mild exertion

YES NO In the past six months have you:

☐ ☐ 6. Been diagnosed with any neurological, orthopedic, or cardiovascular disorders?

YES NO Currently....

☐ ☐ 7. Are you under the care of a physician?
☐ ☐ 8. Do you have an acute systemic infection, accompanied by a fever, body aches, or swollen lymph glands?
☐ ☐ 9. Do you have a neuromuscular or musculoskeletal disorder that is made worse by exercise?
☐ ☐ 10. Do you know of any reason why you should not do physical activity?

If you answered yes to any of these questions, please explain.

____
____

Other Health-Related Questions

YES NO

( ) ( ) 1. Have you had any surgery, serious illness, or serious injury in the last two years?

( ) ( ) 2. Are allergic to isopropyl alcohol (rubbing alcohol)?

( ) ( ) 3. Are you currently taking any medications, supplements, or pills? If so, please list on the next page.

( ) ( ) 4. Do you have any skin problems?

( ) ( ) 5. Do you have any other illness, disease, or medical condition (beyond those already covered in this questionnaire)?

( ) ( ) 6. Have you had any caffeine, food, or alcohol in the past 2 hours?

( ) ( ) 7. Have you exercised today?

( ) ( ) 8. Are you feeling well and healthy today?

If you answered yes to any of these questions, please explain.
____
____
____

Please list your current medications and/or supplements here. Include dosage and frequency.

Medication Dosage Frequency
____
____

Physical Activity and Running History

YES NO In the past six months have you:

☐ ☐ 1. Run a minimum of 20 minutes, three or more times per week?

How long have you been running? __________ years / months / weeks

What is your present longest run? ______ miles and/or _____ hours

What is your estimated amount of running in the last 2 weeks? ____ miles and/or ____ hours

What is your estimated best 5k time? __________

Do you have previous treadmill experience? __________

I certify that the information I have provided is complete and accurate to the best of my knowledge.

Date __________
Signature of Client____