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

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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 was to examine the relationship between GM activation and running kinematics.

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 kinematic variables at 11km/hr. For each trial, muscle activation (2000 Hz; Delsys Trigno) of the Rectus Femoris (RF), Biceps Femoris (BF), Soleus (SOL), Tibialis Anterior (TA) muscles and leg kinematics (200 Hz; Vicon Nexus) were collected in the last two minutes of each six-minute trial.

Results/Discussion: When examining the relationship between muscle activation and kinematic variables, no lower extremity muscles examined were correlated with peak joint angles and spatio-temporal kinematics. This lack of a relationship between muscle activation and running kinematics may be related to the Spring-Mass mechanics of running in which elastic energy is stored and released in the muscle-tendon units, thus reducing the amount of work performed by the muscles.

Conclusion: GM activation does not correlate with running kinematic variables 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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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 kinematics. To date, no study has examined the relationship between the GM muscle activation and running kinematics. Thus, the purpose of this study was to examine the relationship between GM activation and running kinematics.

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).

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).

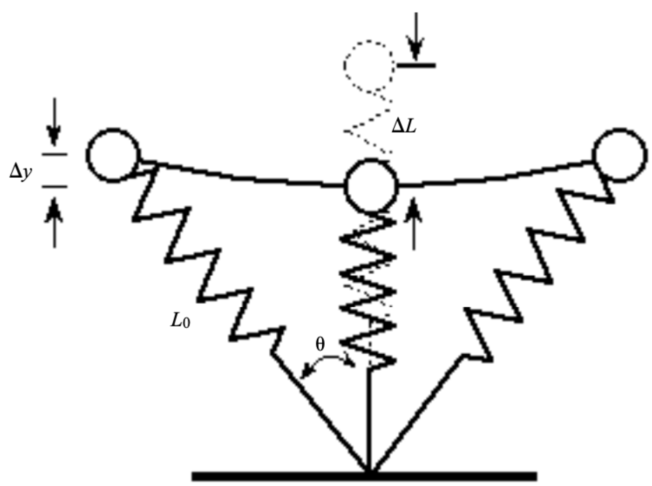

Figure 1: A depiction of the spring-mass model, where the center of mass is compressed and to store energy and this energy is converted to kinetic energy (Farley et al., 1993).

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 and increased 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, 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 showed that 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 running kinematics. A secondary purpose of this study was to examine the relationship between leg muscle activation and running kinematics. In relation to the primary questions, we hypothesized that there is no significant relation between GM activation and running kinematics. We also hypothesized that there is no significant relation between leg muscle activation (RF, BF, SOL, TA) and running kinematics.

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 is activities 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

The study consisted of one testing session in which participants ran at four speeds (8, 9, 10, and 11 km/hr) where leg muscle activation, and running kinematics were measured. Prior to these experimental trials, anthropometrics, and isometric maximum voluntary contraction (MVC) of leg muscles were measured.

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)

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). EMG and lower body kinematics were collected for 10 consecutive strides within the final 2 minutes of each trial.

Electromyography (EMG)

Surface electromyography (EMG) signals were measured 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., 1999). Electrode positions and signal quality was 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 that the crosstalk between muscles was negligible.

Following data collection, Visual 3D software (C-Motion, Germantown, MD) was used for the 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 for each MVC trial was determined for each muscle tested. The MVC magnitude for each muscle was quantified as the mean EMG_{RMS} activation level (mV) for a 25 ms window at the time of peak activation. The average peak EMG_{RMS} activation was 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 for 10 consecutive strides (20 steps) were calculated during the last minute of each trial. The iEMG of each muscle was calculated over the entire stride, stance phase, and swing-phase.

Kinematics

Spatio-temporal and leg joint kinematics were measured during the collection using a nine camera 3D motion capture system (200 fields/s, Vicon Nexus, Centennial, CO) (Hebert-Losier et al., 2015). A lower body cluster marker system was used to capture joint kinematics, stride length, ground contact time and vertical oscillation of center of mass (Tartaruga et al., 2012). Foot strike and toe off events of gait cycle were identified by visual inspection using foot kinematic data.

Statistics

To address the relationship between muscle activation and biomechanical variables, a secondary set of Pearson Product-Correlations was used to measure these relationships. The biomechanical variables being investigated included hip, knee and ankle peak joint flexion during the stance phase, stride length/stride frequency, ground contact time and vertical oscillation of center of mass. The strength of the relationship was 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 muscle activation and kinematic variables across speeds 8-11km/hr (n=10)

	8 km/hr	9 km/hr	10 km/hr	11 km/hr
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
COM Displacement (m)	0.07 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
Stride Frequency (Hz)	1.35 ± 0.10	1.37 ± 0.09	1.38 ± 0.10	1.39 ± 0.10
Stride Length (m)	1.65 ± 0.12	1.83 ± 0.12	2.02 ± 0.14	2.20 ± 0.16
Peak Ankle Dorsiflexion (°)	22 ± 8	22 ± 8	22 ± 8	23 ± 8
Peak Knee Flexion (°)	33 ± 4	33 ± 4	33 ± 4	34 ± 5
Peak Hip Flexion (°)	30 ± 6	31 ± 7	32 ± 7	33 ± 6

Kinematics

Despite the minimal changes in muscle activation, runners exhibited typical but equally moderate changes in running kinematics across the range of speeds tested. Specifically, COM displacement increased 14% (~1 cm, p=.555) and stride frequency increased 3% (0.04 HZ, p=.312), stride length increased by 33% (55 cm, p<.001) across tested running speeds.

Although stride length changed with speed, peak leg joint flexion during the stance phase of running did not change significantly (Table 2). Specifically, peak ankle dorsiflexion increased by 2% (1 degree, p=.900), peak knee flexion increased by 3% (1 degree, p=.628), and peak hip flexion increased by 9% (3 degrees, p=.326).

Correlation Between Muscle Activation and Kinematics

No significant relations between GM activation and spatiotemporal/joint kinematics were observed when running at 11 km/hr (Table 3). Unlike GM activation, BF activation had a moderate significant correlation with vertical COM motion (r= 0.662, p=.037), and RF activation had a strong significant correlation with peak ankle dorsiflexion during the stance phase of running (r=0.792, p<.01) (Table 3).

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Table 3: Correlation matrix between muscle activation (integrated EMG) and kinematic variables at 11km/hr

Variable	*n*	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11
1. COM Displacement (m)	10	0.08	0.01	-										
2. Stride Frequency (Hz)	10	1.39	0.10	-.826**	-									
3. Stride Length (m)	10	2.20	0.15	.815**	-.997**	-								
4. Peak Ankle Dorsiflexion (°)	10	23	8	0.33	-0.46	0.43	-							
5. Peak Knee Flexion (°)	10	34	5	0.49	-0.41	0.40	0.09	-						
6. Peak Hip Flexion (°)	10	33	6	0.21	-0.44	0.45	-0.17	0.51	-					
7. Biceps Femoris (%MVC)	10	5.05%	2.65%	.662*	-0.52	0.54	0.30	0.39	0.12	-				
8. Gluteus Maximus (%MVC)	10	4.27%	3.03%	-0.42	0.17	-0.19	0.08	-0.16	0.39	-0.29	-			
9. Rectus Femoris (%MVC)	10	4.04%	3.20%	0.12	-0.42	0.39	.792**	-0.25	-0.10	-0.14	0.29	-		
10. Soleus (%MVC)	10	10.95%	6.23%	-0.02	0.12	-0.12	-0.03	-0.12	-0.36	-0.21	-0.10	0.02	-	
11. Tibialis Anterior (%MVC)	10	6.05%	2.47%	-0.03	-0.29	0.30	0.20	0.04	0.22	-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 running kinematics in recreational distance runners. While running at moderate speeds between 8-11 km/hr, no significant correlations were found between GM activation and running kinematics.

No significant relationship was found between four other lower extremity muscles and running kinematics was observed while running at speed between 8-11 km/hr. However, when investigating the relations of muscle activation to running kinematics, a significant correlation between BF and peak ankle dorsiflexion was observed.

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 was 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). Yokozawa et al. (2007) also observed similar trends in activation levels of all lower extremity muscles such as the BF, SOL, and TA. Interestingly, RF was observed to have the lowest muscle activation, 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.

Kinematics

Spatiotemporal variables of COM displacement, stride frequency and stride length were within normal limits as compared to studies using similar speeds (Tartaruga et al., 2012). Peak joint angles at the hip, knee and ankle during the stance phase were also within normal limits (Table 3) (Heiderscheit, 2011). In studies that utilized faster speeds up to 13 km/hr, similar joint angles were reported (Ferber et al., 2003).

Gender Differences

When analyzing differences between men and women across all kinematic variables there were no significant differences found. There were no significant differences in joint angles between males and females. This was consistent with findings from Ferber et al., (2003). 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 Kinematics

There were no significant relations between GM muscle activation and the running kinematic variables measured in this study. Despite this lack of relationships, hip extension at the end of the stance phase was observed to increase with a concomitant increase in hip flexing and stride length as speed increased (Novacheck, 1998). As speeds increased from 8 km/hr to 11km/hr, hip flexion increased from 30-33 degrees and stride length increased from 1.65- 2.20 meters. However, gluteus maximus activation stayed consistent at 4.2% of MVC across speeds (Table 2). As suggested by prior studies, this lack of relation may be related to the fact that GM activation was relatively low and was not the primary mover for hip extension at slow to moderate speeds(Montgomery et al., 1994).

Muscle Activation and Kinematics

As an individual runs, they are exerting energy to produce force to propel them forward. The utilization of mechanical energy in running can be best described by the Spring-Mass model (Farley et al., 1993). According to the Spring-Mass model of running, elastic energy is stored in the muscle tendon unit as potential energy during the first half of the stance phase (absorption) and transferred into kinetic energy during the second half of the stance phase (propulsion). This is an example of the energy saving mechanism in which tendons are acting as springs leaving less work to be done by muscles (Alexander, 1991). A similar utilization of the tendon elastic properties associated with Spring-Mass dynamics can be seen in jumping, a movement very similar to running. A study by Arampatzis et al., showed that when individuals were asked to perform drop jumps and alter the contact time there was no significant difference in muscle activation but a change in joint angles and leg stiffness (Arampatzis et al., 2001) suggesting the body is capable of meeting increased mechanical demand without increased muscle activation and energy consumption. A similar spring-mass phenomenon in running may very well explain why GM activation did not change with speed nor was closely related to metabolic cost.

Additional studies have altered running kinematics and found similar results regarding muscle activation and running kinematics. A study by Chumanov et al., altered stride frequency and examined the effects on muscle activation and found no significant difference in leg muscle activation during the stance phase as stride frequency increased by 5 and 10% (Chumanov et al., 2012).

Strengths

This study utilized both male and female subjects. Only one study was found that demonstrated a sex difference in GM activation while running. This 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 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 there was such a 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.

Limitations

A potential limitation of this study was that the running speeds tested may not have been fast enough to observe a relationship between GM activation and running kinematics. One study by Kyröläinen et al., 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 this study exceeds the fastest speed of 11 km/hr collected in this study. Although all the speeds were submaximal and participants were given ample time to recover, the order in which participants completed the trials may have influenced fatigue.

Another potential limitation of the study was that the EMG data was normalized to each muscle's MVC. Although all participants were given 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 by Kyröläinen et al., 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 the study. When looking at a power analysis between GM and running kinematics to assess the strength of the statistical relationship, the relationship between GM activation and center of mass displacement had the strongest power of 0.21. This low power shows that there is a high probability of committing a type 2 error, failing to reject the null hypothesis when the alternative is true. To fully assess the relation of GM activation and running kinematics 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 leg kinematics 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____