THE PENNSYVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF KINESIOLOGY

THE EFFECTS OF ALTERATION IN STRIDE FREQUENCY DURING BOUTS OF DOWNHILL RUNNING: AN EMG, KINEMATIC, AND METABOLIC ANALYSIS

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Fall 2012

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Kinesiology
with honors in Kinesiology

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Abstract

Previous literature regarding running has largely been about the benefits associated with level and uphill running. For this reason, I thought it would be interesting to study the effects downhill running has on the human body. Specifically, when running downhill what type of stride frequency will produce the most optimal results, depending on the runner. The effects of altered stride frequency can have profound implications for those trying to either lose weight or beat a previous time. Stride frequency was altered in one of two ways, by either increasing the frequency to 15% above the participants preferred frequency, or by decreasing the frequency by 15%. The specific parameters used to gauge which running style was most efficient, metabolic, kinematic, as well as EMG data was collected.

10 healthy college students were recruited for the study and asked to run on a treadmill at 3 m/s for trials lasting 2 minutes each. During this time information regarding muscle activity was collected for eight muscles of the lower limbs which included: TA, LG, SL, VM, VL, RF, BF, and ST. Temporal-spatial variables as well as oxygen consumption (kg/ml/min) were also measured while changing the stride frequency.

Due to the lack of extensive research regarding downhill running, I formulated my hypothesis on previous articles related to downhill walking or level running. Based on these articles I expected to see a decrease in muscle activity when running downhill as compared to level running. I also predicted that the muscles would be least activated when running downhill with strides 15% faster than the preferred frequency. Due to the direct relationship between muscle behavior and metabolic activity I also expected the least amount of oxygen consumption when running with strides 15% faster than preferred. In terms of kinematic variables, I expected

to see an increase in stride time and stance time when running with strides 15% slower than preferred.

Overall, the results matched my hypothesis and the results of previous studies related to the experiment. We found that metabolically, running with the participants preferred stride frequency proved most efficient, and provided support for many research articles claiming the human body will find the most efficient way to run given new circumstances. Perplexingly, the least amount of muscle activity was seen when participants ran with strides 15% faster than preferred. Due to these differences in efficiency, it is tough to conclude which running style should be utilized when running downhill but presents a unique opportunity for future research.

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Chapter 1: Introduction

Practical Implications

Aerobic exercise in the form of running has a variety of benefits both for those who run recreationally as well as those who run for sport. Running has long been associated with a reduced risk of cardiovascular disease, fat loss, and a significant drop in blood pressure. While many of these health benefits are generally common knowledge, a vast majority of Americans remain sedentary and overweight[1]. Downhill running contains all of the aforementioned benefits, but also serves as a useful training tool for coaches and athletes competing in the sport of running[2]. Training that utilizes downhill running has been associated with lower instances of injury along with a decreased risk of muscle damage on subsequent runs. Uphill running as well as level running did not contain the same benefits that are exclusive to downhill running[3].

While downhill running offers many advantages to those trying to lose weight, it is the subject of much controversy in the competitive running world due to the differences in how to "attack the downhill". This refers to the different stride frequencies a runner can use when navigating a downhill portion of a course. There are many advantages to be gained by learning about the optimal stride frequency that corresponds to downhill running. These implications could be of much use to those who run cross country either in high school, college, or later in their career. Optimal stride frequency is still not completely understood in regards to running, all that is known now is that it essentially exists and may be related to elastic potential energy of the muscles and tendons involved[4]. Many coaches and runners advocate using shorter, choppy strides so as to ensure a smoother transition during heel strike. Others insist that utilizing the runners preferred stride frequency is best because it is what comes natural to the runner.

Therefore, the primary goal of this study was to examine the effects of variable stride frequency on muscle activation as well as metabolic costs during downhill running.

Electromyography

Muscle activity can be measured relatively objectively through the use of electromyography. This technology essentially is able to record the amount of muscle fibers activated, which comprise a single motor unit[5]. The degree to which a motor unit is activated is a function of the intensity of the exercise, and the extent to which the muscle is utilized during the action[6]. Obviously, altering the slope of an exercise will bring about a change in the recruitment of different muscles in different proportions. There are eight leg muscles inherently used during downhill running that were the subject of this study, they included: tibialis anterior, lateral gastrocnemius, soleus, rectus femoris, biceps femoris, semitendinosus, vastus lateralis, and vastus medialis. The data from the electromyography will provide valuable information as to the percent each muscle contributes to the movement.

Level Running

The *tibialis anterior* (TA) is active throughout a majority of the gait cycle. The maximal activity can be seen during heelstrike where the TA acts eccentrically as the foot is lowered towards the ground to ensure a smooth initial contact[7]. The TA will then act concentrically in order to move the shank forward in a controlled fashion. Constant activity can be seen in the TA throughout the swing cycle, while inactivity can be observed shortly after footstrike and during the last half of the stance phase[8,9].

The *lateral gastrocnemius* (LG) is active from the late swing phase to 50%-80% of the stance phase. During the late swing phase, the LG works eccentrically with the concentrically contracting TA in order to stabilize the foot prior to heel-strike[10]. After heel strike, the LG acts eccentrically to decelerate the forward moving shank before once again acting concentrically as plantar flexion begins at the ankle. Controversy regarding when exactly maximum contraction occurs has been reported, although it is generally believed the LG is operating at maximum activity at toe-off[7]. The *soleus* (SL) serves the same purpose as the LG and they are often considered one functional unit. For this reason the SL has similar electrical activity as the LG.

The knee flexors comprise a group of muscles that are situated on the posterior portion of the upper leg. The *biceps femoris* (BF) is one such muscle that acts to extend the hip and flex the knee, due to the fact that it (along with the other knee flexors) crosses two joints[11]. Little to no activity is observed in the biceps femoris up until mid-swing because the knee is being passively flexed. The BF is first active through the last 25%-40% of the swing phase, acting to decelerate the formerly accelerating thigh[8]. The BF now acts eccentrically just prior to heel-strike by extending the hip and flexing the knee. This serves to cushion the heel before its initial contact with the ground[12]. It was reported that flexors increase activity from this initial footsrike throughout the entire stance phase, ending at toe-off. The maximal activity recorded for the BF has been recorded at heel strike and toe-off[7].

The *semitendinosus* (ST) is another muscle that comprises the knee flexors located on the posterior thigh. Similar to the BF, the ST also crosses two joint muscles which aids in extending the hip as well as flexing the knee[13]. The ST works together with the BF to decelerate hip flexion during the last 25%-40% of swing phase[9]. It is interesting to note that during footstrike, the knee flexors and extensors muscles are working together to provide stability during the initial contact. The ST reported a strong level of activity during heel-off and toe-off, much in the same way the BF did. However, this was not the time during which maximal activity was recorded. The ST has the greatest variability among all knee muscles so it is difficult to generalize when the muscle will be activated most among different participants[14].

In addition to the knee flexors, the knee extensors are the other group of muscles largely responsible for controlling our gait cycle. The *rectus femoris* (RF) is one such muscle that's unique origin and insertion allows it to aid in many aspects of running. The RF crosses the hip joint in addition to the knee joint, allowing it to assist in hip flexion[8]. It exhibits a unique burst of activity during early swing, indicative of its ability to facilitate hip flexion. However, its primary function and activity is seen during late swing and the first half of stance, where the knee extends to allow clearance and stabilization for the foot[15].

The *vastus medialis* (VM) is another muscle associated with extension of the knee. Unlike the RF, however, this muscle does not cross two joints and concentrates its efforts on extending the knee[16]. VM activity was seen during early swing that is commonly associated with hip flexor function, but it is likely the muscle controlling the knee flexion at this point[14].

The *vastus lateralis* (VL) performs very much the same activity as the VM during a normal gait cycle. Activity can be seen during early swing that is most likely associated with controlling knee flexion[17]. High levels of activity for both the VM and VL can be seen during the last half of swing phase into the first half of stance. All the knee extensors act in unison with the knee flexors through co-activation in order to support a controlled planting and swing of the shank during the gait cycle[18].

Downhill Running

While the literature available on running has certainly been voluminous, the amount of that literature devoted to downhill running is scarce at best. Many of the findings are inconsistent or not detailed enough to provide substantial evidence. For this reason, data found from downhill walking studies may be used to provide a basis to compare. The knee extensors were found to have no significant difference between level and downhill walking, with most of the activity coming during the early stance phase[19]. The flexor muscles displayed similar peaks in activity during late swing phase but showed greater activity during early and late stance phase. During level walking it was reported that little to no activity was reported from the knee flexors at this time. The gastrocnemius showed two main periods of increased activity when walking downhill, during heel-strike as well as in late stance. Although this data does provide a base of support to form hypothesis, it is also important to look at a few studies conducted utilizing downhill running[20].

Some research has been looking into the effects of muscle soreness after running downhill, which is relatable to the amount with which the muscle of interest has been activated beyond normal levels[21]. Delayed onset muscle soreness (DOMS) following downhill running was most apparent in the muscles of the gluteus, quadriceps, and anterior and posterior tibialis. This would indicate that these muscles are stressed more during downhill running than they are during equivalent bouts of level running[22].

Hypothesis

Generally, I would expect to see the largest increase in activity during downhill running coming from the knee flexors and extensors. Due to their ability to aid in leg stabilization, they should be utilized more than the TA, SL, and LG which provide support for the shank. Between the knee flexors and extensors, however, I am expecting the extensors to have a higher percentage increase in activity due to the expected increase in eccentric contraction inherent during downhill running.

During heel strike, I would not expect a huge increase in activity from the LG because it will not play a critical role in stabilizing the foot during the initial contact. This load will have to be taken by the TA, for which I would expect a significant increase in activity during heel-strike to aid in lowering the foot down in a controlled manner. During the stance phase of the gait cycle, I am expecting all the knee extensors to show a significant increase in muscle activity to eccentrically control the extension of the knee. The flexors should also show an increase in activity, but to a lesser extent. Of the knee flexors, I would expect the ST to show the smallest increase in activity due to its versatile nature. During toe-off, I am expecting the biggest increase in activity from the LG because it should be in contact with the ground longer.

When examining the data from shorter stride frequency, I am expecting to see a decrease in activity from the knee flexors and extensors. This is because the movement appears more fluid, and less energy is wasted stopping the runner’s momentum from going down the decline. Conversely, when the participants have to run with longer stride frequencies, I expect the activity in the knee flexors and extensors to increase because they must now forcefully impede the motion of the body from going down the decline.

Metabolic Activity

Athletes or recreational runners who engage in endurance training will derive most of their energy through aerobic processes. These processes depend greatly upon the amount of oxygen the person can consume from the environment in combination with how much they can utilize[23]. Due to the unique chemical pathway involved in aerobic respiration, the more oxygen a person consumes, the more adenosine triphosphate (ATP) that can be generated, and as a result, the more energy the runner will have[24].

Many researchers indicate that the rate of oxygen consumption (VO_2) increases linearly with running speed[25]. Differences in oxygen can be attributed to other factors as well keeping running speed constant. These factors can include gross changes to movement such as altering stride length or strike indices, but can include such minor events as altering arm motion or trunk lean[26].

By examining the differences in oxygen consumption for the different stride frequencies, I will be able to make predictions about which stride frequency uses the least amount of energy. This increase in running efficiency could further help those in competition as a means for increasing performance. Also, those attempting to run for recreation or weight loss purposes can reap the benefits as suited to their particular goals. This study will examine specifically whether utilizing shorter strides proves more efficient (as is commonly believed), or if longer strides lead to a better running economy. By maintaining a constant treadmill speed, valuable comparisons and generalizations can be made for each condition.

Level Running

The energetic cost of running on level ground has been extensively researched in laboratories, mainly because it is relatively facile to do so. However, this does not mean the field is set on generalizations involving average oxygen consumption. Many discrepancies still arise as most data is specific to that participant. The average metabolic cost for running at 3.00 m/s is 33.6 ± 3.00 ml/kg/min. This equates to roughly 54.44% ± 6.37% of each individuals VO_2 max[27]. This data displays how much variation can be seen in both VO_2 as well as percent VO_{2max} given a variety of participants.

Downhill Running

The subject of metabolic costs during downhill running has been the topic of much speculation recently, mainly because of its upward trend during prolonged periods not seen in level running. However, the rate of oxygen consumption inherent during downhill running is markedly lower than those associated with level running, by a margin of 17.8 ml/kg/min at a speed of 3.83 m/s[28].

The steady increase in oxygen consumption seen during downhill running is at a value of 2.8ml/kg/min, and as stated earlier is not seen during level running. This topic of research is gaining much attention in recent years; however, it does not apply to this study as the upward drift is only seen in prolonged downhill running[28].

Hypothesis

Generally, I am expecting to see an overall decrease in metabolic activity during downhill running as compared to equivalent bouts of level running. All the recent literature and articles suggest this is the case, and I have no reason to suspect otherwise. What will be interesting to examine is the rate of metabolic activity during shorter strides versus longer strides. I believe that during longer strides, the body will be using less energy and therefore less oxygen. This is because less energy will be spent swinging each leg forward to make contact with the ground. Conversely, when the strides are shorter, I would expect an increase in metabolic activity due to the increased rate at which the legs must move.

Kinematics

Kinematic markers are a useful tool to use in order to determine how different body segments move as a result of the forces acting upon them[29]. For this study, kinematic markers were utilized to distinguish how the lower limbs move throughout the course of running. By analyzing kinematic markers, we can make accurate conclusions about the unique ways our body produces a controlled movement, such as running. More specifically, kinematics can be used to calculate total center of gravity location, moments of inertia, and angular velocities of joints[16].

Joint angles of the lower limbs are of particular interest in this study because they show when the gait cycle is altered during different running forms, and also by how much. The differences seen when the participant is running downhill versus level grades will further substantiate the evidence provided by the electromyography and VO_2 data compiled earlier.

In addition to the altered joint angles from the level and downhill running, the stride frequency should also have a significant impact on the joint angles of the lower limbs. Since the speed is held constant for the duration of the experiment, any changes in joint angles can be directly attributed to the altered step frequency. This data in combination with the electromyography and VO_2 information should suggest which method is more efficient, if at all, as opposed to preferred step frequency.

Level Running

Kinematic data regarding level running has been well documented in previous research articles. Much of the literature reports values based off an average running speed of 3.8m/s, and the following information can be assumed to be taken from that speed.

During footstrike, the thigh has reported and angle with the vertical of twenty five degrees, indicating a slight flexion. Amongst researchers, there has been a significant difference of opinion on whether the thigh moves backwards, forwards, or remains sedentary immediately after foot-strike. However, most agree that after maximal support phase knee flexion, the thigh and knee extend at the same rate up until toe-off. During swing, the hip flexes at a slower rate (45 degrees) than the corresponding knee flexion (86 degrees). Although there has not been a consensus over the exact amount of thigh flexion and extension, the angles are roughly around 33.5 degrees and 25.8 degrees for hip flexion and extension, respectively.

The knee is a crucial component of the lower limbs during running for its ability to cushion the runner's foot during initial contact, thereby preventing injury. This cushioning occurs during foot-strike, where the knee is not fully extended but rather flexed at an angle of 10 to 20 degrees. It is also important to note that the maximum value of knee extension which occurs during late stance is approximately equal to the angles reported during foot-strike. During the swing phase, the knee has a maximum flexion angle of 82 degrees. Also, the angular velocity of the knee during the extension phase (stance) is equal to the angular velocity during the flexion phase (swing).

During foot-strike, the ankle is in a neutral position of 90 degrees, and exhibits only a small amount of plantar flexion immediately following foot-strike. The ankle will then experience an average of 20 degrees of dorsiflexion during the stance phase of movement, followed by a plantar flexion of 70 degrees[16]. During the swing phase the ankle will dorsiflex back to its original neutral position of 90 degrees[26].

Downhill Running

Literature regarding the kinematics during downhill running has not been well documented in the past, but a few generalizations have been made. All reported values were made at a grade of -10% and a speed of 3.4 m/s. During stance phase, where the thigh is actively extending, the maximum angle reported has been 22.4 degrees with respect to the vertical. During swing phase, the thigh has flexed to an angle of 29.4 degrees, for a total range of motion of 51.8 degrees[16]. Compared to the values reported for level running, the thigh both flexes and extends less during downhill running. It is important to note that stride frequency was not factored in during this study.

The knee has been reported to flex roughly the same amount during the cushioning portion of the stance phase. The knee moves slightly more during the propulsive extension phase, by about 3 degrees. During the flexion phase (swing), the knee reported a smaller range of motion by almost 10 degrees, all other things being constant[16].

The ankle reported a greater stance phase dorsiflexion as expected. The total plantar flexion during toe-off reported for downhill running was greater by about 8 degrees. The total range of motion for the ankle was less for the duration of downhill running at a -10 % grade and 3.4 m/s.

Hypothesis

The kinematic data taken from previous literature has enabled me to conclude that the various thigh, knee, and ankle angles will all change during downhill running as compared to level running, as well as make inferences on stride length and stride time. When these angles will change and by what degree is the important aspect of the study in terms of kinematics.

Based on Milliron and Cavanagh's study comparing thigh, knee and ankle angles during level and downhill running I am expecting to see an average decrease in the range of motion for all three lower limb segments. When the step frequency is altered, however, should produce novel results. While running at a step frequency 15% above the runners preferred frequency, I am expecting the angles of the thigh, knee, and ankle all to decrease very slightly or even stay the same as those recorded during level running. This is because the leg is being forced to stay in the air longer, and therefore make broader angles with respect to the vertical. The thigh should remain very close to if not increase its angle slightly, while those of the knee should show a slightly higher change in angle. The ankle should not stray too far from its original angle values.

In terms of stride length, it should be clear that running with strides 15% slower than their preferred frequency should elicit a longer stride length, whereas those running 15% faster than preferred should have a smaller stride length. I would guess that both will be statistically significant in regards to level running due to the large percentage with which the alteration is occurring.

When the participants must run at a stride frequency 15% under their preferred frequency, I am expecting all angles to decrease severely as well as range of motion. This can be attributed to the shorter, choppier stride that corresponds with the leg being in the air for a shorter duration. Here, the thigh should experience the greatest change from level running angle, followed closely by the knee and ankle angles. It is important to note that when the stride frequency is 15% above the preferred I do not expect the ankle angle to change very much, but when the stride frequency is 15% below the preferred I am expecting the ankle angle to show a significant decrease in range of motion.

Chapter 2: Materials and Methods

Participants

The participants utilized in this study consisted of 10 college students, 5 females and 5 males all of whom were approximately 21.9 years of age. The average height of each subject was 1.72m ± 0.1 meters, and the average weight was 65.6kg ± 11.3kg. Previous experience in distance running was not required for the experiment, although each subject admitted to having run in their spare time for either recreation or sport. The participants signed a standard consent form as per The Pennsylvania State University guidelines.

Kinematic markers were used in order to accurately measure the movement of the body throughout the course of the experiment. In total, 15 reflective markers ranging in size depending on the location of the body part were placed in the areas of interest. In general, larger markers were placed on the hip and pelvis, while the smaller markers were used for the knee and lower leg segments. 1 marker was placed on C-7, 1 on either side of the hip at the anterior superior iliac spine as well as another on the right pelvis, 1 on the sacral crest (Large and raised), 1 on the left thigh, 1 on the lateral side of each knee at the fibular head, 1 on the right shank, and finally 1 on both the left and right heel, ankle, and toe. “Toe” is referencing the big toe.

EMG electrodes were used in order to measure the electrical activity produced by 8 muscles of the lower limbs. The muscles of interest were taken from the left leg of each participant, and included the TA, LG, SL, RF, VL, VM, BF, and ST. Each muscle belly was located using a simple body ruler, black tip marker, and palpation techniques.

The tibialis anterior was measured by first locating the lower margin of the patella and stretching the tape measurer to the lateral malleolus. The muscle belly was approximately 1/3 of the way from the patella. The lateral gastrocnemius was measured in a similar fashion, stretching the measuring tape from the head of the fibula to the heel, and marking the point approximately 1/3 of the way from the head of the fibula. The soleus was measured also from the heel to the head of the fibula, with its central point being ½ the distance. In order to check that we accurately located the LG and SL we would have subjects extend their ankle and adjust our measurements if necessary. The rectus femoris was located by placing the tape measurer from the anterior superior iliac spine to the superior border of the patella. The muscle belly was roughly ½ the distance. The vastus lateralis was measured 3-5cm superior and lateral from the superior border of the patella. The vastus medialis was measured 2-4cm superior and medial from the superior border of the patella. Similar to the way we measured the LG and SL, for the VL and VM it was helpful to have the subject extend their knee in order to locate the muscle and adjust our measurements if needed. The biceps femoris was measured from the ischial tuberosity to the lateral epicondyle of the tibia. Where this line intersected the biceps femoris tendon is where we placed the electrode. The semitendinosus was found in a similar fashion. The measuring tape was extended from the ischial tuberosity to the medial epicondyle of the tibia. Where this line intersected with the semitendinosus tendon is where the electrode was attached.

After each lower leg muscle had been successfully found and palpated, the belly was marked with a black marker. This marking would later be the site of EMG electrodes, but prior to their placement had to be properly cleaned and prepared. We went over each marking with a fine grade sandpaper to reduce the amount of hair and dead skin cells present. Next, we swabbed the area with rubbing alcohol to further clean the location. After repeating this procedure for each muscle belly, the electrodes could then be attached. One electrode that acted as the "ground" was placed on each subject's left tibia. The 2cm bipolar spaced electrodes were placed on each muscle in accordance with the muscles natural orientation. Each muscle received two electrodes, firmly applied at the location previously marked.

After the electrodes had been placed on each muscle, the lead lines could then be attached to its corresponding area. For convenience, we would drape each attached line over the subject's outstretched arm, so as not to tangle any wires. Once the lead lines had been adequately attached, we asked the participant to neatly tuck in their shirt. To keep the wires close from becoming tangled during the run, we placed them along the subject's waist before wrapping them with athletic tape. We made sure to have the participant extend and flex their leg, giving each line the appropriate slack needed during the course of running. Next, the EMG battery pack was strapped snugly around the subject's waist, but not too tight so as to cut off circulation. The battery pack strapped in much like a belt, and we tucked the leftover slack into the athletic tape. Each wire was inserted into its proper location along the battery pack, and we checked once again if the subject was constricted by the wires in any way.

The participant was then required to perform a series of pre-trial tests in order to determine if the electrodes had been placed properly. After connecting the battery pack to the computer, each subject was asked to stand straight up as they normally would. To test the LG and SL, the participant was asked to stand on their toes. The TA was tested by having the subject rock back onto their heels. Next, the subject was asked to extend their knee, testing the VM, VL, and RF. Finally, the subject was asked to flex their knee which tested the BF and ST. After each pre-test we checked the computer monitor to ensure adequate muscle activity was being seen from each muscle. If little to no muscle activity was seen, we first adjusted the computer to perceive more sensitive muscle activity. If this did not work, we had to re-adjust the electrodes and then further check the muscle activity.

Information regarding metabolic data was measured using a small mask lightly strapped around each subjects head. The mask was directly connected to a computer which could monitor the rate of oxygen consumption as well as carbon dioxide production. A small nose clip was required to eliminate any excess inspiration or expiration on the part of the subject which we could not monitor.

Protocol

To begin, each subject was asked to stand on the treadmill with arms at their sides for a duration of five minutes. This allowed us to acquire base metabolic data for each individual subject, as well as check to see if the kinematic markers were showing up on the computer monitor. After five minutes, the metabolic mask was detached from each subject. This was followed by a three minute downhill warm-up, where no data was actually recorded. While no data was recorded during this time period, we calculated the step frequency of each subject approximately one minute into their warm-up. Step frequency was calculated by counting the number of steps each participant took in one minute, timed by a standard stopwatch. Three experimenters conferred results to ensure an accurate step frequency for each subject.

Each condition consisted of four trial segments that were proposed in a random order for each subject. They included running downhill (3 degree decline) at the runners natural step frequency, running downhill at a rate fifteen percent faster than the runners step frequency, running downhill at a rate fifteen percent slower than the runners step frequency, and finally running on a level treadmill at the runners specific downhill preferred frequency.

A generic trial would be run as follows. A subject would begin by running downhill (3 degree decline) for two minutes at a rate of 3 m/s, at their preferred step frequency. During this time, we collected five separate segments of kinematic data that lasted twenty seconds each.

Next, the subject would run the same downhill grade, with the same speed, at a step frequency fifteen percent faster than their preferred frequency. In some subjects, it was noticed that kinematic markers fell off either due to sweat or simply the mechanics of their running. To combat the former, we set up a small fan behind the treadmill which served the cool the subject, and hopefully alleviate the problem of kinematic markers detaching during the trials. Any time a kinematic marker fell off for a trial, the data had to be discarded.

Next, the subject would run level at their preferred downhill frequency. This served as a baseline measurement from which we could compare and contrast the different activities of the muscles during different treadmill grades.

The last trial would then consist of the subject running downhill at a rate fifteen percent slower than their preferred frequency. The same kinematic data was collected, and the subject was then given a short break lasting up to five minutes. During this period each subject was supplied with a bottle of water to replenish and rehydrate prior to the last segment of the study.

While taking the short break, we asked the subject to step off the treadmill so we could detach the various kinematic markers and EMG electrodes from their skin. After successfully detaching all markers and electrodes, the subject was then asked to step back onto the treadmill to begin collecting the metabolic data inherent in downhill running.

The same mask used to collect baseline metabolic data was reattached to each subject, along with the nose clip. It was important to fixate the mask so that the headpiece was holding the bulk of the weight, and not the mouthpiece. Once the mask was tightened to the proper degree as indicated by the subject, the trials could begin.

The metabolic trials were set up much in the same was the kinematic trials were set up, having four separate segments that included: downhill running at a preferred frequency, downhill running at a frequency fifteen percent higher than preferred, downhill running at fifteen percent lower than preferred, and level running at the downhill preferred frequency. It is important to note that the conditions were completely randomized for each participant so as to reduce normalization in our study. Downhill once again refers to the treadmill being at a three degree decline. The only difference between the metabolic and kinematic trials is the duration. For adequate metabolic data to be collected, we lengthened each segment to five minutes each. Data from each subject was collected onto a computer for further evaluation into oxygen consumption and carbon dioxide production.

Chapter 3: Results

Electromyography

The electromyography data corresponding to semitendinosus muscle activity displayed a few statistically significant differences in muscle activity depending on the slope conditions. Statistically significant data had marked differences with p-values lower than 0.05. Muscle activity versus percent gait cycle can be seen in figure 1. During mid-swing was the first statistically significant data regarding the ST. The ST exhibited an increase in muscle activation by 45% when the participant ran with strides 15% faster as compared to level running. When compared to the downhill preferred frequency, running with strides 15% faster showed a marked increase in muscle activation by 30.6%. The corresponding EMG data for the ST can be seen in figure 1.

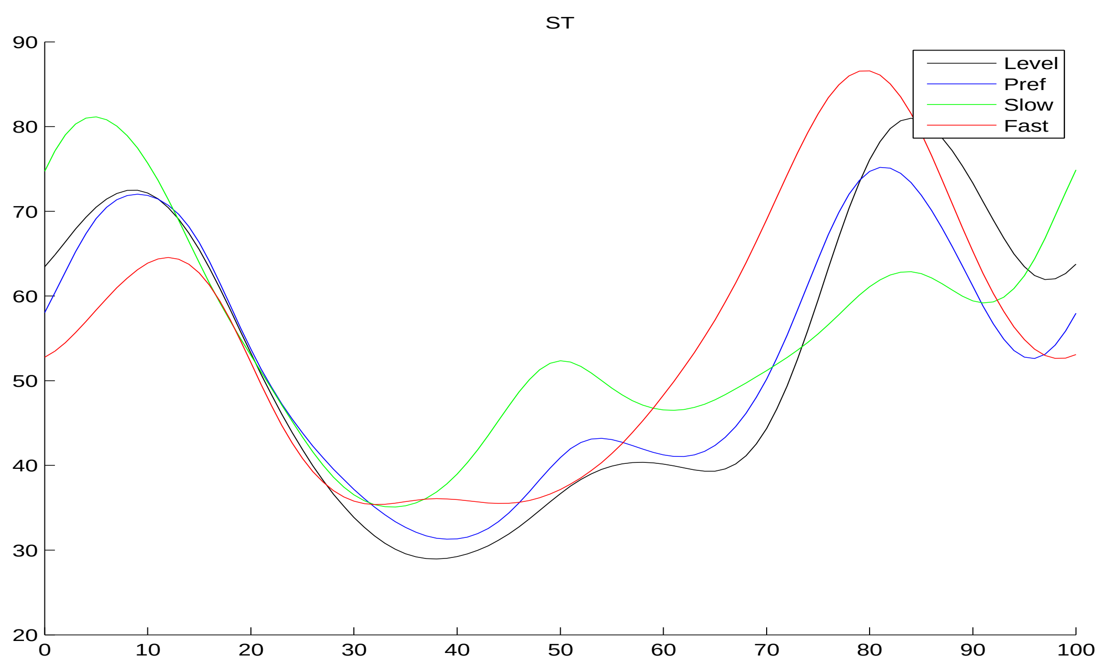

Figure 1: Muscle activity of the ST during each running condition relative to the gait cycle.

The vastus medialis experienced its most statistically significant differences during the initial stance portion of the gait cycle. When the participant ran with strides 15% faster than preferred, the VM experienced a decrease in muscle activity by 34% when compared to level running. When compared to the downhill preferred frequency, the faster strides reduced VM muscle activation once again by 22.3%. When compared to the 15% slower stride frequency, VM muscle activity was reduced by 36.5%, its largest difference. Data from the VM during mid-stance through terminal swing produced no statistically significant differences. The corresponding EMG activity of the VM can be seen in figure 2.

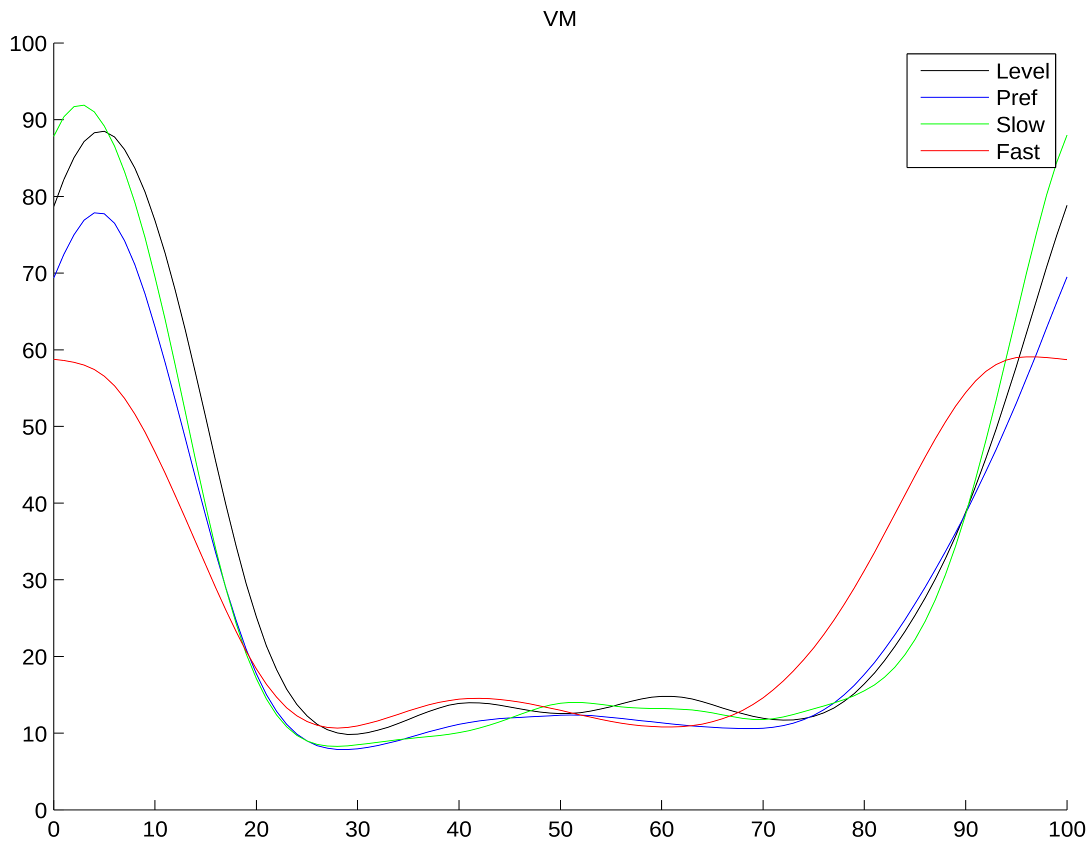

Figure 2: Muscle activity of the VM during each running condition relative to the gait cycle

The vastus lateralis showed very similar results to the VM during initial stance phase. When the participant utilized strides 15% faster than preferred, VL activity saw a marked decrease by 30% when compared to level running. Also, the VL showed a large decrease in muscle activation by 36% when switching from strides 15% slower to those 15% faster than preferred. The corresponding EMG activity for the VL can be seen in figure 3.

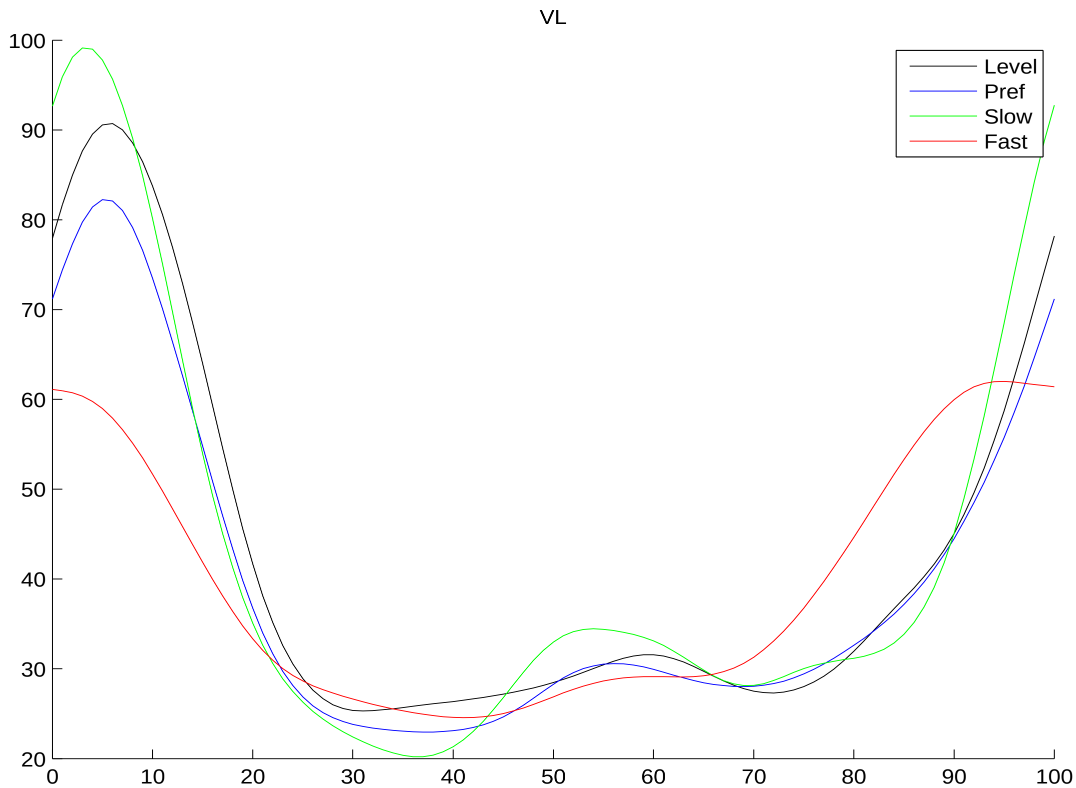

Figure 3: Muscle activity of the VL during each running condition relative to the gait cycle

The rectus femoris showed similar results to the VM and VL, as expected. During initial stance phase, the RF showed an increase in muscle activity by 22.4% when utilizing strides 15% slower than the downhill preferred frequency. During terminal stance, the RF showed a marked increase in muscle activity by 72% when utilizing quicker strides as compared to level running. RF activity increased by 89% when utilizing strides 15% faster as compared to the downhill preferred stride frequency. The corresponding EMG activity for the RF can be seen in figure 4.

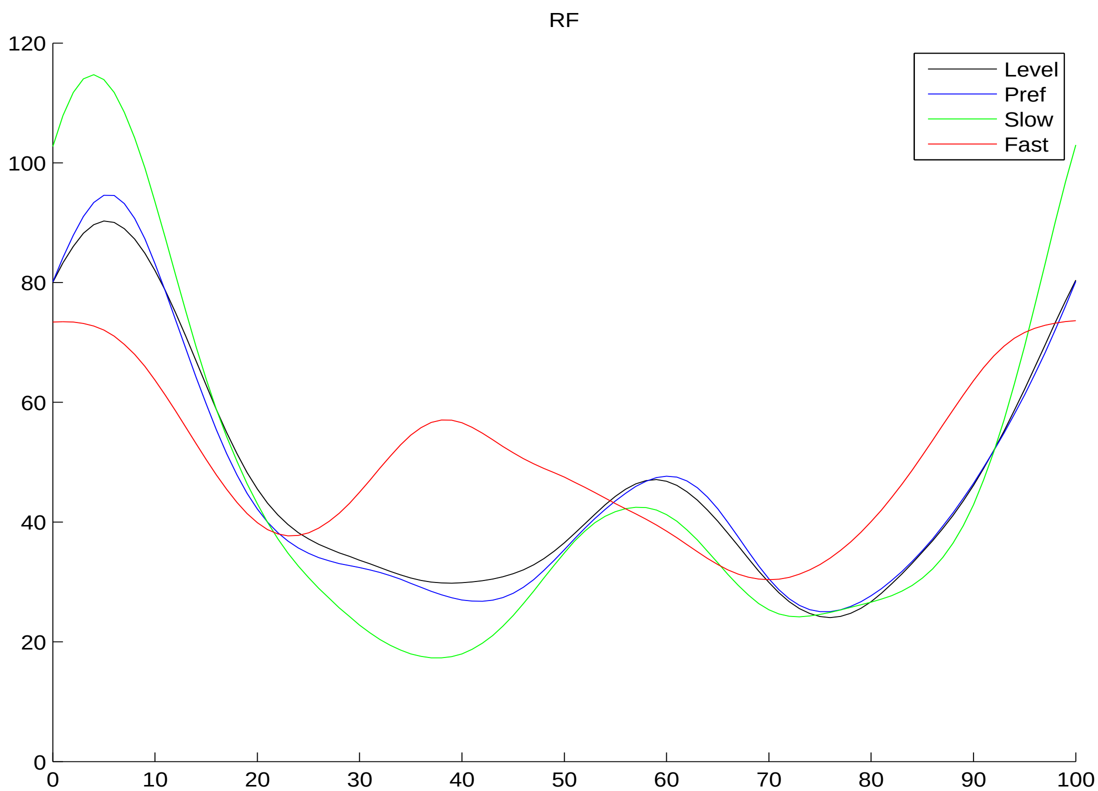

Figure 4: Muscle activity of the RF during each running condition relative to the gait cycle

The biceps femoris recorded statistically significant data during both the stance and swing phases. During initial stance, BF muscle activity saw a marked decrease by 32% when utilizing strides 15% faster as compared to those 15% slower than preferred. During initial swing the BF saw a significant decrease in activity by 24.5% when using strides 15% faster than preferred compared to those 15% slower. During mid-swing when the participant utilized strides

15% faster than preferred, the BF saw an increase in muscle activity by 45% when compared to level running, and an increase of 26% when compared to downhill preferred frequency. The corresponding EMG data for the BF can be seen in figure 5.

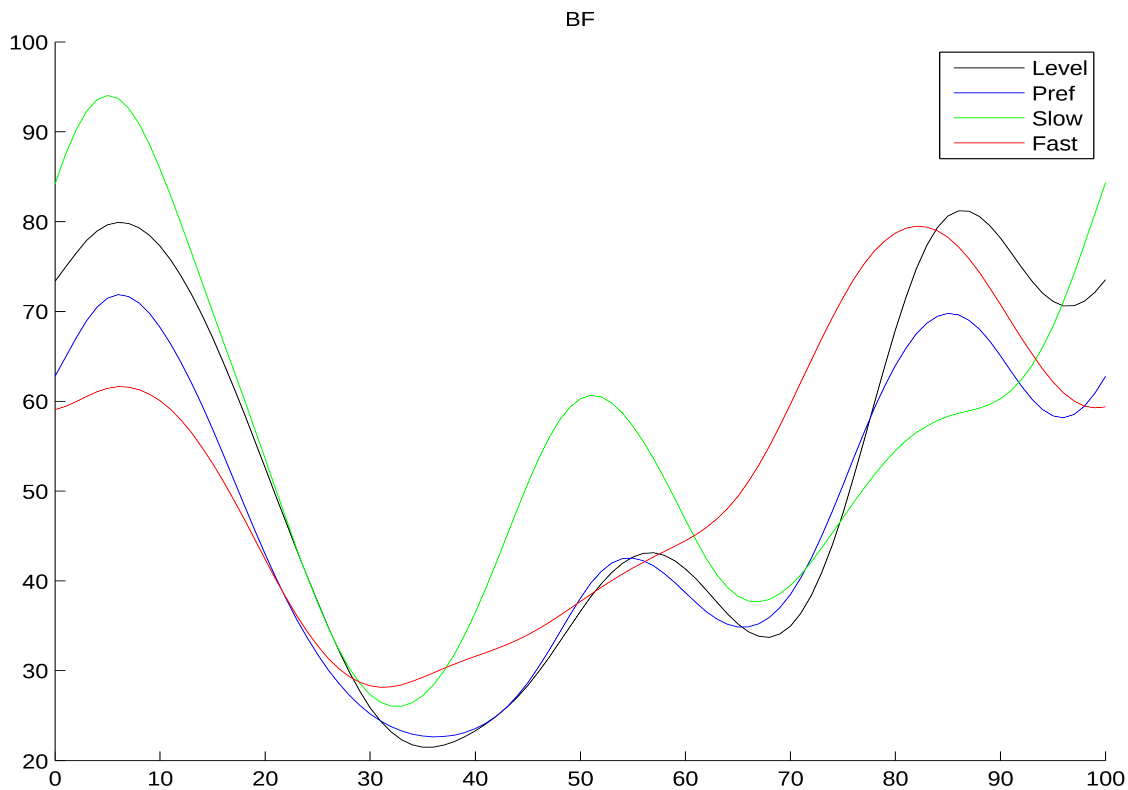

Figure 5: Muscle activity of the BF during each running condition relative to the gait cycle

The soleus muscle saw a decrease in muscle activity by 24.3% during the initial stance phase when utilizing strides 15% faster than preferred as compared to those 15% slower than preferred. During mid-stance, there was a statistically significant difference between level running SL activity and SL activity during downhill running at preferred frequency. When running downhill at the participants preferred frequency, the SL muscle activation decreased by

23%. When running downhill at a frequency 15% faster than the preferred frequency, SL muscle activation decreased by 29.5% as compared to level running. The corresponding EMG data for the SL can be seen in figure 6.

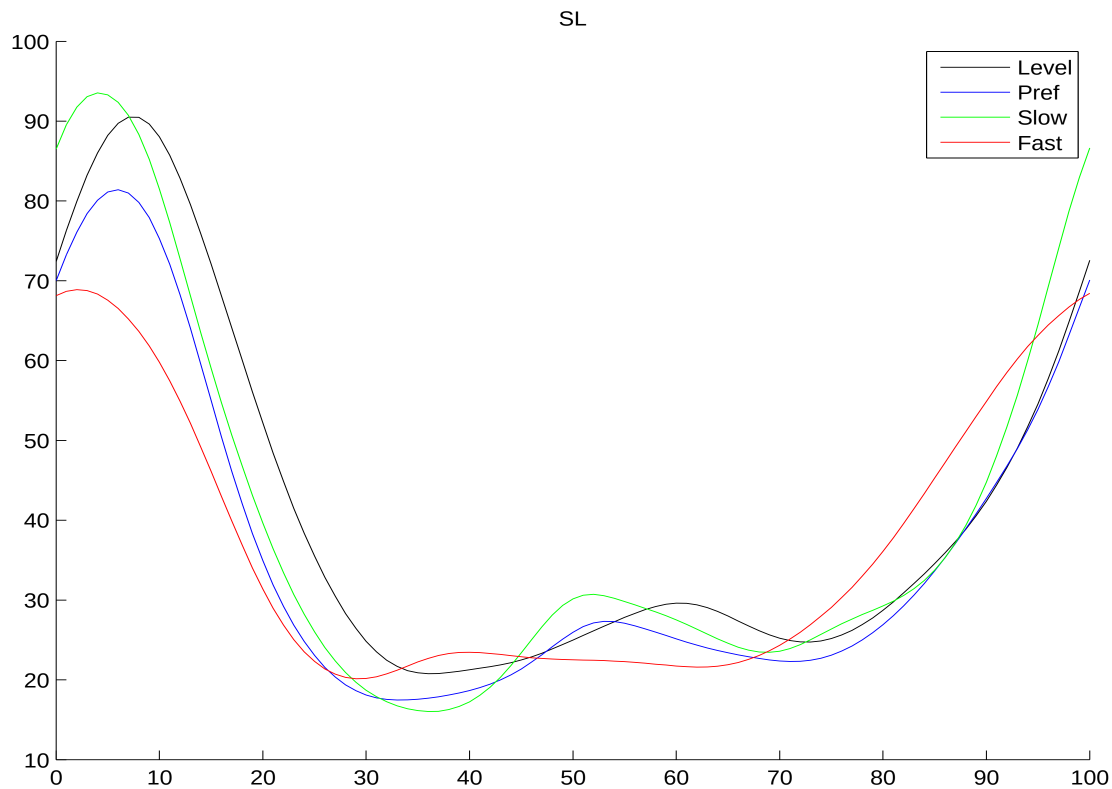

Figure 6: Muscle activity of the SL during each running condition relative to the gait cycle

The lateral gastrocnemius produced marked differences during both stance and swing phases of the gait cycle. During mid-stance the downhill preferred, 15% faster, and 15% slower stride frequencies all produced significant results when compared to level running. LG activity during mid-stance decreased by 29.2%, 16.3%, and 31.8% respectively. During mid-swing, LG activity increased significantly by 39% when utilizing strides 15% faster than preferred, as compared to level running. The corresponding EMG data for the LG can be seen in figure 7.

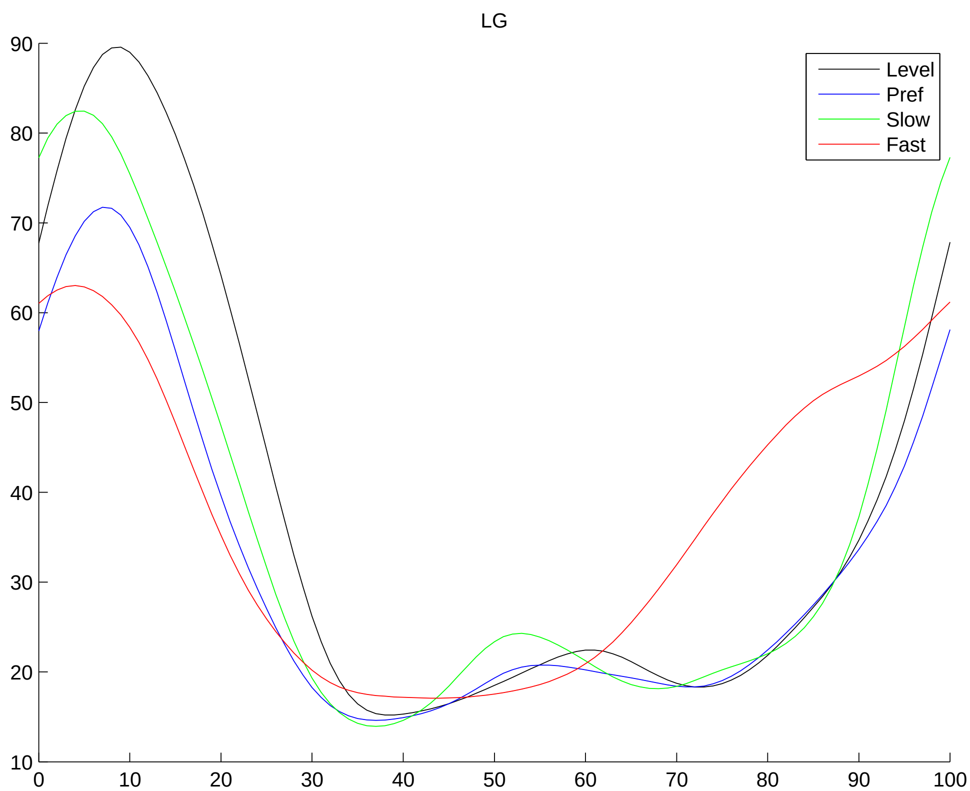

Figure 7: Muscle activity of the LG during each running condition relative to the gait cycle

The tibialis anterior failed to produce any statistically significant data over the course of the study. Although the various slope conditions did not elicit a huge change in the TA muscle activity, which is not to say that small trends can be overlooked. It appears that utilizing strides 15% slower than preferred recruits more TA muscle activation whereas strides 15% faster than preferred recruits less TA activation. The corresponding EMG data for the TA can be seen in figure 8.

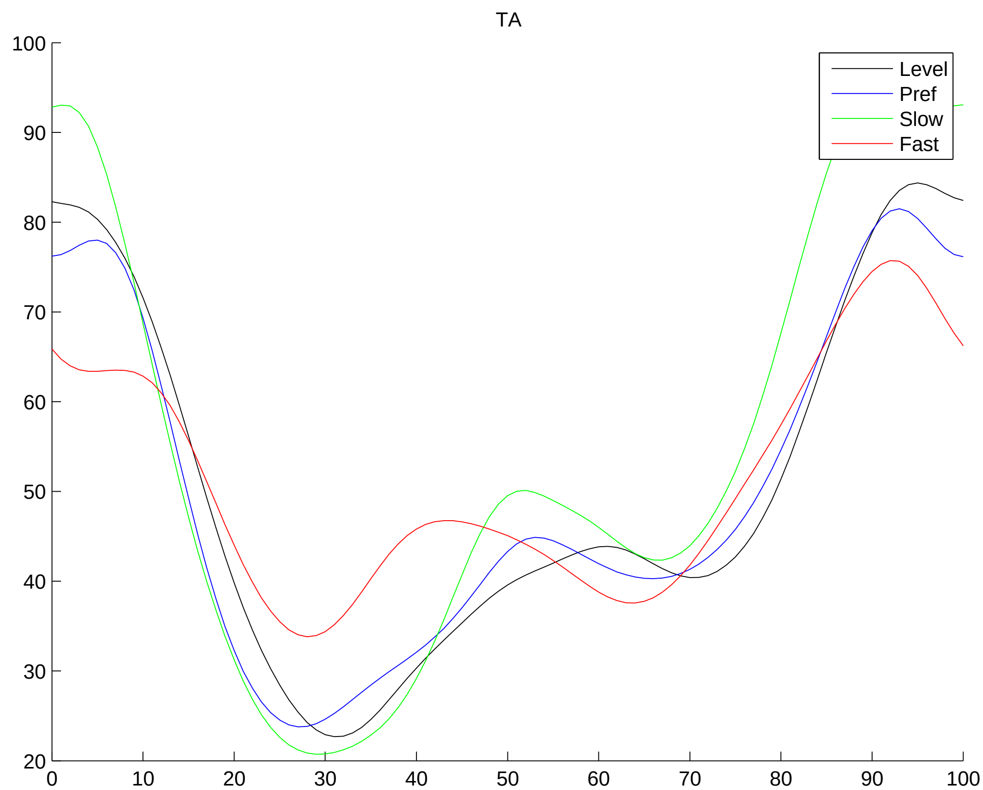

Figure 8: Muscle activity of the TA during each running condition relative to the gait cycle

Metabolics

The changes in the average VO_2 among participants can be seen in figure 1. The standing trial produced significantly lower values of oxygen consumption in the range of 5.17 ml/kg/min of O_2. This baseline metabolic data was then used to subtract from each participant values during each bout of exercise to obtain a more accurate level of exertion. The average rate of oxygen consumption during level running was 31.48 ml/kg/min of O_2.

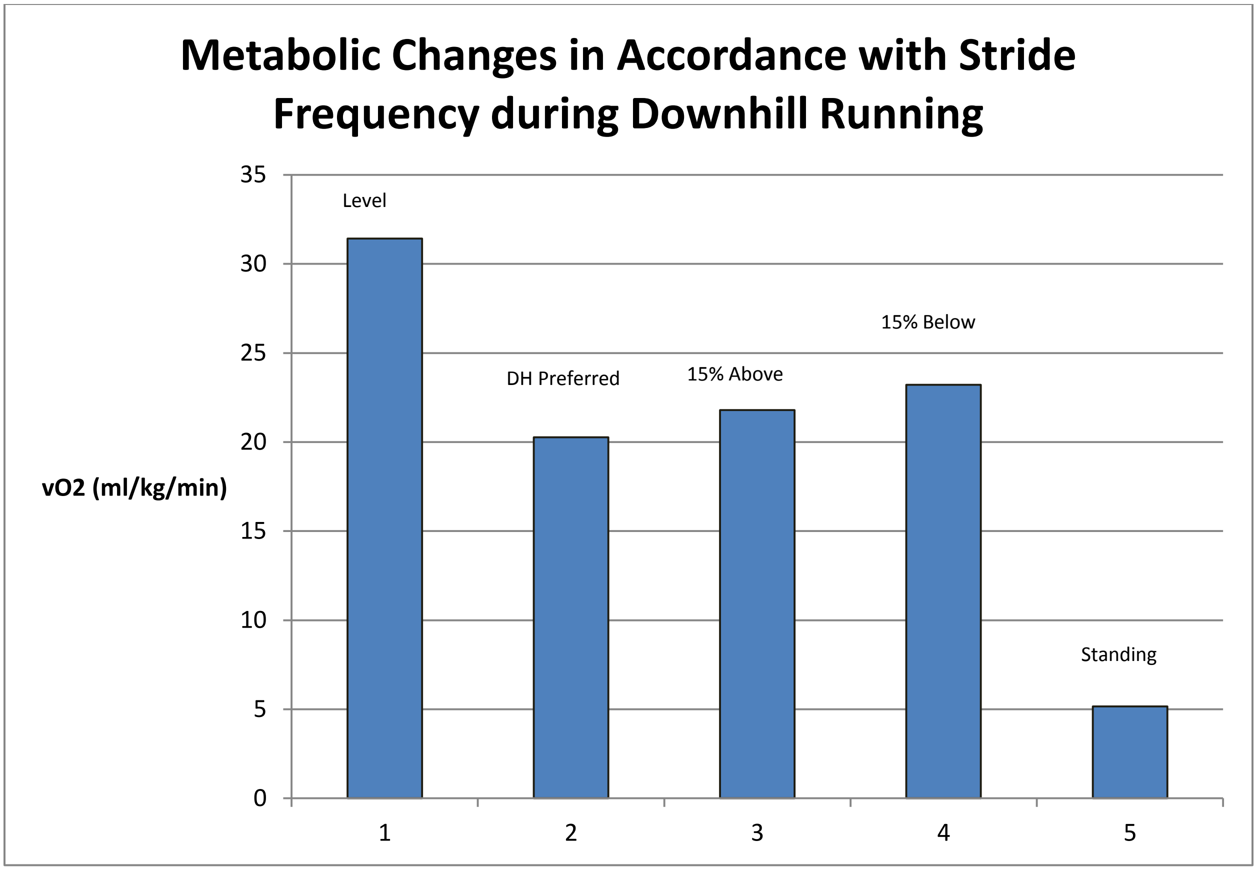

Figure 9: Figure represents metabolic averages of participants during the various stride frequencies encountered in downhill running.

According to the figure, level running elicited the highest amount of oxygen consumption in comparison to the other variables in this study. This is in agreement with my original hypothesis in regards to level and downhill running. Running with a stride frequency 15% below the participants preferred frequency was closest to those values associated with level running. The average metabolic rate for these strides was 23.22 ml/kg/min O_2.

Running with shorter strides elicited the next highest amount of oxygen consumption in comparison with level running. The average metabolic rate for those running with 15% faster strides than preferred was 21.79 ml/kg/min O_2. Finally, running at the downhill preferred stride frequency used the least amount of oxygen at a rate of 20.26 ml/kg/min O_2.

Kinematics

The results from the kinematic gait parameters in response to the varying stride frequencies can be seen in table 1. Statistically significant data is highlighted, and indicates a p values less than 0.05.

Variable	Condition			
	Level	Downhill Preferred	15% Above	15% Below
Total Stride Time (ms)	100	100.11	88.34	113.47
Swing Time (ms)	100	99.89	92.59	116.87
Stance Time (ms)	100	100.22	83.705	109.20
Step Length	100	99.78	77.029	99.65
Ankle Step Width (mm)	100	572.59	430.8	494.4
Toe Step Width (mm)	100	93.236	199.07	83.64

Table 1: Displays the normalized averages of each variable in response to each condition. Those numbers highlighted in red indicate a statistically significant difference in comparison to level and downhill preferred running while those highlighted in green indicate a significant difference to downhill preferred running only.

Total stride time was greatly impacted when varying the frequency with which each stride is taken, as seen in table 1. When running with strides 15% faster than the preferred frequency, there was a decrease of 11.8% in the total stride time as compared to the downhill preferred frequency. When running with strides 15% slower than preferred, there was an increase in total stride time by 13.3%. These values were also statistically significant in comparison to level running, but are very similar to those seen when compared to the downhill preferred frequency.

Swing time also saw statistically significant data, but this time only for the condition in which participants ran with strides 15% slower than preferred. In comparison to the downhill preferred frequency, these strides saw an increase in swing time by 17%. Once again, these numbers are extremely close to those found when comparing level running to strides 15% slower than preferred.

When running with strides 15% faster than preferred, the total stance time decreased by 16.5%. Conversely, strides that were 15% slower than preferred saw an increase in stance time by 9%. It is interesting to note that the strides 15% slower than preferred only calculated statistically significant data when compared to downhill preferred stride frequency and not level running.

Step length also saw statistically significant information when comparing the downhill preferred stride frequency to those 15% faster. In this case, step length decreased by 23% when switching from the preferred frequency to 15% faster. Utilizing strides 15% slower than preferred did not produce any statistically significant data. Finally, ankle step width along with toe step width failed to produce statistically significant results.

Chapter 4: Discussion

Electromyography

The TA, SL, LG, VM, VL, RF, BF, ST are all of major importance when it comes to human locomotion. Analysis of the EMG graphs pertaining to the eight muscles of the lower extremities will provide valuable insight into human locomotion, specifically during downhill running. From this data it will be easy to compare and contrast muscle activity to previous literature, as well as indicate what implications the data has for the future.

The TA failed to produce statistically significant data throughout the course of the study. However, a few generalizations can be made about muscle activity during the different step frequencies. When the participant ran with strides 15% slower than their preferred frequency, there was an increase in TA muscle activation when compared to level running. Conversely, strides 15% faster than the participants preferred elicited less TA muscle activation when compared to level running. Elliot and Blanksby reported that the TA was activated most during heel-strike, where the muscle acted eccentrically to lower the foot towards the ground. Perhaps the lower TA activation associated with strides 15% faster than preferred is a result of the nature of the strides themselves. These shorter, choppier strides in such a quick amount of time significantly reduce the amount of force the TA must work against for a given stride, as seen in the decreased muscle activation. Strides 15% slower than preferred with therefore elicit greater TA muscle activation because the foot is coming down with more force, a direct result of the longer strides.

The SL and LG muscles are most active from late swing into 50% to 80% of the stance phase. Specifically, the SL showed a significant decrease in muscle activation during initial stance phase by 24.3%, when the participant ran with strides 15% faster than preferred. This strongly supports my findings from the TA muscle activation. During initial stance, the SL is co-acting with the TA in order to produce a stabilized lowering of the foot to the ground[16]. As was the case with the TA, during strides 15% faster than preferred, there is less force experienced by the muscles actively lowering the foot to the ground. When comparing downhill running at preferred frequency to downhill running with strides 15% faster than preferred, there are more statistically significant results. Downhill running with strides 15% faster than preferred decreases SL muscle activation due to the smaller angles produced between the shank and the foot. This is especially helpful during toe-off, where the SL will not be needed as much due to the limited range of motion.

Both the LG and SL displayed a decrease in muscle activity when comparing downhill running to level running. This is a result of the smaller angles experienced between the shank and the foot, limiting the amount of force the muscles can and need to produce. Maximum LG and SL activity is often reported during toe-off, indicating a strong concentric contraction of the muscles especially evident during faster running speeds. Muscle activity during the swing phase is not generally seen for these muscles, up until terminal swing when the foot is getting ready to plant itself. However, during mid-swing when running with strides 15% faster than preferred, the LG saw an increase in activity by 39%, as compared to level running. These results are a bit perplexing to me, and could indicate a significant role the LG plays during the swing phase that was not previously noted. One possible explanation for this marked increase in activity can be that the LG must work in an eccentric fashion during mid-swing in order to assist with a controlled toe clearance. This may not be as evident in level running because the toe is not as susceptible to making contact with the ground.

The BF is generally most active during terminal swing as well as heel-off and toe-off[7]. During terminal swing and initial stance, the BF works together with the knee extensors to provide stability during impact. During toe-off, the BF works to flex the knee and simultaneously extend the hip in order to propel the runner forward and prevent the toe from making contact with the ground. The BF saw a decrease in activity by 32% during initial stance when comparing strides 15% faster than preferred to those 15% slower. This can be attributed to the shorter time the leg in in contact with the ground, resulting in less force experienced by the muscles. Conversely, longer strides have been shown to cause a greater shock to the lower limbs following foot-strike. During mid-swing, the BF saw an increase in muscle activity by 45% when running with strides 15% faster than preferred, as compared to level running. When comparing the strides 15% faster than preferred to the downhill preferred frequency, there was still an increase in activity by 26%. When using faster strides, the knee must flex faster in a shorter period of time so as to prevent the foot from catching on the ground. This requires greater activation from the muscles responsible for lifting the knee (BF and ST). During typical downhill running, it has been noted that there is not much BF activity during early to mid-swing because the knee is often passively flexed by the accelerating thigh[8]. When running with strides 15% faster than preferred, however, the knee must be actively flexed which is why the BF activity rose so greatly.

The RF muscle belongs to a group of muscles commonly lumped together called the knee extensors, which are most active during downhill running to stabilize the foot and thigh during heel-strike[7]. When running with strides 15% slower than preferred, it is apparent that more muscle activity is needed to stabilize the foot and thigh. These longer, more forceful strides put much more stress on the muscles and joints of the lower limbs when compared to running with strides 15% faster than preferred or even the preferred frequency itself. This fact is evident simply by listening to the more forceful sound produced during heel-strike. Therefore, it is of no surprise that the RF showed an increase in activity by 22.4% when running with strides 15% slower than the natural downhill preferred frequency. As stated earlier, this is necessary to act as a "brake" for the accelerating lower limb. Interestingly, RF muscle activation showed the greatest difference during terminal stance. Previous literature has indicated that the RF exhibits a characteristic burst of activity during early swing that is associated with the flexing of the hip. When compared to the downhill preferred stride frequency, RF activity increased by 89% when the participant ran with strides 15% faster than preferred. This drastic increase in force indicates that the hip must flex quickly and forcefully in order to continue with the quicker strides and as a result, requires more RF muscle activation.

Similar to the RF, the VL is a muscle that belongs to the knee extensors. However, since this muscle does not cross two joints, it does not display the same burst of activity during initial swing associated with hip flexion. Instead, the VL aids in stabilizing the shank during terminal swing. When running with strides 15% faster than preferred, the foot makes contact with the ground with less force. Conversely, strides 15% slower than preferred create more force when coming in contact with the ground. The findings of this study support these hypotheses. VL muscle activity decreased by 30% when the participant ran with strides 15% faster than preferred, as compared to level running. The difference was even more distinct when comparison was made to the strides 15% slower than preferred, a decrease by 36%. This indicates that there is less of a need for a "braking" mechanism when running with strides 15% faster than preferred due to the shorter time the legs are in contact with the ground.

The VM recorded very similar data to the VL, and also does not cross two joints so cannot assist with hip flexor function. The strides that were 15% faster than the preferred frequency elicited a decrease in VM activity by 34% when compared to level running. When compared to the downhill preferred frequency, this difference was 22.3%. When compared to the 15% slower stride frequency, the decrease in activity by 36.5%. This data supports the notion that utilizing strides 15% faster than preferred produces less force during heel strike, and therefore less muscle activation is needed to serve as “brake” for the lower limbs.

The ST, along with the BF, belongs to a muscle group known as the knee flexors. As stated earlier in regards to the BF, the flexors are activated during the later portions of the swing phase and co-act with the extensors to provide stability during heel-strike[8]. When running with strides 15% faster than preferred, the ST saw an increase in muscle activation by 45% as compared to level running during mid-swing. When compared to the downhill preferred frequency during mid-swing, the strides 15% faster increased ST activation by 30.6%. Much in the same way the BF increased activity during mid-swing, I believe it is a result of the knee needing to be actively flexed in order to provide clearance for the rest of the swing phase. The quicker strides require a faster flexion of the knee, and therefore require more activation of the muscles that create the movement.

Metabolic

There has been much literature present on the differences in oxygen consumption associated with level, downhill, and uphill running. Clearly, the heightened metabolic costs above resting levels inherent in running are a result of the increased muscle activity[26]. However, when analyzing the relationship between VO_2 and stride frequency it is important to note that the increase or decrease in VO_2 is not a direct product of the altered strides. Rather, the differences in stride length require the body to adjust its overall pattern of segmented movement. With this in mind, the differences in VO_2 between each condition can be properly analyzed in the right context.

The average rate of oxygen consumption during level running was 31.48 ml/kg/min of O_2. As expected, this was the highest average among the other downhill conditions but served as a baseline measure to compare values. As stated earlier, any increase or decrease in muscle activity results in a direct correlation with oxygen consumption. It should then follow that since the lower limb muscles are less active overall during downhill running that they are using less oxygen. The use of less oxygen translates into a better running economy and a more efficient runner.

Running downhill with strides 15% slower than preferred elicited a VO_2 value of 23.22 ml/kg/min O_2. This indicates that each participant was not consuming as much oxygen as they would have running on a level surface, but is not the most efficient way to run downhill. Conversely, running with strides 15% faster than the preferred frequency elicited a VO_2 of 21.79 ml/kg/min. This indicates the participant was using less oxygen than either level or running with strides 15% slower than preferred, but still leaves out the most efficient method, the preferred stride frequency.

Running downhill at a preferred stride frequency gave the participants an average VO_2 of 20.26 ml/kg/min. This is the most metabolically efficient method of running downhill, and supports studies done in previous literature. One such study measured the VO_2 of a single participant while altering stride frequency. He concluded that an alteration in stride frequency resulted in an increased energy costs and that a well-trained runner is able to adopt the most economical stride frequency on their own.

Kinematic

The spatial-temporal parameters that were analyzed in this experiment include total stride time, swing time, stance time, step length, ankle step width, and toe step width. Although runners will often times face various slopes when training or in competition, very little research has gone into the kinematics of grade running, specifically a downhill grade. For this reason, it should be the topic of future research within the field of biomechanics.

Total stride time is perhaps the easiest to predict when altering stride frequency. Runners who ran with strides 15% faster than preferred experienced a decrease in stride time by 11.8% when compared to the downhill preferred frequency. Clearly, using shorter strides will limit the total stride time. Conversely, strides 15% slower than preferred increased total stride time by 13.3%. In accordance with my original hypotheses, swing time also increased by 17% when participants ran with strides 15% slower than preferred. This increase in swing time is seen in order to compensate for the fewer amount of strides taken to cover the same distance.

Stance time and step length both saw statistically significant decreases when the participants ran with strides 15% faster than preferred, also in accordance to my original hypotheses.

Limitations

When conducting a study there are always various components that can skew the results. Perhaps the most important of them is the finding of participants. Although I chose an equal amount of men and women for the study, they were all college-aged and relatively in shape. Clearly this limits the implications the study can have on the American public. If a participant could not complete the running portion of the experiment, the data had to be discarded and another participant needed to be found. The kinematic, EMG, and metabolic data also are limited in the ways in which the data was recorded.

The kinematic variables recorded all rest on the proper location and placement of the markers. It has been noted that values derived from these skin markers are only a rough approximation of the movement of limbs and bones[26]. It was sometimes difficult to locate the bony landmarks needed to correctly identify the endpoints for different muscles. This could have skewed the results and given us false data.

EMG data collection was, similar to marker placement, another way for human error to skew the results of the study. Palpating and locating the muscle belly went perfectly fine for the most part, but some participants' muscles gave very weak readings which may have altered the results.

Metabolic data collection is perhaps the most sensitive and therefore the most care must be taken in order to analyze the correct results. During each 5 minute trial, I discarded the first two minutes as each subject became accustomed to the new condition. This left me with 3 minutes of metabolic data to compile results with. This was done in an attempt to match the metabolic data more closely with the trial condition that was eliciting it.

Future Implications

Kinematic, EMG, and metabolic data in regards to downhill running has largely been ignored in previous literature. For this reason, many implications from this study could be further examined in new areas of research. For one, it could not be tested whether metabolic efficiency or EMG efficiency mattered more during running, which has huge implications depending on the outcome. If metabolic data is more important during running, than running downhill at a preferred step frequency is most efficient. If EMG efficiency is more important, however, than running with strides 15% faster than preferred will prove most beneficial when running downhill. Due to this uncertainty, more research is needed into figuring out which parameter is more important during distance downhill running.

Practical Significance

Whether you are running to get in shape or training to improve your latest 5k time, the results recorded during this study should be extremely important to your fitness program. The obesity problem in America has reached epidemic proportions, with more people turning to running as a viable option for losing weight. Those seeking weight lose should review the results of this study and conclude that while running downhill, using strides 15% slower than your preferred frequency will increase your oxygen consumption and therefore, metabolism. Many distance runners have been bombarded with various techniques for running downhill, most of which have not been tested. This paper provides conclusive evidence that running downhill with strides 15% faster than preferred will require less muscle activation, however, running downhill at your preferred frequency is the most efficient metabolically. Whichever the case, the topic should be of interest to those in the research field for its vast implications on runners everywhere.

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THESIS

The Effects of Altered Stride Frequency During Bouts of Downhill Running: An EMG, Kinematic, and Metabolic Analysis
Supervised by Jinger S. Gottschall

RELEVANT EXPERIENCE

Anatomy Lab **Fall 2010**
Teaching Assistant

Assisted in group activities regarding the different muscles and bones within the human body
Coordinated group exercises utilizing a cadaver to demonstrate origins and insertions

Kinesiology Peer Mentor **Fall 2010-Present**

Aided incoming Kinesiology students to ensure a smooth transition from high school to college
Prepared activities and speak at events such as freshman orientation and Kinesiology meetings

State College High School - Tutor **Fall 2011-Present**

Facilitated the learning of high school students in areas such as Chemistry and Physics
Adapted to each new students unique learning style utilizing a variety of techniques

PROFESSIONAL SKILLS

- Strong work ethic and ability to communicate clearly and effectively with peers
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EXTRACURICULAR ACTIVITES

- Active member in THON OPP and Hospitality
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