5-2018

Learning to run on an LBPPT: neuromuscular and metabolic adaptations

Jordyn Naylon

Learning to Run on an LBPPT: Neuromuscular and Metabolic Adaptations

by

Jordyn Naylon

Submitted in Partial Fulfillment of the
Requirements for the Master of Science in Exercise Science Degree

Kinesiology Department

STATE UNIVERSITY OF NEW YORK COLLEGE AT CORTLAND

May 2018

Approved:

5-31-18 Date	Kevin D. Dames, Ph.D. Thesis Advisor
5-31-18 Date	Larissa True, Ph.D. Thesis Committee Member
5-31-18 Date	Mark Sutherlin, Ph.D. Thesis Committee Member
5-31-18 Date	Eileen Gravani, Ph.D. Associate Dean, School of Professional Studies

Abstract

Previous research on lower body positive pressure (LBPP) treadmills have focused primarily on muscle activation (EMG), spatiotemporal variables, and metabolic differences from running on a standard treadmill. The current study aimed to establish the necessary accommodation time needed for runners to display reliable metabolic and neuromuscular responses on the LBPP treadmill. Fifteen habitually trained runners (11 males, 4 females, average± SD VO_{2Max}=62.81 ± 5.43mL·kg^{-1}·min^{-1}) ran a total of 3, 15-minute trials on the AlterG® treadmill during a single testing session. For each trial, the AlterG® was set to support 30% of body weight at 70% of the speed at which the participant reached VO_{2Max} on a standard treadmill. Oxygen consumption, the RMS EMG of the vastus medialis, and stance time were recorded every five minutes. A series of one-way ANOVAs with repeated measures were used to test whether dependent variables changed over time. Simple contrasts were made to compare each DV's initial recording against all subsequent values. Significant differences in VO_2were observed, with a 3.7% decrease from the first (31.37 mL·kg^{-1}·min^{-1}) to second (30.21 mL·kg^{-1}·min^{-1}) trial. RMS EMG of the vastus medialis also displayed significant changes over time, with~16% decrease in magnitude between trials one (0.13 mV) and two (0.11 mV). The third trial displayed similar magnitudes as trial two for each of these measures. Though not significant, there was an overall ~7% decrease in stance time from the first (0.200 s) to third (0.186 s) trials. Thus, approximately 20-minutes is necessary to observe stable metabolic and neuromuscular responses for running on an LBPP treadmill at 70% of bodyweight. Future research should provide sufficient accommodation time prior to collecting dependent variables and previous findings on these devices may need to be reconsidered.

Acknowledgements

I would first like to thank my thesis chairman Dr. Kevin Dames of SUNY Cortland. Dr. Dames helped shape this project and helped push me to not only be a better student, but also be a better researcher. He consistently helped with the editing of this thesis paper and with any questions I had over the time of us working together. I can now say that I'm basically an expert in accommodation on the LBPP treadmill. This project wouldn't have gone so well without him and I greatly appreciate his time and energy on this project.

I would also like to acknowledge the two experts who aided in editing this thesis document and brought in their own expertise in statistics as well as EMG analysis. Dr. Larissa True and Dr. Mark Sutherlin of SUNY Cortland were very helpful in adding to this thesis paper as well as the experimental protocol. I very much appreciate their help and their time on this project.

I would also like to thank the participants who came from areas around Cortland, NY to be a part of this study. The protocol required them to come into the lab for 2 separate days and I appreciate them all for coming in and giving their time to the thesis study.

Finally, I want to express the gratitude I have for my fiancé and my family for providing me with endless support and encouragement throughout the pursuit of my Master's Degree. Specifically, I want to thank my fiancé for all of the amazing food he has made me over the last 2 years while I worked endless hours writing and editing as well as driving back and forth from Syracuse to Cortland, NY every day. I appreciate his love and commitment in helping me finish my thesis.

Author

Jordyn Naylon

Table of Contents

List of Tables and Figures

CHAPTER 1

INTRODUCTION

In sports performance and healthcare settings, individuals with and without lower body injuries need equipment for rehabilitation, strengthening, and training. Lower body positive pressure (LBPP) treadmills are now included in that repertoire of equipment. LBPP treadmills are commercially available to the public and research into the effects of exercising on such a device is very active (Farina, Wright, Ford, Wirfel, & Smoliga, 2017).

LBPP treadmills are used in a variety of applications. Injured runners and clinical populations may use one for recovery, while healthy individuals may use one for training. One of the primary reasons for this is LBPP treadmills offer a mechanism to run with reduced vertical ground reaction forces (vGRF)(Hansen, Einarson, Thomson, Whiteley, & Witvrouw, 2017; Raffalt, Hovgaard-Hansen, & Jensen, 2013). Athletes may desire this method as a way to train in higher volumes with lower impact compared to running outdoors, which may be associated with lower risk of injury. As with any new modality, an accommodation period is required for an individual to adapt to a new stimulus. For example, there are differences between running over ground compared to running on a standard treadmill (Schieb, 1986). Schieb (1986) showed that trained runners who were novices on a treadmill required up to 3 days of running on a treadmill before consistent intra-session kinematic data were observed. The conclusion was that up to an 8-minute accommodation period might be necessary within a given day’s testing session to achieve stable patterns (Schieb, 1986). Kinematic accommodation to LBPP treadmills have yet to be addressed in the literature. The main areas of interest when evaluating LBPP treadmills have been the metabolic, electromyographic (EMG), and spatiotemporal responses (Temple et al., 2017; Mercer, Applequist, & Masumoto, 2013; Sainton et al., 2015).

Kinematic differences are often associated with altered muscle activity and kinetic responses. Running on an LBPP treadmill reduces EMG activity of lower extremity extensor muscles (e.g., gastrocnemius, rectus femoris) (Hunter, Seeley, Hopkins, Carr, & Franson, 2014; Jensen, Hovgaard-Hansen, & Cappelen, 2016; Liebenberg et al., 2011). While increasing levels of body weight support decreases muscle activity, the muscular response does not seem to be proportional to the total body weight supported. For example, for a participant running at a given speed at 60% of their body weight, the root mean square (RMS) EMG magnitudes are ~75-95% of the unsupported magnitudes (100% body weight) for the same speed (Liebenberg et al., 2011). However, an issue with these findings is the short bouts (up to 5 minutes) at which participants ran in each experimental condition. As in the treadmill study by Schieb (1986), up to 8 minutes might be needed for an individual to become accommodated to a standard treadmill. Considering the lateral support around the waist when using an LBPP treadmill and the novel weight supporting feature, a longer accommodation time might be needed in order to produce stable muscle activity responses.

Spatiotemporal variables are also shown to change while running on an LBPP treadmill. As body weight support increases while running on the LBPP treadmill, variables such as stride frequency, stance time, and stride length differ from 100% body weight. Specifically, stride frequency and stance time decrease, whilestride length increases as more body weight is supported (Raffalt et al., 2013). Collectively, this indicates thatparticipants spend more time in flight and less time in contact with the treadmill belt with body weight support. Multiple studies have focused on differences in spatiotemporal variables with LBPP treadmill use (Raffalt et al., 2013; Sainton et al., 2015). These studies found significant differences between the variables mentioned above with body weight support, but a similar issue as with the EMG data above is also present in these data. That is, the participants were not provided an ample amount of time to accommodate to the LBPP treadmill. In the Sainton et al. study (2015), participants only had a 5 minute warm up and each trial was 5 minutes long. In the Raffalt et al. (2013) study, participants ran 3-minute bouts at varying body weight supports, and each bout was run at varying speeds. In summary, only acute responses in spatiotemporal variables have been addressed on the LBPP treadmill.

Total body weight is a significant contributing factor to total energy expenditure during running. That is, as the LBPP treadmill supports more body weight, less metabolic power is required for a given running speed (Grabowski & Kram, 2008). Indeed, ~80% of the metabolic cost of running can be attributed to the task of supporting and propelling body weight while in the stance phase (Arellano & Kram, 2014). It is not surprising then that manipulating body weight via the LBPP treadmill would have a metabolic consequence. Several studies have demonstrated that reducing the total weight the runner has to support leads to a decrease in oxygen consumption (Grabowski & Kram, 2008; Gottschall & Kram, 2005). However, McNeill, de Heer, Williams, & Cost (2015) demonstrated that a stable, minimum metabolic response required a significant accommodation period while running on an LBPP treadmill. While there was an initial lower value in the oxygen consumption (VO_2) value compared to the standard treadmill condition, the VO_2 continued to decrease as time accrued on the device. That study found significant decreases in relative VO_2 measurements after a total of 45 minutes were accumulated on the LBPP treadmill (McNeill et al., 2015). Some methodological considerations of that study warrant further investigation. First, participants performed several trials over a three-week period, not during one continuous segment of running. This limits the ability of researchers to initiate an experimental protocol in a timely manner after ensuring the participants are familiarized. Second, the researchers could not conclude if accommodation happens by minute 20, 15, or even 10 minutes due to the confounding factor of variations in body weight supports within each 15-minute segments (McNeill et al., 2015). Each 15-minute trial was split into three, five-minute sections with body weight supports of 50, 70, and then 90% of body weight each. Faster accommodation may occur if trials are completed within a single testing session and at a single body weight support condition. The current study seeks to establish accommodation thresholds for a single body weight support and at a single speed to of running on a LBPP treadmill. A secondary component of this study addresses the lack of additional dependent variables that could explain the noted accommodation period previously reported.

Statement of the Problem

The very short trial lengths adopted in previous LBPP treadmill studies limit confidence in their EMG and spatiotemporal findings. Limited trial lengths do not consider full accommodation to the LBPP treadmill, so observed results may not truly characterize stable measures. In contrast, previous metabolic accommodation work lacked any explanatory variables to note how participants altered gait parameters to optimize their form. This study will investigate metabolic accommodation to LBPP treadmill running at a single speed and body weight support while simultaneously observing EMG and spatiotemporal measures to explain any noted metabolic adaptations.

Purpose

The purpose of this study is to identify neuromuscular and mechanical mechanisms that can explain the VO_2 responses previously observed in trained athletes learning to run on an LBPP treadmill during one session. That is, this study will evaluate if adaptations in EMG and/or gait patterns can explain the previously noted period of metabolic adaptation on the LBPP treadmill.

Hypotheses

$\mathbf{H_0}$: There will be no difference in RMS EMG magnitude of the vastus medialis throughout the protocol

$\mathbf{H_a}$: There will be a decrease in RMS EMG magnitude of the vastus medialis throughout the protocol

$\mathbf{H_0}$: There will be no difference in VO_2 throughout the protocol

$\mathbf{H_a}$: There will be a decrease in VO_2 throughout the protocol

$\mathbf{H_0}$: There will be no difference in stance time throughout the protocol

$\mathbf{H_a}$: There will be a decrease in stance time throughout the protocol

Delimitations

The delimitations of this study include:

1. Participants were trained runners who were novices on the LBPP treadmill. They were all 18-35 years old and could run a 5k under 23 minutes. Novices on the LBPP treadmill were individuals who had never run on this type of treadmill before.
2. LBPP treadmill was set to zero incline and at the speed that elicited 70% of a runner's VO_{2Max} score as observed on a standard treadmill.
3. LBPP supported 30% of the runner's bodyweight. This is a moderate amount of support compared to previous investigations.
4. Surface EMG measurements were taken from the vastus medialis of the right leg.

Limitations

The limitations of this study include:

1. Analyzing EMG data only on the right leg precludes investigation of possible asymmetries between limbs.
2. Running trials on the LBPP were fixed at a given speed relative to the participant's VO_{2Max}. Different speeds might elicit unique responses not observable in the present study.
3. The participants ran at 70% of their body weight. Changes in EMG activity and VO_2 were not recorded at varying body weight support levels.

4. The number of participants reached was 15 and all were trained runners (average VO_{2Max} = 62.81 $mL \cdot kg^{-1} \cdot min^{-1}$). Results might not be indicative of how the general population might adapt to LBPP treadmills.
5. The participant demographic was mostly male (n=11).

Assumptions

The following assumptions were made about this study:

1. Participants performed the VO_{2Max} protocol to the best of their ability and to volitional exhaustion.
2. Gait symmetry is assumed (EMG and spatiotemporal) between left and right limbs.
3. All participants provided accurate information about training, previous injuries, and fitness level.
4. The participants, without instruction, would naturally adopt a gait pattern that minimized oxygen consumption on the LBPP treadmill.

Definition of Terms

LBPP treadmill	A specifically designed treadmill that uses positive air pressure to lift a runner at their hips to decrease the weight of an individual during a bout of exercise.
EMG	Electromyography is used for the detection and analysis of electrical signals associated with active muscles.

Accommodation	A time period during which individuals change their running stride towards an optimal pattern for a new modality. This gradual change is marked by a decrease in the metabolic rate required to perform a task.
Vastus Medialis	Muscle of the lower limb that produces knee extension. It is located anteriorly and medially on the thigh.
Spatiotemporal Variables	Spatial and temporal variables associated with gait.
Stance	A spatiotemporal variable representing the portion of the gait cycle that the foot is in contact with the ground, measured in seconds.
Metabolic Rate	Rate of energy expenditure quantified by volume of oxygen (VO_2) consumed per unit of time – $mL^{-1} \cdot kg^{-1} \cdot min$.
Metabolic Cost	VO_2 per distance traveled – $mL \cdot kg^{-1} \cdot km^{-1}$.
Running Economy	Energy demand for any given submaximal running speed. Better economy indicates lower metabolic rate at a given speed of running.

VO_{2Max} The maximal amount of oxygen ($mL \cdot kg^{-1} \cdot min^{-1}$) a runner can consume is an indicator of aerobic fitness.

Significance of the Study

One study has suggested that new users of an LBPP treadmill require an accommodation period of at least 20 minutes at a given support level before a stable, minimum metabolic response is achieved (McNeill et al., 2015). Other data suggests that in short term bouts on an LBPP treadmill there are decreases in muscle activity in response to the amount of body weight supported (Jensen et al., 2016). There has yet to be a study that joins these findings together. As a novice LBPP runner adjusts their running form on a LBPP treadmill, it is expected that the EMG and gait pattern changes will influence the observed metabolic responses. Therefore, the goal of this study is to measure the differences in muscle activation as novice individuals acclimate to the new experience of running on a LBPP treadmill to explain previously reported findings. Establishing thresholds for LBPP treadmill accommodation can allow future investigations to capture reliable data from participants using this type of device. Outcomes from previous research using this type of treadmill may need to be reconsidered.

CHAPTER 2

LITERATURE REVIEW

LBPP Treadmills

LBPP treadmills are a special type of treadmill. A picture of the LBPP treadmill (AlterG®) used in the present study can be found in Appendix D. In short, a plastic bubble surrounds the entire treadmill and in the center, above the treadmill belt, there is an opening. The runner stands inside this section with their feet on the treadmill belt. A technician then raises the support bar up so that the opening of the plastic bubble can be attached to a pair of neoprene shorts that the user wears. Once the shorts are zipped into the plastic bubble there is a hermetic seal that prevents air from escaping. A pump inflates the bubble to provide body weight support to the user. Manufacturers, such as AlterG®, market these treadmills to “reduce impact, pain, and effort” while “supporting normal gait and balance” (Mishra, 2015). Another term for these devices is “anti-gravity treadmills®”, given that they reduce the proportion of a person’s body weight (i.e., the force of gravity on a person’s mass) the user has to support during activity. Uses vary from high-intensity athlete training to physical therapy applications (Mishra, 2015).

Muscle Activity on LBPP Treadmills

The electrical activity associated with muscle contractile efforts is measured by electromyography (EMG). These electrical signals represent the neural excitation of muscle tissue. EMG has a variety of uses, including measurement of muscle force (in isometric conditions), activation level, and fatigue. Surface EMG measures muscle activity when electrodes are placed on the skin after palpation of the skin to find the muscle belly (De Luca, 2006). Surface EMG signals represent when, and how much, a muscle is "on." The timing of activity, magnitude of the signal, and frequency content are all meaningful components indicating how a given muscle is behaving during a motor task. Some example data from the current study depicting processed EMG signals is provided in Appendix C.

Few studies have focused on muscle activity patterns during running on LBPP treadmills. Therefore, this section will provide an in-depth discussion of each of the available studies on this topic. The similarities, differences, general message, and issues warranting further investigation will be included.

One of the few studies analyzing muscle activity with varying weight support and speed conditions was published by Liebenberg et al. (2011). Participants were asked to choose a speed that they could sustain for 30 minutes at 100% body weight on the LBPP treadmill. Preferred speed was the average of 3 preferred speed trials and was later used as the reference condition of the experimental protocol. Experimental protocols were then run at 100%, 115%, and 125% of the preferred speed and at 100%, 90%, 80%, 70%, and 60% of body weight at each speed. This resulted in 15 total running conditions, but each weight-speed combination was only held for 1 to 1.5 minutes. The order was always slow to fast and from high to low body weight to minimize the time for the participant to accommodate. The researchers hypothesized that the magnitude of the average EMG of the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius would be almost directly proportional to the amount of body weight supported. This hypothesis was not supported by the results. Data from the 60% supported condition elicited 75-95% of the average EMG magnitudes of all the muscles measured of the 100% body weight condition. When more body weight was supported the muscle activity decreased, but would increase in a given body weight condition when speed increased. There were two exceptions to this; the tibialis anterior and the biceps femoris did not show any differences in activation between speeds at 100% and 90% body weight and the biceps femoris was not different between speeds at 60% body weight. The authors concluded that the same running intensity could be obtained at a lower body weight support when the speed is increased. Although, despite EMG magnitudes decreasing with body weight support, the muscle activity pattern remained unchanged meaning that the timing of activation of the muscle remained the same at every body weight support.

These results differ from the other common method for reducing an athlete's weight in rehabilitation, which is water running. In this approach, the individual runs while fully or partially submerged in water. While water running decreases body weight due to buoyancy, the muscle activation patterns are different than running on land. Specifically, running in an aquatic treadmill has been shown to increase the absolute duration of muscle activation by 231.1% in the vastus medialis due to the increase in drag as the individual moves through the water (Silvers, Bressel, Dickin, Killgore, & Dolny, 2014). LBPP treadmills reduce the vGRF, like water running, but appear to maintain more similar muscle activation patterns as running on land because the system uses air pressure to provide lift. Thus, if an athlete wants to maintain similar neuromuscular coordination as in unsupported running, then this type of treadmill seems preferable over water running (Liebenberg et al., 2011).

A more recent study(Mercer et al., 2013) obtained similar conclusions as Liebenberg et al. (2011), but did not appreciably extend trial lengths. Each subject ran for

1.5-2 minutes per condition on the LBPP treadmill for a total of around 30 minutes with a break in between each 2-minute bout. Similar to Liebenberg et al. (2011), these authors reported that muscle activity did not decrease by the same magnitude as imposed decreases in body weight. That is, the researchers concluded that there might be a "ceiling effect" of reduction in muscle activity for the rectus femoris, gastrocnemius, and tibialis anterior muscles as body weight is being reduced down to 20% (Mercer et al., 2013). These two articles found similar results, but comparisons of their populations is not possible because Lienbenberg et al. (2011) recruited individuals who ran an average of 4.6 miles per week, while Mercer et al. (2013) did not define their participant characteristics. It is expected that fitness levels and running experience can play a large role in the responses observed.

Hunter et al. (2014) analyzed more muscle groupings than Liebenberg et al. (2011) and Mercer et al. (2013) and recruited Division I collegiate distance runners. This is a much more fit population than the previous investigations. Hunter et al. (2014) analyzed 12 lower extremity muscles, which included the gluteus medius and maximus and the adductors, in addition to the muscle groups previously addressed by the two prior works outlined above. Hunter et al. (2014) decided the warm up to be at 6:00min/mile due to this speed being a common training intensity of the participants for their long runs. Each participant ran in each body weight supported stage (40%, 60%, 80%, and 100% bodyweight) at the same pace for 2 minutes (Hunter et al., 2014) Again, a short duration at each body weight protocol was used like the previous two articles, but this time with speed consistent across all trials. Results indicated that some muscles decreased activity during stance in response to unloading more than others. For example, the gluteus medius and vastus medialis had a greater decrease in activation from 100% to 40% body weight compared to the medial/lateral hamstring and the peroneus. This has implications for return-to-running rehabilitation programs or individuals seeking to manage an overuse injury as the LBPP treadmill seems to be more beneficial for reduction in muscle activity in some muscles more than others. Running on the LBPP treadmill does not seem to decrease activity in the hamstrings as much as the quadriceps, for example (Mercer et al., 2013). Therefore, individuals with hamstring injuries might not benefit from LBPP treadmill use.

One other study analyzed muscle activation while running on the LBPP treadmill, but the participants ran for 6 minutes at each body weight support (100%, 80%, 60%, 40%, and 20% bodyweight) for two separate trials performed at 2.22 m/s and 3.33 m/s. The muscles analyzed were the vastus lateralis, vastus medialis, biceps femoris, lateral gastrocnemius and soleus. The findings were consistent with the previous article (Hunter et al., 2014). Specifically, the knee extensor muscles (i.e., vastus medialis and vastus lateralis) showed reduced peak and average EMG signals while the biceps femoris showed no responses to increases in body weight support or speed. While the lateral gastrocnemius and soleus activity were reduced in response to the unloading, the relative reductions of these muscles were not as pronounced as the knee extensor group. These results reflect the differences in the functions of these muscles while running. While the knee extensors are mainly used to resist gravity and prevent collapse of the knee joint, the calf muscles (i.e., lateral gastrocnemius and soleus) are used for propulsion as well as weight support against gravity (Jensen et al., 2016).

There are few studies focusing on muscle activity while running on the LBPP treadmill (Hunter et al., 2014; Jensen et al., 2016; Liebenberg et al., 2011; Mercer et al., 2013). A common limitation of these studies is the running times for each protocol. At most, participants ran each individual trial for only up to 6 minutes. In fact, Jensen et al. (2016) was the only study to have trials longer than two minutes. Even on a standard treadmill, which most runners have at least some experience with, a minimum of 3 minutes is required to reach a stable kinematic pattern (Riley et al., 2008). Thus, the novelty of the LBPP treadmill may require additional time for runners to develop a stable running pattern.

Spatiotemporal Variables on LBPP Treadmills

Running technique is known to influence metabolic cost of running. For example, selecting a stride rate that is higher or lower than optimal elevates oxygen consumption at a given speed (Barnes & Kilding, 2015). Stride lengths that are too short or too long can also cause an increase in oxygen usage and an increase in muscle activity (Barnes & Kilding, 2015). Adopting an optimal gait pattern is an important component of running performance and takes time to develop.

On LBPP treadmills specifically, variations in bodyweight support requirements seem to also influence spatiotemporal outcomes. Sainton et al. (2015) analyzed the changes in runners' gait cycles on the LBPP treadmill to find out if a runner maintains their preferred pattern when body weight support is provided. Participants ran for three minutes at 100% bodyweight, followed immediately by three minutes at 80% body weight, and finally a second three-minute segment at 100% body weight. The same nine-minute protocol was repeated at the 60% body weight condition. A 5-minute rest interval was provided between the 60% and 80% unweighing and reloading protocols. Flight time significantly increased at 60% and 80% body weight support and step frequency significantly decreased. A significant decrease in early stance vertical accelerations of the center of mass, soleus EMG, and impact forces, as well as duty factor (i.e., the fraction of the left foot contact time divided by the stride duration, or the percentage of time that the foot is in stance) in both bodyweight conditions were observed. These results agree with Raffalt et al. (2013), who reported an increase in flight time in response to increased running speed and to decreased body weight. However, this measure was more significantly affected by body weight than running speed in that study. Interestingly, during the reloading part of the protocol (i.e., the second three minutes at the 100% bodyweight), all spatiotemporal variables regained their initial values as observed in the initial 100% bodyweight bout (Sainton et al., 2015). From this, it seems that runners can revert to their preferred, familiar gait patterns quite quickly after being exposed to novel running conditions.

Stride length is another lower body kinematic variable that has been researched on the LBPP treadmill. As with flight times, stride length has been shown to increase about 15% with body weight supports at 60, 70, and 80% compared to no body weight support, but with no differences among these three body weight support levels (Mercer & Chona, 2015). Mercer and Chona (2015) also reported that stride length increased in response to faster speeds independently of the body weight support condition. Each speed/body weight support combination in their study lasted at least 1 minute, which the authors claimed was to allow for acclimation to each new condition. A step length investigation by Raffalt et al. (2013) agreed with these findings, showing that a higher body weight support will increase stride length. Manufacturers of the LBPP treadmill claim that athletes can maintain their normal gait pattern while using these devices, but this does not seem to be the case based on available literature.

As demonstrated above, stride characteristics differ across levels of body weight support. Athletes wanting to train on the LBPP treadmill need to adjust its settings to meet their training criteria. In order to create a more normal gait cycle, an athlete would have to increase the speed of the treadmill while at a lower body weight. This is supported by the results from Raffalt et al. (2013), who demonstrated that running patterns are less affected by body weight reduction while at higher running speeds. Between 100% to 25% body weights at 10km/hr there was a 19% decrease in step frequency compared to only a 6% decrease at 22km/hr (Raffalt et al., 2013). Most of the research on lower body kinematics have included multiple speeds and a variety of body weight supports in each study, with each speed/bodyweight combination lasting a relatively short time (Jensen et al., 2016; Mercer et al., 2013; Sainton et al., 2015). No studies have considered potential long-term accommodation of lower body kinematics while running on the LBPP treadmill.

Running Economy

Running economy (RE) is the steady-state volume of oxygen consumption, or $VO_{2,}$ at any given submaximal running velocity and is usually reported relative to body mass as $mL^{.}kg^{-1.}min^{-1}$ (Barnes & Kilding, 2015). RE has been shown to even be a better predictor of endurance performance than maximal oxygen consumption (VO_{2Max}) (Saunders, Pyne, Telford, & Hawley, 2004). In past research, VO_{2Max} was shown to correlate highly with endurance performance with correlations ranging from r = -0.82 to r

= -0.91 (Saunders et al., 2004). In contrast, Conley and Krahenbuhl (1980) showed a much lower correlation between VO_{2Max} and endurance performance, but a high correlation between steady state oxygen uptake and the submaximal treadmill running pace (r = 0.86). This relationship means that 65.4% of the variation in 10 km times can be explained by variability in running economy and is an important metric for runners to monitor (Conley & Krahenbuhl, 1980).

Many variables influence RE, including the running surface, the force production and stiffness of the lower legs, and kinematics (Barnes & Kilding, 2015; Saunders et al., 2004). For example, when participants ran with an increased knee flexion, or what is called "Groucho running," there was a 50% increase in oxygen demand (Barnes & Kilding, 2015). Some previous research has shown that VO_2 is lowest when stride lengths are self-selected, but this is not unanimous (Morgan, Martin, Krahenbuhl, & Baldini, 1994; Barnes & Kilding, 2015; Saunders et al., 2004). In support of this self-selection hypothesis, researcher-imposed stride lengths increase oxygen consumption at a given speed (Barnes & Kilding, 2015). In contrast, another study showed that audio and visual feedback to alter stride frequency could reduce VO_2 at that submaximal speed. Thus, optimizing the step length and decreasing the aerobic demand may benefit distance runners who have an uneconomical freely chosen step length (Morgan et al., 1994). Optimizing these and other gait characteristics can improve endurance performance (Saunders et al., 2004). For example, timing and amplitude of muscle activity prior to and at initial contact can augment leg stiffness and impact running economy (Barnes & Kilding, 2015).

As mentioned in the previous section, step frequency decreases and flight time increases are observed on an LBPP treadmill (Sainton et al., 2015; Raffalt et al., 2013). These temporal adaptations are also associated with longer stride lengths (Mercer & Chona, 2015) and may indicate altered muscle activity. Shifting away from preferred patterns often has a metabolic penalty. However, optimal gait kinematics and EMG patterns while running on an LBPP treadmill are yet unclear. Optimal patterns and the necessary time to develop them; have yet to be addressed in the literature.

While running on LBPP treadmills, a trained runner will experience different stimuli compared to running on a standard treadmill or when running over ground. Bodyweight support factor aside, the LBPP treadmill also provides lateral stability, preventing the runner from moving side-to-side or drifting toward or away from the front of the treadmill. This is more restrictive than outdoor running or running on a standard treadmill, which are known to differ in regards to oxygen consumption for a given speed, even in elite endurance athletes habituated to treadmill running (Mooses, Tippi, Mooses, Durussel, and Mäestu, 2015). Mooses et al. (2015) had participants perform running tests to volitional exhaustion on a track behind a pace bike to help maintain running speed, and also on the treadmill. The protocol consisted of VO_{2Max} tests starting at 8km·h^{-1} and increasing speed by 2 km·h^{-1} every 3 minutes up to 20 km·h^{-1}. The speeds at 20 km·h^{-1} and 22 km·h^{-1} were maintained for 2 minutes and from that point speed was increased by 1 km·h^{-1} until volitional exhaustion. In both experimental protocols, VO_{2Max} was found to be the same (Track - 68.5 ± 5.3 vs. Treadmill - 71.4 ± 6.4 ml·kg^{-1}·min^{-1},$p = 0.105$), but RE was found to be significantly better in the track protocol (215.4 ± 12.4 ml·kg^{-1}·km^{-1}) compared to the treadmill (236.8 ± 18.0 ml·kg^{-1}·km^{-1}) at 16km·h^{-1}. The authors attributed this to the significantly lower (11.2%) ventilation rates during the track protocol. Thus, greater ventilation rates required greater muscle activity in the treadmill condition and this was associated with greater metabolic activity. Overall, the athletes were 8.8% more economical on the outdoor track than the treadmill while running at the submaximal speed of 16 $km \cdot h^{-1}$(Mooses et al., 2015). Even when running on a standard treadmill, running mechanics can change and cause poorer RE scores (Temple et al., 2017; Mooses et al., 2015) and/or increased muscle activation (Hunter et al., 2014).

Grabowski and Kram (2008) analyzed differences in metabolic power during running on an LBPP treadmill using healthy, experienced treadmill runners. Each participant ran 13 trials that were 7 minutes long with 8 trials on the first day and 5 on the second day. Participants ran 3.0 m/s and 4.0 m/s at 75%, 50%, and 25% body weight, and 5.0 m/s at 50% and 25% body weight. Kinetic variables collected included vertical impact peak ground reaction force (GRF), active peak GRF, and loading rate, along with the metabolic power during each running condition. Gross metabolic power increased as velocity increased independent of body weight condition. Likewise, greater body weight support resulted in lower gross metabolic power independent of running velocity. That is, any decrease in the participant's weight or velocity would result in less metabolic power (Grabowski & Kram, 2008). As in the EMG parameters, it seems that any decreases in the VO_2 by providing greater body weight support can be made up for by increasing running speed when using an LBPP treadmill. This may be helpful for athletes who wish to maintain training intensity while benefiting from lower impact forces.

Despite seeing differences between bodyweight support conditions, participants may not have adopted optimal gait patterns for their most economical running in these prior investigations. McNeill et al. (2015) investigated metabolic adaptations to LBPP treadmill running over many trials over several days in eight recreational runners. The main inclusion criteria for the participants were that they had never run on an LBPP treadmill before but had previously run on a standard treadmill. A VO_{2Max} test was first performed on a standard treadmill. Each participant then ran seven, 15-minute sessions on the LBPP treadmill at a speed that would elicit 70% of their VO_{2Max} on the standard treadmill. Each session took place on a different day. Within each 15-minute trial, 5 minutes were allocated to a 50%, 70%, and then 90% body weight condition. Not surprisingly, VO_2 had a significant main effect with body weight such that greater body weight support resulted in a lower VO_2. There was also a main effect of trial, which indicated that there was a reduction in VO_2 over time within a given body weight condition. That is, as the participant continued to experience the LBPP treadmill, they had a lower oxygen consumption (VO_2) in the later parts of the running protocol compared to the initial trial in that condition. As for the accommodation period, there were no significant reductions in VO_2 between trials after the fourth trial in the 50% condition (i.e., 20 minutes in that condition, 50 minutes total time). There were no significant reductions in VO_2 after the third trial for 70% (i.e., 15 minutes in that condition, 40 minutes total time), or after the second trial for the 90% condition (i.e., 10 minutes in that condition, 30 minutes total time). As higher amounts of body weight were supported, the accommodation period was shorter, but the interaction effect was not significant. This makes sense, as conditions more closely replicating the habitual experience of the runner required less adjustments. The researchers could not recommend a specific accommodation time threshold because total time was confounded by the three body weight conditions. However, they suggest a complete metabolic accommodation occurred after about an hour of running on the LBPP treadmill.

Identifying tasks that consume metabolic energy is important for recommending meaningful changes to a runner's form and understanding how runners adapt to novel conditions. Arellano and Kram (2014) outlined four categories that have a metabolic cost to running: body weight support/forward propulsion accounts for ~80% of the metabolic cost of running, leg swing uses 8%, lateral balance 2%, and a remainder of 11% that isn't fully explained. This last category is likely accounted for by braking forces and physiological variables like ventilation (Arellano & Kram, 2014). Given these parameters, running on the LBPP treadmill reduces metabolic cost due to the decrease in total body weight and the lateral support provided by the system holding the runner in place. Initially, novice runners on an LBPP treadmill seem to experience higher relative VO_2 values than are later observed in a given body weight support level (McNeill et al., 2015). The adjustments made during this period of accommodation are currently unknown. As mentioned above in previous sections, muscle activation and/or stride characteristic adaptations toward some optimal pattern may explain the noted metabolic changes.

Mechanical adaptation to novel running conditions is expected. Given the substantial time necessary to develop an optimal running pattern that minimizes oxygen consumption on an LBPP treadmill (McNeill et al., 2015), prior work indicating a decrease in VO_2 with body weight support may underestimate the drop in VO_2 for a given reduction in body weight. However, mechanisms to explain these altered metabolic rates across trials were not evaluated. Further work is also necessary to understand what adaptations are made during LBPP treadmill running to identify the driving factors behind the metabolic adaptations. Then, updated recommendations for ensuring familiarization can be made to be confident in the outcomes of future investigations.

Summary

Studies involving muscle activity, mechanical responses, and/or metabolic function in LBPP treadmills are limited due to their protocols lasting up to a max of 6 minutes (e.g., Jensen et al., 2016; Sainton et al., 2015, Hunter et al., 2014; Mercer et al., 2013). Specifically, Mercer et al. (2013) had participants run at each condition for ~2 minutes total with a short rest in between each condition. In contrast, McNeill et al. (2015) found that a much longer period than this duration is necessary to obtain true metabolic responses. Their results showed accommodation happening via a decrease in relative VO_2 across repeated trials, but no EMG analysis was undertaken and the participants did not run an even 15 minutes at a single weight support (McNeill et al., 2015). Thus, current literature may be misrepresenting EMG and gait kinematic outcomes due to a lack of familiarization to the LBPP treadmill.

It is not surprising that muscle activity and VO_2 are both reduced in LBPP treadmill running. However, given that metabolic adaptations continue to occur well beyond 6 minutes (the longest trial length of any EMG study) it is unknown whether muscle activity also continues to change during that time. Further research is necessary to understand what adaptations runners make to become as economical as possible in the novel task of LBPP treadmill running.

CHAPTER 3

METHODS

Participants

Participants were recruited via email from the greater Syracuse and Cortland areas. Eligible participants had to be 18-35 years old, able to run a 5k in under 23 minutes, have no injuries within the past 6 months, and had to be novices on the LBPP treadmill. Fifteen habitually trained runners who self-reported that they met these characteristics participated in the current study. Participant demographics can be found in Table 1.

Instruments

Participants performed a VO_{2max} protocol and warm-up runs on a Precor treadmill (Woodinville, WA). Experimental running trials were then performed on an LBPP treadmill (AlterG®, Fremont, CA). During VO_{2max} and all AlterG® trials, expired gasses were collected via a Parvo Medics TrueOne 2400 (Provo, UT) metabolic cart. Delsys Trigno sensors (Natick, MA) were used to collect EMG and accelerations of the lower leg. Each sensor records four channels. These channels include the EMG signal (Fs = 1,926 Hertz) and three orthogonal accelerations (Fs = 148 Hertz). The vertical acceleration profile from the sensor over the medial gastrocnemius was used to determine stance and swing phases. EMG activity of the vastus medialis was collected and analyzed during the stance phase. The EMG sensors have a bandwidth of 20-450 Hertz and common mode rejection ratio greater than 80dB. Delsys Trigno electrodes have a fixed inter-electrode distance of 1 cm. EMGWorks Acquisition software (Delsys, Inc., Natick, MA) was used for the simultaneous collection and storing of all sensor data. A Polar heart rate monitor (Polar Electro, Kempele, Finland) synchronized with the Parvo Medics system was used during each protocol to collect heart rate data.

Design and Procedures

Participation included two days of activity with at least 1 day of rest in between. During the first session, participants completed an informed consent form (Appendix A). Then, anthropometric and demographic measures were recorded. These included height, weight, and leg length. Leg length was measured using a tape measure from the anterior iliac spine (ASIS) to the medial malleolus of the right limb while standing. Running history (e.g., days per week of running, weekly mileage) was also recorded based on participant self-report. All demographic and anthropometric data were recorded on a data collection sheet (Appendix B). Next, participants performed a 10-minute warm up on the standard treadmill at a self-selected pace. This pace was also recorded for each participant and kept consistent across both testing days.

Once the warm-up was completed, the participants put on a Polar heart rate monitor. The researchers then assisted the participant in fitting a mouthpiece and headset for the gas analyzer. Next, participants completed a VO_{2max} protocol as reported in McNeill et al. (2015). This protocol for male participants is as follows: the initial speed for the VO_{2max} protocol was 0.67 $m \cdot s^{-1}$ below their self-reported "easy" pace. Then, the researchers increased the speed by increments of 0.67 $m \cdot s^{-1}$ every three minutes. The participant continued running at progressively faster speeds until volitional exhaustion. Women followed the same protocol except their initial pace was 0.54 $m \cdot s^{-1}$ slower than their "easy" pace. Similarly, their incremental increases in treadmill belt speed were 0.54

$m \cdot s^{-1}$. During the protocol, the treadmill incline was kept at zero until the treadmill speed reached 12mph (5.36 $m \cdot s^{-1}$), which was the Precor treadmill's top speed. If the participant indicated that they could proceed further with the test at that speed, a 2% increase in grade was given every three minutes until volitional exhaustion. After the VO_{2max} test, the participant performed a self-selected cool down on the treadmill. This concluded the initial testing session.

During the second session, the participant performed a 10-minute warm up on the standard treadmill at the same self-selected "easy" pace as in the initial testing day. Then, researchers prepared the skin over the vastus medialis for placement of telemetered EMG sensors (Delsys Trigno, Natick, MA). This process included shaving the skin, abrading it with a rough cloth, and cleaning the area with alcohol to wipe away any dead skin cells, dirt, oil, and sweat that may be present. Sensors were placed in line with the expected fiber orientation of the underlying muscle (Cram, Krisman, & Holtz, 1998) using double-sided tape. Confirmation of correct placement was assessed via manual muscle testing. Then, sensors were secured to the skin using an elastic wrap and athletic tape to minimize movement artifact. Data from this system were collected for the last 30s of each 5-minute interval. This is the same 30s that the VO_2 data was analyzed as well. EMGWorks Analysis software was used to export trial data as a text file. Further processing was performed in MATLAB (Version r2016a, Natick, MA).

Participants were instructed to choose their correct size for the special compression shorts that are provided by the manufacturer of the AlterG®. Then, researchers helped the participant put on a heart rate monitor. Finally, the participant stepped into the circular opening of the AlterG® treadmill. Researchers lifted the metal support arms up to the level of the ASIS and zipped the skirt-like portion of the compression shorts into the plastic bubble lining of the treadmill. The participants ran at 70% of their body weight at a speed that would elicit 70% of their VO_{2peak} that was observed in their first day of testing on the standard treadmill. The participants ran in this condition for three bouts lasting 15 minutes each. A brief rest (at least 5 minutes) was provided between bouts. Researchers changed out the spit valve of the mouthpiece and ensured EMG sensors were secure during this time. After the third trial participation in the study was concluded. Researchers helped the participant exit the AlterG® and removed all data collection instruments.

Data Processing

All metabolic data were exported as 5-second averages from the metabolic cart. Then, researchers averaged the final 30 seconds of VO_2data for every 5-minute interval using Microsoft Excel (Redmond, WA).This resulted in an average relative VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$) at minutes 5, 10, and 15 for the first trial, minutes 20, 25, and 30 of trial 2, and minutes 35, 40, and 45 from trial 3.

Spatiotemporal and EMG data were also analyzed for the final 30 seconds of each 5-minute interval as mentioned above. An additional 30-second set of data was recorded after only 30 seconds into the first trial for these two measures for comparison with previous literature. All acceleration and EMG data were analyzed using a custom MATLAB script based on the methods reported by (Hunter et al., 2014). Researchers identified initial contact and toe-off for 10 strides using the vertical acceleration profile from the medial gastrocnemius sensor. Stance time for each stride was calculated as the difference in time between toe-off and initial contact in seconds. The root-mean-square

(RMS) EMG magnitude of the vastus medialis was analyzed during these stance phases according to equation 1:

$$\boldsymbol{RMS(EMG) = \sqrt{\frac{\sum EMG(t)^2 * dt}{T}}} \quad (1)$$

Where EMG is the magnitude of the signal at time t and dt is the time between samples. The raw EMG signal was processed throughout the entire duration of the stance phase (T = duration of stance). Hunter et al. (2014) used the full stance phase for some muscles but divided the stance phase into subsections for others using a sliding window to identify when a muscle had highest activity, while in the present investigation we chose to analyze the entire duration of stance. Because the RMS magnitude squares the value of each sample, the raw EMG signals were used in these calculations. The researchers analyzed EMG activity from the entire stance phase for each of the 10 unique strides and obtained the average at each 5-minute interval identified above. Thus, with the exception of the initial collection after only 30 seconds into the initial trial, all EMG and stance time magnitudes were temporally associated with the VO_2 scores.

Statistical Analysis

All statistical analyses were completed using JASP (Amsterdam, The Netherlands). A series of ANOVAs with repeated measures were performed to detect differences in dependent measures across trials. Where the assumption of sphericity was violated, the Greenhouse-Geisser adjustment was used. Dependent measures includedVO_2, stance time, and RMS EMG of the vastus medialis during stance. Where appropriate, a simple planned contrast was performed to compare the initial value of the dependent variable (i.e., Minute 5 for VO_2 and Minute 0 for the EMG and stance time variables, respectively) against subsequent values. Risk of type I error was set at .05 for all tests. Effect sizes are reported as partial eta squared.

CHAPTER 4

RESULTS

Participant demographics can be found in Table 1. A total of 15 participants were recruited for the current study. The participant group was also homogenous due to the VO_{2Max}coefficient of variation ([SD/mean]*100) being 8.6%, which is consistent with previous work (Heise & Martin, 2001).While most of the participants ended their VO_{2Max} test at or before they reached 12mph due to exhaustion on the standard treadmill, 2 participants ended their respective tests at 2% and 4% incline at that same speed.

Table 1. Participant demographics. Values are Mean ± SD

Variables	Total (n = 15)	Males (n = 11)	Females (n = 4)
Age (years)	27.33 ± 3.66	27.44 ± 2.07	26.75 ± 0.96
Mass(kg)	69.08± 9.30	76.21± 3.52	59.57± 4.25
Height (cm)	173.73 ± 20.50	176.23 ± 2.11	165.83 ± 1.76
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	62.81 ± 5.43	64.01 ± 3.06	60.39 ± 4.88
$Runs \cdot week^{-1}$	5.67 ± 1.05	6.19 ± 0.68	5.00 ± 0
$Miles \cdot week^{-1}$	47.13 ± 20.61	60.1 ± 20.35	27.5 ± 9.01

With a Greenhouse-Geisser correction, a significant difference in VO_2 was found $F(3.533, 49.468) = 3.170$, $p = 0.026$, partial $\eta^2 = 0.185$ (Table 2). The initial reference point for relative VO_2 was Minute 5 and the results of the contrasts can be found in Table 2 below. The subsequent contrasts performed on this measure revealed significant differences between Minute 5 and Minute 10 ($p = 0.004$), Minute 15 ($p = 0.013$), Minute 20 ($p = 0.011$), and Minute 35 ($p = 0.022$). Minutes 10 and 15 had significantly higher averages than the initial reading while Minutes 20 and 35 were significantly lower than the initial reading. As time on the LBPP treadmill continued, the coefficient of variation for the relative VO_2 values decreased (from 19.16% at Minute 5 to 15.29% at Minute 45) indicating that, as a group, the VO_2 responses became more stable around the mean. Relative VO_2 decreased by 3.7% from the initial (31.37mL·kg^{-1}·min^{-1}) to the second (30.21 mL·kg^{-1}·min^{-1}) trial.

Table 2. Relative VO_2 across time. Data are presented as Mean± SD.

Trial	Time (Minutes)	Relative VO_2 (mL·kg^{-1}·min^{-1})
1	5	30.75 ± 5.89
1	10	31.76 ± 5.55*
1	15	31.60 ± 5.57*
	Average of Trial 1	31.37 ± 5.56
2	20	29.67 ± 5.44*
2	25	30.22 ± 5.29
2	30	30.74 ± 4.97
	Average of Trial 2	30.21 ± 5.13
3	35	29.77 ± 5.06*
3	40	30.71 ± 5.23
3	45	30.61 ± 4.68
	Average of Trial 3	30.37 ± 4.90

* Indicates a significant difference from Minute 5. $p < .05$

Analysis of the RMS EMG of the vastus medalis (Figure 1, Table 3) found statistically significant differences using a Greenhouse-Geisser correction for sphericity violation, $F(4.289, 60.042) = 3.766$, $p = 0.007$, partial $\eta^2 = 0.212$. The time segments found to be significantly different from the initial measurement (Minute 0) in the subsequent contrast analysis were Minute 5 (p = 0.006), Minute 10 (p = 0.026), Minute 15 (p = 0.010), and Minute 40 (p = 0.019). The time segments after Minute 0 were on average higher than the initial while Minute 40 was significantly lower than Minute 0. Overall, the RMS EMG of the vastus medialis decreased by 16% from the initial (0.126mV) to the final (0.107mV) values.

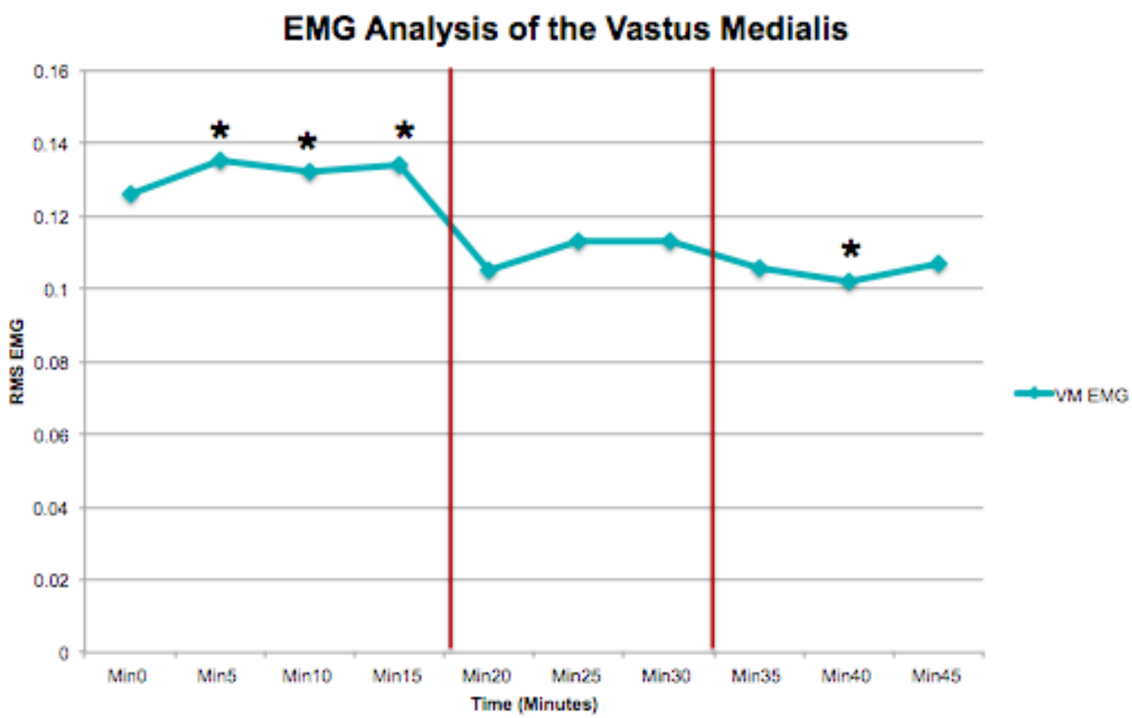


Figure 1. RMS EMG of the vastus medialis. Points reflect means. * indicates a significant difference from Min0 ($p < 0.05$). Vertical lines represent when breaks occurred between trials.

Table 3. RMS EMG of VM across time. Data are represented by mean ± SD.

Time (Minutes)	RMS EMG (mV)
0	0.126 ± 0.048
5	0.135 ± 0.078*
10	0.132 ± 0.073*
15	0.134 ± 0.072*
20	0.105 ± 0.060
25	0.113 ± 0.059
30	0.113 ± 0.057
35	0.106 ± 0.056
40	0.102 ± 0.061*
45	0.107 ± 0.055

* Indicates a significant difference from Minute 0. $p < .05$

With the Greenhouse-Geisser correction, no significant differences in stance time ($p = 0.086$) were observed. Effect size was small (partial $\eta^2 = 0.139$) which likely contributed to this result. Although there were no significant differences, there was a trend toward smaller stance time magnitudes throughout the protocol (Table 4). Despite the low effect size and lack of significance, there was ~10% decrease in stance time between the initial (0.206 s) and final (0.186 s) values.

Table 4. Stance time in seconds across time. Data are represented by mean ± SD.

Time (Minutes)	Stance time (seconds)
0	0.206 ± 0.010
5	0.201 ± 0.019
10	0.198 ± 0.026
15	0.197 ± 0.022
20	0.198 ± 0.028
25	0.195 ± 0.023
30	0.189 ± 0.031
35	0.184 ± 0.033
40	0.189 ± 0.030
45	0.186 ± 0.030

No significant differences found.

CHAPTER 5

DISCUSSION

The current study analyzed VO_2, stance time, and RMS EMG of the vastus medialis during a one-day protocol consisting of 3, 15-minute sustained runs on the LBPP treadmill. The novelty of this study is that it is the first to describe both metabolic and biomechanical responses in long-duration LBPP treadmill use. Significant differences were found in relative VO_2 and RMS EMG of the vastus medialis, but not for stance time. Relative VO_2 significantly increased from Minute 5 to Minute 15, but then significantly decreased at Minute 20 with no other differences from Minute 5 occurring (Table 2). However, when viewed from the context of each 15-minute trial, the response appears more clear. The average of the first trial was 31.37 $mL \cdot kg^{-1} \cdot min^{-1}$, while the second was slightly lower at 30.21 and the third at 30.37 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively (Table 2). The RMS EMG also significantly increased during Minutes 5, 10, and 15 compared to the initial Minute 0 data collection point as well as decreased (though not significantly) at Minute 20 (Figure 1). Therefore, it seems that approximately 20 minutes of running time on the AlterG® treadmill is sufficient for accommodation of metabolic and neuromuscular responses.

The metabolic results of the present study partially agree with the results of McNeill et al. (2015) who reported a steady decrease in VO_2 from the initial reading, with the lowest VO_2 measurements occurring around 35-45 minutes of running. Whereas in the present study a significant difference in VO_2 was also observed, the initial measurement was not the largest. The values significantly lower than the initial measurement in the present study were seen at Minutes 20 and 35, but VO_2 increased in the intervening time segments. One explanation of the conflicting outcomes can be the overall time on the LBPP treadmill. McNeill et al. (2015) had participants run at 15-minute time segments 7 different times with at least 2 days of rest in between each protocol. Participants in the current study ran for a total of 45 minutes on the LBPP treadmill with at least a 5-minute break every 15 minutes in a single day. However, it seems that the runners in the present study reached accommodation sooner than in McNeill et al. (2015). Their results showed no significant decreases after about 60 total minutes of running while the current study found no significant differences after Minute 20. Their participants spent a greater total time on the treadmill (105 minutes) but less time at the 70% bodyweight condition (35 minutes) compared to our 45-minute protocol.

An explanation for the current findings could also be the differences in the participant demographics between the studies. The current study had more highly trained runners as seen in the average VO_{2Max} (62.81 ± 5.43 $mL \cdot kg^{-1} \cdot min^{-1}$ in the current study vs. 58.4 ± 7.1 $mL \cdot kg^{-1} \cdot min^{-1}$ in McNeill et al. (2015)), which may have been the reason for the quicker accommodation time compared to McNeill et al. (2015).The current participant group was also more homogenous than McNeill et al. (2015). The VO_{2Max}coefficient of variation for the present study was 8.6%, while theirs was 12.2%. The current study also had a larger sample size of 15 participants, compared to 8 in McNeill et al. (2015) and many of the other research articles reviewed here (Mercer et al., 2013; Sainton et al., 2015; Baur, Hirschmüller, Müller, Gollhofer, & Mayer, 2007; Hunter et al., 2014; Liebenberg et al., 2011; Mercer & Chona, 2015). With a larger sample size, the current study has stronger external validity and the results more readily applied to the target population of trained runners who want to utilize the LBPP treadmill for rehabilitation or injury prevention purposes.

The RMS EMG of the vastus medialis results parallel those of the relative VO_2. Significant differences were found between Minutes 0 and 5, 10, 15, and 40 and an overall 16% decrease in muscle activity during the protocol. This result is important for researchers to consider when conducting EMG analysis using an LBPP treadmill. Whereas previous studies regarding EMG during LBPP treadmill running have only considered acute responses (Jensen et al., 2016; Hunter et al., 2014), the results of the present study suggest that runners require some accommodation time before they adopt a stable EMG response. While data at Minute 0 were collected 30 seconds after the beginning of the current experimental protocol, the RMS EMG was significantly increased from Minute 0 to Minute 5, but no differences by Minute 20. In Appendix C, the two graphs shown represent the absolute value of the EMG data from the vastus medialis for a single subject. The top graph is the EMG data from Minute 0 while the bottom graph is from Minute 45. Though the average amplitude of the signals at these times were not found to be significantly different ($p = 0.100$), there is a noticeable change in the signal amplitude between these two time points in this individual. Thus, researchers should be cautious in collecting data within the first 15 minutes of a participant running on the LBPP treadmill. At least a 20-minute warm up on the LBPP treadmill should be included to make sure EMG data is stable. Most research focusing on EMG analysis has collected data in a short timeframe of 30 -120seconds into a condition with the entire experimental protocol lasting only 20 minutes total (Hunter et al., 2014; Mercer et al., 2013; Baur et al., 2007). The current findings of this study should be a guideline to future researchers wanting to focus on EMG activity differences. A period of about 20 minutes should be used as an accommodation period for the participants running on the LBPP treadmill in order to collect more accurate representations in EMG activity.

The EMG results can help explain the observed differences in relative VO_2here as well as in McNeill et al. (2015). Muscle activity significantly increased in the same times that oxygen utilization was elevated. As the participants accommodated to the LBPP treadmill, muscle activity seems to have adjusted as well. Qualitatively, the researchers in the current study observed that participants made noticeably louder foot strikes while running in the first 15-minute trial on the LBPP treadmill compared to the subsequent two trials. The lowered metabolic responses (3.7% decrease) following the initial trial may be a consequence of the lower EMG activity, or perhaps due to factors not observable in the present study. Arellano and Kram (2014) found lateral stability accounted for 2% of the metabolic cost of running. The current study did not measure this factor, but the lateral support provided by the AlterG® might have also contributed to the noted decrease in oxygen utilization. Additionally, the participants may have reduced their vertical forces as they learned to let the AlterG® support their body weight more completely. These explanations, among others, likely also contributed to the observed responses here.

Stance time was not significantly different over the 45-minute experimental protocol, but a trend toward lower stance times can be seen in Table3. Most research on spatiotemporal variables has focused on changes between running on a treadmill and running on a LBPP treadmill, or across various running speeds and body weight supports on the LBPP treadmill (Mercer & Chona, 2015; Raffalt et al., 2013; Sainton et al., 2015).

Specifically, Sainton et al. (2015) analyzed the adjustments in kinetic outcomes and muscle activity during unweighing and reloading and found that it took participants about 3 minutes to adapt to the unweighted and reloading procedure. They also reported that contact time did not significantly differ between the 100% weighted condition and the 80% and 60% bodyweight conditions. Raffalt et al. (2013) analyzed spatiotemporal variables at varying speeds and body weights lasting 3 minutes for each bout. They found a decrease in contact times as speed increased and as body weight decreased, but again, no research articles have looked at a single body weight support at a single speed over longer durations. Though it was not significant, there was ~10% decrease in stance time over the 45-minute protocol. Runners and clinicians should consider whether this is meaningful when making decisions regarding training and/or rehabilitation programs.

Conclusion

Relative VO_2 and the magnitude of the EMG of the vastus medialis significantly changed over the first 20 minutes of the experimental protocol while stance time did not. Thus, it seems that the metabolic accommodation observed here and elsewhere (McNeill et al., 2015) may be due to changes in EMG activity rather than spatiotemporal adjustments. The present results suggest that 20 minutes is adequate for participants to develop a gait pattern that minimizes metabolic rate on an LBPP treadmill. This is less than the previous recommendation by McNeill et al. (2015), who stated that four 15-minute bouts of running (or about an hour of running) was necessary for a runner to accommodate to the new modality. Differences in these recommendations are likely due to the use of a single bodyweight support in the present study compared to three settings in the prior investigation providing unique stimuli that likely played a role in their delayed accommodation recommendation. This information is helpful for future researchers and athletes who want to utilize the LBPP treadmill in training, rehabilitation, or for ensuring reliable data in a research setting.

REFERENCES

Arellano, C., & Kram, R. (2014). Partitioning the metabolic cost of human running: A task-by task approach. *Integrative and Comparative Biology, 54*(6), 1084-1098. doi: 10.1093/icb/ice033

Barnes, K. R., & Kilding, A. E. (2015). Running economy: measurement, norms, and determining factors. *Sports Medicine - Open*, *1*(1), 8. http://doi.org/10.1186/s40798-015-0007-y

Baur, H., Hirschmüller, A., Müller, S., Goollhofer, A., & Mayer, F. (2007). Muscular activity in treadmill and overground running. *Isokinetics and Exercise Science*, *15*, 165–171.

Chapman, R. F., Laymon, A. S., Wilhite, D. P., McKenzie, J. M., Tanner, D. A., & Stager, J. M. (2012). Ground contact time as an indicator of metabolic cost in elite distance runners. *Medicine & Science in Sports & Exercise*, *44*(5), 917–925. http://doi.org/10.1249/MSS.0b013e3182400520

Chumanov, E. S., Wille, C. M., Michalski, M. P., & Heiderscheit, B. C. (2012). Changes in muscle activation patterns when running step rate is increased. *Gait and Posture*, *36*(2), 231–235. http://doi.org/10.1016/j.gaitpost.2012.02.023

Clansey, A. C., Hanlon, M., Wallace, E. S., & Lake, M. J. (2014). Influence of tibial shock feedback training on impact loading and running economy. *Medicine & Science in Sports & Exercise*, *46*(5), 973-981. doi:10.1249/MSS.0000000000000182

Conley, D. L., & Krahenbuhl, G. S. (1980). Running economy and distance running performance of highly trained athletes. *Medicine & Science in Sports & Exercise*, *12*(5), 357–360. http://doi.org/10.1249/00005768-198012050-00010

Cram, J.R., Krisman, G.S., & Holtz, J. (1998). *Introduction to Surface Electromyography*. Gaithersburg, Md: Aspen Publishers.

Daniels, J. T. (1985). A physiologist's view of running economy. *Medicine & Science in Sports & Exercise, 17*(3), 332-338.

Farina, K. A., Wright, A. A., Ford, K. R., Wirfel, L. A., & Smoliga, J. M. (2017). Physiological and biomechanical responses to running on lower body positive pressure treadmills in healthy populations. *Sports Medicine*, *47*(2), 261–275. http://doi.org/10.1007/s40279-016-0581-2

Grabowski, A. M., & Kram, R. (2008). Effects of velocity and weight support on ground reaction forces and metabolic power during running. *Journal of Applied Biomechanics*, *24*, 288-297.

Hansen, C., Einarson, E., Thomson, A., & Whiteley, R. (2017). Peak medial (but not lateral) hamstring activity is significantly lower during stance phase of running. An EMG investigation using a reduced gravity treadmill. *Gait and Posture*, *57*(April), 7–10. http://doi.org/10.1016/j.gaitpost.2017.05.012

Heise, G. D., & Martin, P. E. (2001). Are variations in running economy in humans associated with ground reaction force characteristics? *European Journal of Applied Physiology*, *84*(5), 438–442. http://doi.org/10.1007/s004210100394

Hunter, I., Seeley, M. K., Hopkins, J. T., Carr, C., & Franson, J. J. (2014). EMG activity during positive-pressure treadmill running. *Journal of Electromyography and Kinesiology*, *24*(3), 348–352. http://doi.org/10.1016/j.jelekin.2014.01.009

Jensen, B. R., Hovgaard-Hansen, L., & Cappelen, K. L. (2016). Muscle activation and estimated relative joint force during running with weight support on a lower-body positive-pressure treadmill. *Journal of Applied Biomechanics*, *32*(4), 335–341. http://doi.org/10.1123/jab.2015-0075

Kyrolainen, H., Belli, A., Komi, P. V. (2001). Biomechanical factors affecting running economy. *Medicine & Science in Sports & Exercise, 33*(8), 1330-1337.

Liebenberg, J., Scharf, J., Forrest, D., Dufek, J. S., Masumoto, K., & Mercer, J. A. (2011). Determination of muscle activity during running at reduced body weight. *Journal of Sports Sciences*, *29*(2), 207–214. http://doi.org/10.1080/02640414.2010.534806

McNeill, D. K. P., de Heer, H. D., Williams, C. P., & Coast, J. R. (2015). Metabolic accommodation to running on a body weight-supported treadmill. *European Journal of Applied Physiology*, *115*(5), 905–910. http://doi.org/10.1007/s00421-014-3071-y

Mercer, J. A., Applequist, B. C., & Masumoto, K. (2013). Muscle activity while running at 20%-50% of normal body weight. *Research in Sports Medicine*, *21*(3), 217–228. http://doi.org/10.1080/15438627.2013.792084

Mercer, J. A., & Chona, C. (2015). Stride length-velocity relationship during running with body weight support. *Journal of Sport and Health Science*, *4*(4), 391–395. http://doi.org/10.1016/j.jshs.2015.01.003

Mishra, D. K. (2015). *Summary of Clinical Research involving the AlterG Anti-Gravity Treadmill* ®. Retrieved from https://www.alterg.com/images/AlterG_CRS_p3.pdf

Mooses, M., Tippi, B., Mooses, K., Durussel, J., & Mäestu, J. (2015). Better economy in field running than on the treadmill: Evidence from high-level distance runners. *Biology of Sport*, *32*(2), 155–159. http://doi.org/10.5604/20831862.1144418

Morgan, D., Martin, P., Craib, M., Caruso, C., Clifton, R., Hopewell, R. (1994). Effect of step length optimization on the aerobic demand of running. *Journal of Applied Physiology*, *77*(1), 245-251.

Paavolainen, L., Häkkinen, K., Hämäläinen, I., Nummela, A., Keefe, Z. B., Helgerud, J., … Ha, K. (1999). Explosive-strength training improves 5-km running time by improving running economy and muscle power. *Journal of Applied Physiology*, *86*(March 2016), 1527–1533. http://doi.org/10.1034/j.1600-0838.2003.00340.x

Pugh, L. (1970). Oxygen intake in track and treadmill running with observations on the effect of air resistance. *The Journal of Physiology*, *207*(3), 823-835. doi:10.1113/jphysiol.1970.sp009097

Raffalt, P. C., Hovgaard-Hansen, L., & Jensen, B. R. (2013). Running on a lower-body positive pressure treadmill: VO2max, respiratory response, and vertical ground reaction force. *Research Quarterly for Exercise and Sport*, *84*(2), 213–222. http://doi.org/10.1080/02701367.2013.784721

Riley, P. O., Dicharry, J., Franz, J., Croce, U. Della, Wilder, R. P., & Kerrigan, D. C. (2008). A kinematics and kinetic comparison of overground and treadmill running. *Medicine & Science in Sports & Exercise*, *40*(6), 1093–1100. http://doi.org/10.1249/MSS.0b013e3181677530

Sainton, P., Nicol, C., Cabri, J., Barthelemy-Montfort, J., Berton, E., & Chavet, P. (2015). Influence of short-term unweighing and reloading on running kinetics and muscle activity. *European Journal of Applied Physiology*, *115*(5), 1135–1145. http://doi.org/10.1007/s00421-014-3095-3

Saunders, P. U., Pyne, D. B., Telford, R. D., & Hawley, J. A. (2004). Factors affecting running economy in trained distance runners. *Sports Medicine*, *34*(7), 465–485. JOUR. Retrieved from http://libproxy.cortland.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=13662995&site=ehost-live

Scheib, D. A. (1986). Kinematic accommodation of novice treadmill runners. *Research Quarterly*, *57*, 1-7. https://doi.org/10.1080/02701367.1986.10605381

Silvers, W. M., Bressel, E., Dicken, D. C., Killgore, G., Dolny, D. G. (2014). Lower-extremity muscle activity during aquatic and land treadmill running at same speeds. *Journal of Sport Rehabilitation, 23*(2), 107-122. doi:10.1123/JSP.2013-0003

Smith, M., Bonacci, J., Mendis, M., Christie, C., Rotstein, A., & Hides, J. (2017). Gluteus medius activation during running is a risk factor for season hamstring injuries in elite footballers. *Journal of Science and Medicine in Sport, 20*(2), 159-163. http://dx.doi.org/10.1016/j.jsams.2016.07.004

Temple, C., Lind, E., Van Langen, D., True, L., Hupman, S., & Hokanson, J. F. (2017). Run economy on a normal and lower body positive pressure treadmill. *International Journal of Exercise Science*, *10*(5), 774–781.

We help people change the way they live. (2018). Retrieved from https://www.alterg.com/who-we-are

White, S. C., Gilchrist, L. A., & Christina, K. A. (2002). Within-day accommodation effects on vertical reaction forces for treadmill running. *Journal of Applied Biomechanics*, *18*(1), 74–82.

Appendix A – Informed Consent

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH

Project Title: Learning to Run on an LBPPT: Neuromuscular and Metabolic Adaptations
Investigators: Kevin D. Dames, Ph.D. (607) 753-4356, kevin.dames@cortland.edu, Kinesiology Department
Larissa True, Ph.D., (607) 753-4562, larissa.true@cortland.edu, Kinesiology Department

Purpose and background:

This study is exploring what adjustments runners make to their movement patterns while running on the AlterG® treadmill. This unique treadmill provides some body weight support, which reduces the impact and metabolic cost of running. Prior research has found that it takes runners at least 20 minutes to reach a stable, minimum metabolic cost on this device. The present study seeks to understand what running technique and muscle activity adaptations occur to achieve that response.

Protocol:

All data collection sessions will take place in the Exercise Physiology Laboratory (Professional Studies 1144E). Involvement will require two sessions. The first will last about 30 minutes and the second about 1 hour. Both of these sessions will require running on a treadmill. Specific components of each session and the criteria for eligibility are outlined below.

Criteria for inclusion:
1. ability to run a 5k in 18-23 minutes or a 10k in 36-46 minutes
2. 18-35 years of age

Criteria for exclusion:
1. musculoskeletal injury that would affect running ability within previous 6 months
2. individuals who have run on an AlterG® treadmill (or equivalent) before

Session 1:

The researchers will collect anthropometric data (e.g., height, weight, age) which will be used for scaling the measures obtained during experimental trials. Then, you will perform a warm up lasting 10 minutes at a self-selected pace on a standard treadmill. Next, you will put on a heart rate monitor and a headset that will collect the air you breathe out. This air is collected to determine how much oxygen you consume (i.e., aerobic exercise intensity) during a VO_{2peak} test. After putting on these two devices you will step back onto the treadmill and perform the VO_{2peak} protocol. This requires you to run at a comfortable pace of your choosing for 3 minutes, followed every 3 minutes by an incrementally faster treadmill speed. The test continues until you feel that you cannot keep pace with the treadmill if it were to go faster. This test provides (1) an indicator of your overall fitness, and (2) will be used to determine the speed of the AlterG® for the second testing session.

Session 2:

You will begin this session with a 10-minute warm up on a treadmill at a self-selected pace. Then, you will put on a heart rate monitor and some special AlterG® shorts. These compression shorts have a skirt-like piece of fabric around the waist. This skirt-like component has half of a zipper on its outer edge. Once in the AlterG® this half zipper will link with the corresponding half on the plastic bubble surrounding the AlterG® treadmill belt. This connection creates a seal that prevents air from escaping. The plastic bubble will be inflated so that it supports a portion of your body weight during the experimental trial. Before you get on the AlterG®, the researchers will place sensors on the back of your calf (lower leg) and the front of your thigh. These sensors measure the level of activity of your muscle tissue. Simply, these indicate if the muscle is “on” and to what extent. Prior to placing these sensors the researchers will prepare the appropriate sites to increase the quality of the signal. This includes shaving the skin, cleaning it with an alcohol pad, and rubbing the skin with a material to brush away dead skin cells, dirt, oil, etc. Researchers are experienced and qualified to perform these procedures. Finally, researchers will place the sensors on the

cleaned areas using double-sided tape and secure them with elastic material to prevent them from falling off or moving while you run. The researcher
performing these procedures will be of your same gender (i.e., male preparing the sensor sites for males, and female preparing the sensor sites for females).

Following these procedures, you will step into the AlterG® and the researchers will help you get zipped in to the plastic bubble. Next, the AlterG® will weigh you and determine the appropriate level of support you need to run at 70% of your total body weight (i.e., 30% of your weight supported by the AlterG®). Then, you will put on the mask for measuring oxygen consumption and testing will begin. You will run for 45 minutes at a speed that requires 70% of the peak VO_2 obtained in the first session. These 45 minutes of running will be split into three 15-minute bouts with rests between.

Benefits to you include access to running on an AlterG®. This special tool is something few individuals get the opportunity to use (especially for free). Second, participation includes a VO_{2peak} test. This measure is useful for designing training protocols and comparing fitness to other runners. Given the specialized equipment and knowledge required to perform such a test, it usually requires a monetary investment to obtain such an opportunity. Receiving free VO_{2peak} testing is considered a benefit.

Potential risks of participating in this study are minimal. Participation will include running on a treadmill. One of these sessions will be similar in intensity to hard sprint/interval type workouts, and the second will be similar to an easy, “conversational” pace. As with any exercise, potential for fatigue, localized muscle soreness, and/or falls are possible. A researcher will be beside the treadmill at all times should you need the treadmill to slow down or stop. Preparing the skin for placement of the sensors on the calf and thigh may cause some slight discomfort (e.g., minor skin irritation, possibility of minor cuts from the razors). You may choose to discontinue participation at any time. In the unlikely event of an injury, we will contact appropriate medical authorities.

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research project. A copy of this form will be given to you to retain for future reference. Questions regarding this research project may be directed to any of the investigators involved in the study. Contact information for these individuals is at the top of this form. This study has been approved by the Institutional Review Board at SUNY Cortland. For more information about research at SUNY Cortland or information about the rights of research participants, please contact the Institutional Review Board by email irb@cortland.edu, or by phone (697) 753-2511.

______ Initial here if photos and/or video from your assessment may be used for academic presentations and/or marketing purposes. These media will not show your face in any outlet in which they are used.

____

Participant’s Signature Date

____

Researcher’s Signature Date

Appendix B – Data Collection Sheet

ID #: _________________

Demographics

Age: _______ Sex: ________ **Best 5k/10k time in last 12 months: __________**

Mileage per week: ___________ Days of running per week: ___________

Easy running pace: ___________ (minutes·$mile^{-1}$) **Warm-up speed: ___________**

Lower extremity injury that would impede running performance in last 6 months? Yes **No**

Have you ever run on an AlterG® (or equivalent) before? **Yes No**

Anthropometrics

Height: __________cm Weight: __________ lb

Leg Length: __________cm (ASIS to medial malleolus)

Session 1

- Equipment:
  - Heart rate monitor – gelled, secured at bottom edge of sternum
  - Mask for collection of expired gasses
  - Standard treadmill
- Tasks
  - Warm-up: self-selected pace (10 min)
  - VO_{2peak} Protocol
  - Cool down

Session 2

- Equipment
  - Heart rate monitor – gelled, secured at bottom edge of sternum
  - EMG sensors (#1: MG, #2: VM) placed on right limb after site preparation
  - Mask for collection of expired gasses
  - Standard treadmill
  - AlterG®
- Tasks
  - Warm-up: standard treadmill – self-selected pace (10 min)
  - Experimental protocol: AlterG® (support bar raised to level of ASIS)
  - Cool down

Table 1. VO_{2peak} Protocol for Men

Stage	Grade (%)	Time (min)	Condition	Treadmill Velocity ($m \cdot s^{-1}$)
1	0	0-3	Preferred – 0.67	
2	0	3-6	Preferred	
3	0	6-9	Preferred + 0.67	
4	0	9-12	Preferred + 1.34	
5	0	12-15	Preferred + 2.01	
6	0	15-18	Preferred + 2.68	
7	0	18-21	Preferred + 3.35	
8	0	21-24	Preferred + 4.02	
9	0	24-27	Preferred + 4.69	

Table 2. VO_{2peak} Protocol for Women

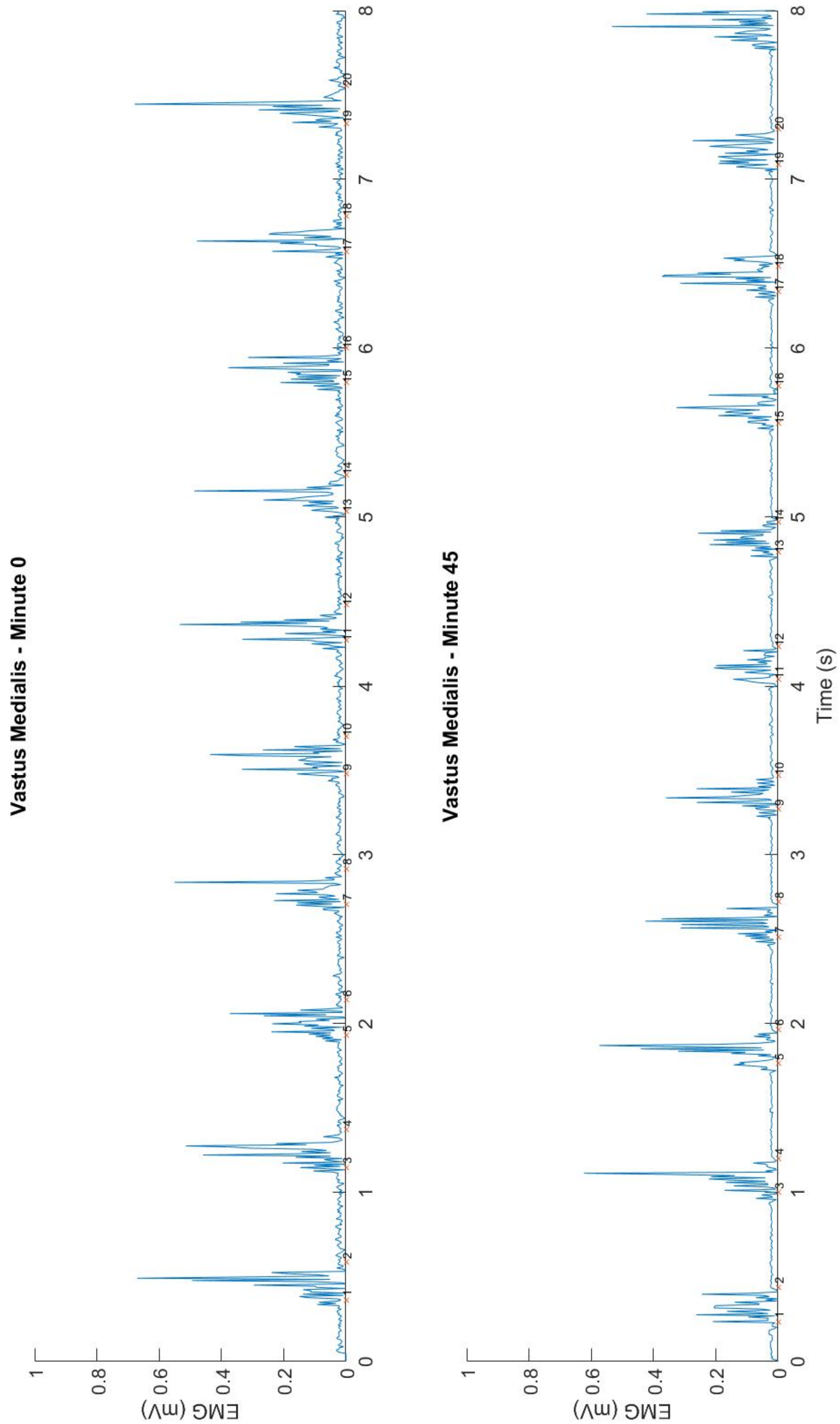
Stage	Grade (%)	Time (min)	Condition	Treadmill Velocity ($m \cdot s^{-1}$)
1	0	0-3	Preferred – 0.54	
2	0	3-6	Preferred	
3	0	6-9	Preferred + 0.54	
4	0	9-12	Preferred + 1.08	
5	0	12-15	Preferred + 1.62	
6	0	15-18	Preferred + 2.16	
7	0	18-21	Preferred + 2.70	
8	0	21-24	Preferred + 3.24	
9	0	24-27	Preferred + 3.78	

Table 3. Second visit

Collection (min)	Event Created (Parvo Medics)	Delsys Collected
5		
10		
15		
BREAK		
20		
25		
30		
BREAK		
35		
40		
45		

Notes:

Appendix C – Sample EMG Data



These charts show the absolute value of the EMG signal for the vastus medialis at Minute 0 (top) and Minute 45 (bottom)

Appendix D – Experimental Setup