An Electromyographic and Video Motion Analysis Study of Elite Sprinters at Varying Speeds and Inclines

Samantha Gould
University of North Dakota

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AN ELECTROMYOGRAPHIC AND VIDEO MOTION ANALYSIS STUDY OF ELITE SPRINTERS AT VARYING SPEEDS AND INCLINES

by

Samantha Gould
Bachelor of Science in Physical Therapy
University of North Dakota, 1998

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
In partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May
1999
This Independent Study, submitted by Samantha Gould in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)
PERMISSION

Title An Electromyographic and Video Motion Analysis Study Of Elite Sprinters at Varying Speeds and Inclines

Department Physical Therapy

Degree Master of Physical Therapy

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Signature Samantha Trowbridge

Date 12/16/98
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ACKNOWLEDGEMENTS

I would like to thank all of those that have so willingly given their time to see this project through to its fruition:

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I would also like to thank John Frappier and his staff for lending their mind, time and equipment for this study. Also, a special thanks to all of the subjects involved in this study. Their willingness to help is what made this study truly successful.

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Another thank you to the PT class of 1999. I never thought I could be close friends with forty-eight people in my lifetime, much less in three years. The memories will last a lifetime..........

Deepest thanks to my “roomie” Jennifer Kennedy. Thanks for not complaining when I stayed up late studying, when I didn’t wash the dishes, when I forgot to vacuum, when I hopped into the shower first when you had an 8 o’clock class, when I ....well, you know what I mean.

Finally, a thank you to my parents and my family: To my mom for living through all my long-distance life crises, from gaining my freshman 15 to my graduate school stress, you’ve been there through it all...... To my dad for all his support and encouragement, there’s no one I’d rather “chunk” concrete for..........................
ABSTRACT

Every athlete trains with the hopes of being bigger, stronger or faster than the competitor. Athletes are eager to jump on the “bandwagon” of new training techniques that claim to produce the results the athlete seeks. One such training technique is sprinting on a treadmill at high speeds and inclines. The purpose of this study is to describe muscle activity and joint motion while running on a treadmill at different speeds and inclines.

Six males between the ages of 21 and 27 years of age ran at 20 miles per hour and 0% grade and at 13 miles per hour on a 30% grade. Surface electrodes and joint markers were used to analyze electromyographic activity of six muscles and calculate joint angles while running. A descriptive analysis was then performed comparing the two trials.

From our results we conclude that the sprinter does adopt different strategies and muscle recruitment patterns to compensate for increases in slope. Examination of range of motion revealed that there was greater overall motion of the hip during incline running, increased range of motion at the knee during level running, with the ankle remaining relatively constant. The EMG data revealed greater average muscle activity with sprinting 13 mph at a 30% grade versus sprinting at 20 mph with a 0% grade trial.
CHAPTER 1
INTRODUCTION

Every athlete trains with the hopes of being bigger, stronger or faster than the competitor. Athletes are eager to jump on the “bandwagon” of new training techniques that claim to produce the results the athlete seeks. One such training technique is sprinting on a treadmill at high speeds and inclines.

Problem Statement

The problem lies in the lack of research available to attest to the efficacy of this training technique. More research is needed to validate the use of this current training method in order to validate its use in training athletes. Although there is research available regarding the biomechanics of running there is a need for more information pertaining to running biomechanics at high speeds and inclines.

Purpose of Study

The purpose of this study is to describe muscle activity and joint motion while running on a treadmill at different speeds and inclines. Elite sprinters were recruited for this study in order to examine whether or not running on a treadmill at high speeds, and on an incline causes particular muscles to work harder or the sprinter to change their running technique to accommodate the increased workload.
Significance of Study

The data collected will provide information concerning muscle activity and joint angles during sprinting. This information will promote the understanding of the biomechanics of elite sprinters and provide a basis for developing protocols specifically designed for training an elite athlete.

Research Questions

1) What muscles are active during sprinting?
2) When during the gait cycle are these muscles active?
3) Are these muscles more highly recruited while sprinting on an incline?
4) What body angles are consistent with elite sprinters at high speeds?
5) How do elite sprinters change their running strategies to adapt to higher speeds?
6) How do elite sprinters change their running strategies to adapt to increased inclines?

Hypotheses

Null: Muscles recruited and joint kinematics do not change while running at increased speed, or on an incline.

Alternate: Muscle recruitment and joint angles increase with increased speed an incline.
CHAPTER 2
REVIEW OF THE LITERATURE

Kinematics of Sprinting

Improving the speed of the athlete has manifested itself into several training
protocols, each of which addresses a component of running speed. Those components
include stride frequency, the number of strides performed in a given time period, and
stride length, the amount of area traveled in one stride. A stride, or one gait cycle, is
defined as the distance from initial contact (IC) of one foot to the IC of the ipsilateral
foot. Many authors have examined the mechanics of the gait cycle and the influence of
both stride length and frequency in running and walking, but few studies have focused
on sprinting and even fewer have concentrated on incline sprinting.

In walking, the gait cycle is divided into two phases: stance and swing. The
stance phase, which accounts for 60% of the gait cycle, can be further divided into
periods of initial contact, loading response, midstance, terminal stance, and pre-swing.
Initial contact is considered the instant that the foot contacts the ground. Loading
response then follows with the shift of weight onto the contacting limb. In midstance,
and on into terminal stance, the shift of weight continues over the limb until, at the end of
terminal stance, the weight has completely transferred onto the ball of the foot. Terminal
stance then extends on to pre-swing, which is identified when the weight is quickly
transferred from the ball of the foot to the opposite foot, allowing swing phase to begin.
The swing phase accounts for the remaining 40% of the gait cycle and is divided into three periods: initial swing, midswing, and terminal swing. Initial swing is identified as the moment when the foot begins to rise from the floor secondary to forward motion of the thigh. Midswing occurs as the foot clears the floor and the thigh continues its forward propulsion to allow extension at the knee. Finally, in terminal swing, the knee reaches almost complete extension to prepare for another initial contact and begin another stride/gait cycle.

During the stride/gait cycle of waking there are two periods known as double-support where both feet are in contact with the ground. The first occurs during the loading response and the second occurs during pre-swing. It is this period of double support that is a differentiation between walking and running/sprinting. In contrast to walking, running and sprinting have two periods of double-float where both feet are not in contact with the ground. One occurs at the beginning of swing and one occurs at the end of the swing phase.

There are other characteristics of the running gait cycle that differentiates it from walking. The stance phase of running is divided into two subphases, absorption and propulsion, which are separated by mid-stance, and the swing phase is divided into two phases as well, initial swing and terminal swing, which are separated by midswing. In running, stance should be less than 50% of the gait cycle and swing should be in greater than 50% of the gait cycle. According to Novacheck, with increased velocity, the length of stance decreases from 62% to 37% of the gait cycle, while swing increases from 38% to 62% of the gait cycle. Also, as velocity continues to increase, and the stance phase decreases, an observer can begin to differentiate sprinting from running by discerning...
which area of the foot strikes the ground at initial contact. During running, it is the heel of the foot that makes initial contact, while in sprinting the forefoot becomes the only area of the foot that makes initial contact. 

**Muscle Activity During Sprinting**

**Stance Phase**

At the hip, the gluteus maximus performs a concentric contraction through the first half of the stance phase. During the second half of stance, muscle activity decreases in the gluteus maximus and remains that way until swing phase. The rectus femoris, a bi-articular muscle of the hip and knee, along with the other quadriceps muscles, perform an eccentric contraction following initial contact and early stance to stabilize the knee joint. Peak activity of the rectus femoris occurs at the middle of the stance phase. The activity at the hamstrings has been shown to be uniform between the medial and lateral groups. The biceps femoris shows peak activity at initial contact and it, along with the other hamstring muscles are active throughout the first half of the stance phase. Near the end of stance phase, at toe-off, the biceps femoris again become active to aid in push-off.

In the leg, the gastrocnemius, another bi-articular muscle, is active from initial contact to midstance and at push-off/toe-off. The gastrocnemius stabilizes the ankle from initial contact to midstance and elicits an eccentric contraction to control the forward movement of the tibia over the foot. At toe-off/push-off the gastrocnemius activity increases again, this time in the form of a concentric contraction to provide a propulsive force into the swing phase. The antagonist of the gastrocnemius, the tibialis anterior, is also active during the first half of stance, again to aid in ankle
stabilization. As there is a constant plantar flexion moment in the stance phase of sprinting, tibialis anterior activity tends to increase during post-ground activity. At the trunk, the rectus abdominus performs an eccentric contraction during hip extension at toe-off during the stance phase.

**Swing Phase**

During swing phase, the activity of the gluteus maximus increases and peaks at the end of the stride cycle. The majority of the activity is utilized during foot descent to initial contact for deceleration of the swinging thigh. The rectus femoris displays a second peak in activity during the swing phase. The rectus, alone, begins to concentrically contract during mid-swing. Then it, along with the other quadriceps muscles, provide a concentric contraction during the foot descent of swing as well. Muscle activity in the biceps femoris/hamstrings begins prior to maximum hip flexion (two-thirds through the swing phase) and has a peak in activity during the end of the second float phase. The function of the biceps femoris at this time is to provide a eccentric control of knee extension during swing by decelerating momentum of the tibia prior to initial contact. The biceps femoris are dominant muscles in preparation for initial contact.

At the ankle, the activity of the gastrocnemius continues from toe-off to the beginning of swing where maximum plantar flexion is reached. Activity then decreases until a second onset of activity at the beginning of foot descent. The tibialis anterior is active just after toe-off, through forward swing, until plantar flexion during foot descent occurs. It has two peaks of activity, one at swing to allow for clearance of the foot during swing, and one just before foot strike to act as an antagonist to the gastrocnemius.
The rectus abdominus provides a concentric contraction during early forward swing when the hip is beginning to flex.⁷

**Muscle Activity with incline sprinting**

During inclined sprinting, all of the lower extremity joints show a large increase in flexion at foot strike while hip and knee extension is significantly larger during late stance.¹⁰ During the stance phase, the gastrocnemius, rectus femoris, and gluteus maximus exhibit increased EMG activity with an additional decrease in hamstring activity to correspond with the increase in joint extension during stance.¹⁰

The swing phase during inclined sprinting exhibits very similar muscle activity to that seen during level sprinting with the exception of two muscles, the gastrocnemius and anterior tibialis which is decreased in activity.

A great deal of this activity is explained through the principles of mono-articular versus bi-articular muscles. The mono-articular muscles act as energy generators while bi-articular muscles tend to distribute energy across joints.¹⁰ With inclines, the increased extension at the hip and knee joints are attributed to the ability of the gluteus maximus (mono-articular) to generate energy and the rectus femoris and gastrocnemius (bi-articular) to transfer energy. The decrease of hamstring activity during stance is evidence of muscle inhibition to allow for an increase in energy generation by the extensors.¹⁰ Hip musculature (rectus femoris, gluteus maximus) are dominant sources of work in the action of sprinting.³ The power generated at the hip by these muscles is transferred by the rectus femoris to the knee which then is able to transmit power to the bi-articular gastrocnemius.³ The chain of power transfer accounts for the increased activity of each muscle during extension moments of sprinting at inclines.
Joint Angles

Sprinting demands a larger total ROM from the hip than jogging or running. Maximal hip flexion in sprinting occurs during midswing and is approximately 80 degrees. Max hip extension begins at 50° degrees during early stance and extends to 15 degrees by late stance.

The knee, during stance, never fully extends and remains in 30 - 40 degrees of flexion and has approximately 20 degrees of flexion during this phase for a maximal flexion of approximately 60 degrees at toe-off. During swing, knee flexion peaks at 130 degrees.

In the ankle, as speed increases, the amount of dorsiflexion decreases. At initial contact the ankle is in 8 degrees of plantar flexion, and moves into 15 degrees of dorsiflexion before hitting maximal plantar flexion of approximately 25-30 degrees right after toe-off. During swing, dorsiflexion begins at forward swing in sprinting and reaches a maximal just before initial contact occurs again. It is at this point at which the foot again begins to plantarflex.
CHAPTER 3
METHODS

Subjects

Six healthy males gave their informed written consent to serve as subjects in this study (See Table 1). The study was conducted at Orthopedic Associates in Fargo, North Dakota. The study was approved by the Institutional Review Boards at the University of North Dakota and Orthopedic Associates (See appendix).

Table 1. Descriptive Statistics of Subjects

<table>
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<tr>
<th></th>
<th>Mean</th>
<th>Range</th>
<th>Standard Deviation</th>
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</thead>
<tbody>
<tr>
<td>Age</td>
<td>22.67 (years)</td>
<td>21 – 27</td>
<td>2.21</td>
</tr>
<tr>
<td>Height</td>
<td>72.33 (inches)</td>
<td>67 – 78</td>
<td>3.86</td>
</tr>
<tr>
<td>Weight</td>
<td>191.67 (pounds)</td>
<td>173 – 215</td>
<td>14.44</td>
</tr>
</tbody>
</table>

Instrumentation

Electromyography

The electromyographic information was collected by a Noraxon Telemyo 8 telemetry unit (Noraxon USA, 13430 North Scottsdale Rd., Scottsdale, AZ 85254). This information was then sent to a Noraxon Telemyo 8 receiver and then digitized by an analog digital interface board in the Peak Analog Module (Peak Performance...
Technologies, 7388 S. Revere Parkway, Suite 601, Englewood, CO 80112-9765). The video data and the electromyographic data were synchronized using the Peak Event Synchronization Unit. To start the EMG data collection, the synchronization unit was triggered by a footswitch.

**Video**

Eight reflective markers were placed on each subject to represent various joint centers in the sagittal plane. The exact placement of each marker is detailed below. The camera used to film the sprinting activity was a Peak High Speed Video 60/120 Hz camera (Peak Performance Technologies, 7388 S. Revere Parkway, Suite 601, Englewood, CO 80112-9765). A camera frequency of 60 Hz was utilized during the trials with a shutter speed of 1/250 of a second. The trials were taped on a JVC model BR-S378U video cassette recorder (JVC of America, 41 Slater Drive, Elmood Park, MF 07407). The video tape was encoded with a SMPTE time code generator.

After recording all of the trials, the subjects movements were digitized using the Peak Motus Software package. The tapes were played back on a Sanyo Model GVR-S955 (Sanyo, 1200 W. Artesia Boulevard, Campton, CA 90220) video cassette recorder for the purpose of digitization.

**Protocol**

The skin on the lower extremity was prepared by cleansing it with alcohol and shaving away any excess body hair for the placement of the six (6) surface EMG electrodes over the chosen muscles. These muscles were chosen because they have been shown in previous studies to be active during sprinting (See Table 2).
<table>
<thead>
<tr>
<th>Muscle</th>
<th>Origin</th>
<th>Insertion</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus Abdominis</td>
<td>Pubic Symphasis, Pubic Crest</td>
<td>Xiphoid process, 5&lt;sup&gt;th&lt;/sup&gt; to 7&lt;sup&gt;th&lt;/sup&gt; Intercostal cartilage</td>
<td>Flex trunk, Stabilize pelvis during walking</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>Posterior Crest of Ilium, Sacrotuberous ligament</td>
<td>Iliotibial Tract, Gluteal Tuberosity</td>
<td>Extend thigh, Laterally rotate thigh, Extend trunk</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>Anterior inferior iliac spine</td>
<td>Base of the patella, Tibial Tuberosity</td>
<td>Extend leg, Flex thigh</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>Ischial Tuberosity</td>
<td>Head of Fibula</td>
<td>Flex Knee, Extend thigh, Extend trunk</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>Condyles of femur</td>
<td>Calcaneal tuberosity</td>
<td>Plantarflexion</td>
</tr>
<tr>
<td>Anterior Tibialis</td>
<td>Upper ½ lateral surface of tibia, Interosseous membrane</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; metatarsal, 1&lt;sup&gt;st&lt;/sup&gt; cuneiform</td>
<td>Dorsiflexion, Inversion</td>
</tr>
</tbody>
</table>
The placement of the electrodes was determined by finding each muscle by a previously identified measurement from anatomical landmarks. Figure 1 displays these points anatomically along with a descriptive measurement for each one. The ground, or reference, electrode was placed on the iliac crest.

The electromyographic signals from the electrodes were transmitted to a receiver, which sent the signals into a computer for display and recording of the data. This information was stored on the computer hard drive for future analysis.

Eight reflective markers were placed on each subject to represent the joint centers of the upper and lower extremity. The markers were placed at the TMJ, acromion, lateral epicondyle of the humerus, dorsal aspect of the wrist, greater trochanter, lateral femoral condyle, lateral malleolus, and the fifth metatarsal head on the left side of each subject. These markers were videotaped and digitized to allow the sagittal motion of the neck, trunk, arm, forearm, thigh, leg, and foot to be analyzed.

Each athlete completed a total of two trials on the treadmill with a duration of six seconds for each trial. The athlete sprinted at 20 mph at 0% grade and 13 mph at 30% grade. Each subject was given a rest period between each trial.

Data Analysis

Prior to videotaping, the camera was calibrated by videotaping a meter stick. Then the video footage for each sprinting trial was calibrated in meters, cropped to the first three completed sprinting trials, and digitized using the Peak system. The software calculated the joint angles and segmental motion. The raw analog data was scaled and matched to the video. Reports were then generated to show anthropometric
Gluteus Maximus - midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter
Rectus Abdominus - 2 cm superior and 2 cm lateral to umbilicus
Biceps Femoris - midpoint of a line from the ischial tuberosity to the lateral femoral condyle
Rectus Femoris - midpoint of a line from the ASIS to superior pole of patella (minimum of 10 cm above the patella)
Gastrocnemius - over the muscle belly 1/3 the distance of the leg (fibular head to calcaneous)
Anterior Tibialis - over the muscle belly 1/3 the distance of a line running from the lower margin of the patella to the lateral malleolus

Figure 1. Electrode Placement.
representation of the motion, joint motion, and integrated EMG data of the sprinting cycles for each trial.

The integrated EMG data was quantitatively processed using the Peak Motus software program. An ensemble average was computed for one complete stride length for each subject. The ensemble average was computed by sampling the EMG activity of an entire sprinting cycle at 0.5 percent intervals. The ensemble average was computed for one sprinting cycle, for each subject, with the averaged curves for each subject added together to yield a grand mean curve representative of all the subjects. The qualitative analysis and timing of the muscle activity was determined from the grand mean, ensemble average curves for each muscle. The muscle activation was graded as maximal, moderate, or minimal in relation to the peak level of averaged EMG activity that occurred during 100% of the sprinting cycle. Maximal activation was defined as 66.6-100% of peak muscle activity, moderate activity fell between 33.3 and 66.6% of peak level, and minimal activation was from 0-33.3%.

The hip, knee and ankle range of motion was processed similar to the EMG data. That is, an ensemble average was computed for one sprinting cycle for each subject, and then averaged to compute a grand mean ensemble average for all of the subjects. Due to the small sample size, statistical testing was not performed.
CHAPTER 4
RESULTS

All electromyographic and kinematic figures were created from a combined average of the six subjects performing at 20 mph on a 0% incline and 13 mph on a 30% incline. The percent time displayed on each figure represents a single sprint cycle. At 20 mph, initial contact occurred at 0% and toe-off at 21% stance phase. The remaining 79% represents swing phase of the cycle. During the 13 mph trial, stance phase occurred from 0-29% and swing phase continued from 29-100% of the sprint cycle.

Kinematics

Twenty miles per hour

Ensemble average curves for hip, knee, and ankle ranges of motion (ROM) are represented in Figure 2. At 20 mph, maximal hip flexion occurred at 76% of the sprint cycle reaching 59°. The hip extended to 7° at 32% of the cycle. The knee flexed to a maximum of 136° at approximately 61% of the sprint cycle and a minimum of 24° at 0% of the sprint cycle. Maximal plantar flexion occurred at 38% of the cycle and reached 60°, while the minimum of 17° of plantar flexion occurred at 13% of the sprint cycle.

Thirteen miles per hour

At 13 mph and 30% incline, maximal hip flexion was 84° at 80% of the cycle and decreased to 10° of flexion at 35% of the cycle. At any given point in the stride, the
degree of hip flexion is greater at 13 mph as compared to 20 mph. Knee flexion peaked at 131° at 68% and minimal flexion occurred at 31% of the cycle reaching 25°. Maximal plantar flexion was 57° occurring at 43% of the sprint cycle. Minimal ROM occurred at 14% of the cycle with 13° of plantar flexion.

Quantitatively, hip flexion was always greater at 13 mph than at 20 mph throughout the sprint cycle. ROM patterns between the two were congruent. At the knee, maximal flexion was greater and occurred earlier in the stride at 20 mph. The knee extension movement was greater at 20 mph during late swing/early stance. ROM at the ankle displayed very similar patterns, but there was generally a greater amount of dorsiflexion during stance and mid to late swing at 13 mph than 20 mph. At 20 mph, the dorsiflexion moment decreased more quickly during stance compared to 13 mph.

EMG

Ensemble averaged EMG activity for all six muscles at 20 mph and 13 mph is shown in Figure 3 and compared in Figure 4. Figure 4 shows that greater muscle activity was only evident in the biceps femoris and gluteus maximus at 20 mph and 0% incline. The gastrocnemius, anterior tibialis, rectus femoris, and rectus abdominus showed more activity at 13 mph and 30% incline. The largest muscle activity level difference between the two speeds was in the gluteus maximus and the least was in the rectus abdominus.

Figures 5 and 6 display ensemble averaged EMG activity for individual muscles at 20 and 13 mph relative to joint motion. Table 3 shows muscle activity as a percentage of the sprint cycle and Figures 7 and 8 graphically display the same information. The gastrocnemius activity showed the most activity at 20 mph during stance phase (See Figures 5 and 6). However, at 13 mph there were two periods of peak activity, once
during stance and once during mid to late swing. The anterior tibialis displayed activity throughout both the 13 and 20 mph trials. However, at 13 mph, it displayed greater average activity with two peaks, one during stance and one during early swing.

The rectus femoris at 20 mph showed peak activity during late stance/early swing and remained active until mid-swing where it began a gradual decrease. At 13 mph, activity in the rectus femoris remained steady until mid-swing where activity showed a significant increase, but again steadily declined during late swing.

The biceps femoris activity was greatest at 20 mph during the stance phase. The activity then declined from early to mid-swing, and rose again peaking just prior to initial contact. The biceps femoris at 13 mph remained relatively steady throughout the sprint cycle, displaying it’s peak activity in late swing.

At 20 mph, the gluteus maximus attained it’s greatest activity during stance, then decreased during early swing, and began to rise again during late swing. In comparison, the gluteus maximus activity at 13 mph was smaller in amplitude but followed the approximate activity timing seen at 20 mph. The rectus abdominus had greater maximal activity during the incline sprint at 13 mph, but the timing of its activity was approximately the same in both trials.
Figure 2. Ensemble averaged curves for range of motion. Red line is sprinting at 20 mph and 0%. Blue line is sprinting at 13 mph and 30%.
Figure 3. Averaged EMG activity for 13 and 20 mph. Thirteen mph is shown in blue and 20 mph is shown in red.
Figure 4. EMG activity during sprinting.
Figure 5. Ensemble averaged kinematic and electromyographic data for all subjects sprinting at 20 mph and 0% grade. The vertical line represents toe off.
Figure 6. Ensemble averaged kinematic and electromyographic data for all subjects sprinting at 13 mph and 30% grade. The vertical line represents toe off.
Table 3. Muscle Activation Patterns.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Sprinting at 20 mph and 0% grade</th>
<th>Sprinting at 13 mph and 30% grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximal Activation</td>
<td>Moderate Activation</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>10-29%</td>
<td>0-10%</td>
</tr>
<tr>
<td></td>
<td>29-34%</td>
<td>26-33%</td>
</tr>
<tr>
<td></td>
<td>63-69%</td>
<td>66-79%</td>
</tr>
<tr>
<td>Anterior Tibialis</td>
<td>0-66%</td>
<td>66-94%</td>
</tr>
<tr>
<td></td>
<td>94-100%</td>
<td>46-55%</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>15-31%</td>
<td>0-15%</td>
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<td></td>
<td>41-63%</td>
<td>31-41%</td>
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Figure 7. Muscle activation for sprinting at 20 mph and 0 percent grade.
Figure 8. Muscle activation for sprinting at 13 mph and 30 percent grade.
CHAPTER 5
DISCUSSION

Kinematics

The ensemble average range of motion (ROM) curves showed that hip flexion was greater at 13 mph at 30% grade than 20 mph at 0% grade. Hip motion went from 7° to 59° of hip flexion during the 20 mph trial. However, during the incline trial, hip flexion went from 10° to 84°. It is hypothesized that the greater hip flexion seen during the incline trial was done to allow the foot to clear the treadmill. Only one study was available to provide data for joint ROM during incline sprinting. They found the hip ROM went from 0° to 75° during a 30% incline. These results are similar to the findings of this study. Mann found hip ROM during level sprinting to be from 15° of flexion to 80°. In that study there was more hip motion than on the present study. I would state that the differences between these two studies cannot be determined at this time.

Knee flexion at 20 mph went from 24° of flexion to 136°. Knee flexion during the 13 mph trial went from 25° to 131°. This was very similar to the ROM found in level running in this study. Range of motion found in this study is very similar to Mann’s, who found knee flexion from 30° to 130° during level sprinting. Owens also found similar ranges in incline sprinting with a measure of 20° to 120°. The increase in overall flexion found during the 20 mph trial suggests that the knee flexes more to create a
shorter lever arm with less effective mass for quicker stride frequency demanded during 20 mph sprinting.

The ankle remained in plantar flexion throughout the sprint cycle, which is also supported in studies by both Novacheck and Owens. During 20 mph sprinting maximal plantar flexion was found to be $60^\circ$ while minimal plantar flexion was found to be $17^\circ$. At 13 mph, maximum plantar flexion was $57^\circ$ while minimal was $13^\circ$. The decreased amount of plantar flexion found during the 13 mph incline trial suggests that more ROM was required to clear the foot from the treadmill in the incline position. Mann found a range of $8^\circ$ dorsiflexion to $35^\circ$ of plantar flexion which differs from the results found in this study and Owens study secondary to different methods and speeds used by the runners.

**EMG**

When comparing EMG activity between the 13 mph trial and the 20 mph trial, the average EMG activity of the six muscles examined was greater during the 13 mph trial with the exception of two muscles, the gluteus maximus and the biceps femoris. These results suggest that the incline is more important than speed in increasing muscle activity. These findings are supported by Swanson, who also concluded that high speed running on an incline was effective in increasing activity levels in some, but not all, lower extremity musculature. In that study however, Swanson found decreased activity in the medial and lateral hamstrings, but increased activity in the gluteus maximus during the inclined sprint cycle, differing somewhat from the results found here.
Gastrocnemius

The gastrocnemius at 20 mph displays maximal activity during the stance and early swing phase. This activity suggests a concentric contraction of the gastrocnemius muscle to aid with push-off into early swing. In a study by Johnhagen 8, peak activity of the gastrocnemius occurred right before toe-off/push-off during level sprinting supporting the results of this study. During the incline trial maximal activity occurred again at stance/early swing but was of a lesser magnitude than the activity at 20 mph. This is probably due to the increased hip flexion in this trial which is related to increased power generation in sprinting. 3 With increased power generated at the hip, less power is required from the gastrocnemius. A second burst of maximal activity in the gastrocnemius during incline sprinting appears from the end of mid-swing to the beginning of terminal swing. This activity suggests an eccentric contraction to control dorsiflexion and knee extension as the leg begins to extend to prepare for initial contact. Mann suggests this activity occurs to stabilize the ankle joint in anticipation of foot contact. 7

Tibialis Anterior

The tibialis anterior, during level sprinting, exhibits maximal activity from the beginning of stance to the middle of mid-swing and another small burst at the end of terminal swing. This activity is supported by Johnhagen 8, who also found two bursts of maximal activity during level sprinting, one at and during swing phase and another just before foot strike. It is hypothesized that during stance and early swing the muscle acts eccentrically to provide a stabilizing force at the ankle and to control the plantar flexion moment occurring at the ankle. During mid-swing, anterior tibialis activity works
concentrically to provide dorsiflexion to clear the foot, and then, at the end of terminal swing, the muscle acts to stabilize the ankle for foot contact. Other studies have suggested the stabilization function of the anterior tibialis at foot contact as well. With incline sprinting the anterior tibialis shows two shorter bursts of maximal activity, once during stance and once at the beginning of mid-swing. This indicates that the anterior tibialis performs eccentrically during stance to provide stabilization but at the beginning of mid-swing the activity becomes concentric to aid the foot in clearing the treadmill.

Rectus Femoris

The rectus femoris, at 20 mph, displays maximal activity at late stance/early wing and at the end of early swing to mid-swing. Johnhagen found two peaks of activity as well, once during the middle of stance and again during swing phase. This activity suggests an eccentric contraction during the late stance/early swing to control extension at the hip. Mann suggests this eccentric contraction also occurs to stabilize the knee joint. Concentric activity appears to occur during early to mid-wing to aid in hip flexion. A study by Mero also suggested that the rectus femoris acts concentrically to flex the thigh forward. At 13 mph the rectus femoris displayed one area of maximal activity during the end of mid-swing. Like at 20 mph, this activity suggests a concentric contraction to aid with hip flexion, and was high in amplitude suggesting a powerful contraction during the incline condition. This activity may also have been needed to control knee flexion during swing.

Biceps Femoris

The biceps femoris activity peaks from the middle of terminal swing, through stance, and into early swing during level sprinting. The muscle activity suggests that the
muscle performs eccentrically in terminal swing to control knee extension. A study by Mann 7 supports this hypothesis. As the leg continues into stance it is suggested that the biceps femoris acts as a stabilizer of the hip and knee and then acts concentrically as the lower extremity moves from stance into early swing. At 13 mph maximal activity of the biceps femoris occurred only at terminal swing, again performing eccentrically to control passive knee extension and hip flexion. According to Swanson 10, the lack of hamstring activity, seen during inclined sprinting, suggests antagonist inhibition to allow for more power generation during the incline sprint.

**Gluteus Maximus**

The gluteus maximus, at 20 mph, displayed maximal activity at the end of terminal swing and again at the end of stance/beginning of early swing. This suggests that at the end of terminal swing, as the thigh is swinging forward, the gluteus maximus acts eccentrically to decelerate the thigh. Several studies have also shown gluteus maximus activity at terminal swing into foot descent. 7,8 During the end of stance/beginning of early swing, as the hip begins to move into extension, the gluteus maximus concentrically contracts to aid extension. At 13 mph, the gluteus maximus exhibited maximal activity at the end of terminal swing and into early stance. This activity suggests an eccentric contraction to control the hip flexion during terminal swing, and aids in hip extension during stance. Also during the stance phase, the gluteus maximus may eccentrically control the hip flexion moment that occurs after initial contact.
Rectus Abdominus

The rectus abdominus, during level sprinting, displayed peak activity during early swing. This activity may provide an eccentric contraction to control hip extension, or to stabilize the pelvis and prevent anterior tilting as a result of the hip flexor muscles. Peak activity also occurs at terminal swing where the rectus appears to contact concentrically to aid with hip flexion. Mann 7 supports these findings. At 13 mph maximal activity occurs only during terminal swing. This suggests a concentric contraction which is greater in magnitude than at 20 mph, to increase hip flexion required of the incline.

Limitations

This study presents a number of limitations. First, the subjects utilized for the sprinting trials were not all of the same training level or were not as accustomed to the equipment used as some other subjects were. This factor tended to alter some of the individual EMG and kinematic data as the subjects were straining to maintain their speed on the inclined treadmill. Second, the number of subjects selected for this study were too small to truly represent the elite sprinter population. Third, no baseline EMG data was acquired before the two different sprint trials were run. This hindered our ability to normalize the data.

Clinical Implications

In comparing the activity of the six muscles it is evident that there was increased activity in all muscles except the biceps femoris and gluteus maximus while sprinting at 13 mph at a 30% incline as compared to sprinting on a level surface. It would appear that training protocols should be directed at increasing strength on all the muscles tested.
Furthermore, it appears that inclined sprinting can provide increased muscle activity in most of the muscles tested.

**Conclusion**

It is apparent that the body makes several biomechanical adaptations between level sprinting and incline sprinting. Included in those adaptations are increased activity in the gastrocnemius, anterior tibialis, rectus femoris, and rectus abdominus muscles, and an increase in flexion at the hip. With these results in mind, it would benefit the sprinter, and his/her trainer, to utilize these findings in developing a training protocol that could enhance the muscular power and muscular adaptations needed for competition.
APPENDIX
REPORT OF ACTION: EXEMPT/EXPEDITED REVIEW
University of North Dakota Institutional Review Board


Thomas Mohr, Carrie Anderson, Samantha Gould,
NAME: Anna Hillig, Teri Parker  DEPARTMENT/COLLEGE: Physical Therapy

PROJECT TITLE: An Electromyographic and Video Motion Analysis Study of Elite Sprinters at
Varying Speeds and Inclines (Protocol Change)

The above referenced project was reviewed by a designated member for the University's Institutional Review Board on September 17, 1998 and the following action was taken:

☑ Project approved. EXPEDITED REVIEW NO. 3
Next scheduled review is on April 1999

☐ Project approved. EXEMPT CATEGORY NO. _____________ No periodic review scheduled unless so stated in the Remarks Section.

☐ Project approved PENDING receipt of corrections/additions. These corrections/additions should be submitted to ORPD for review and approval. This study may NOT be started until final IRB approval has been received. (See Remarks Section for further information.)

☐ Project approval deferred. This study may not be started until final IRB approval has been received. (See Remarks Section for further information.)

☐ Project denied. (See Remarks Section for further information.)

REMARKS: Any changes in protocol or adverse occurrences in the course of the research project must be reported immediately to the IRB Chairperson or ORPD.

PLEASE NOTE: Requested revisions for student proposals MUST include adviser's signature.

cc: Chair, Physical Therapy
Dean, Medical School

Signature of Designated IRB Member
UND's Institutional Review Board

9-17-98

If the proposed project (clinical medical) is to be part of a research activity funded by a Federal Agency, a special assurance statement or a completed 310 Form may be required. Contact ORPD to obtain the required documents.

(1/98)
1. ABSTRACT: (LIMIT TO 200 WORDS OR LESS AND INCLUDE JUSTIFICATION OR NECESSITY FOR USING HUMAN SUBJECTS.)

Sports training facilities are inundated every year with athletes who want to enhance performance. The challenge is to develop training techniques to meet these performance goals. One technique that is being utilized clinically is training athletes on high quality treadmills. These treadmills allow the athlete to run at high speeds and various grades of incline that simulate functional activities.

The purpose of this research project is to describe muscle activity and joint motion while running on a treadmill at different speeds and inclines. The muscle activity will be collected via electromyographic procedures using surface electrodes. Motion analysis video equipment will be utilized simultaneously to film the subject. This will allow us to analyze the EMG data along with joint movement. The data from this study will be used to describe normal patterns of muscle activity and joint motion which will be used in developing training protocols for athletes.

Normal, trained, healthy subjects will be used in this research project. Human subjects are needed for this EMG research study in order to determine when the selected muscles are active when running at high speeds and at various grades of incline.
PLEASE NOTE: Only information pertinent to your request to utilize human subjects in your project or activity should be included on this form. Where appropriate attach sections from your proposal (if seeking outside funding).

2. PROTOCOL: (Describe procedures to which humans will be subjected. Use additional pages if necessary.)

Subjects:
It is anticipated that we will recruit 10 male subjects between ages 18 and 28. These subjects will participate voluntarily. These subjects will be chosen due to their elite athletic abilities since they will be required to run at high speeds and various inclines. They will also have participated in a previous training program. The project will be completed at Orthopedic Associates in Fargo, ND.

Methods:
Prior to the running trials, each subject's age, height, and weight will be recorded. During the trial, we will measure electromyographic (EMG) activity in selected trunk and lower extremity muscles. We will measure activity in the following muscles while the athletes are running on the treadmill: 1) rectus abdominus, 2) gluteus maximus, 3) rectus femoris, 4) biceps femoris, 5) anterior tibialis, and 6) gastrocnemius.

To record EMG activity, the motor points of the above muscles will be located using a small electrical stimulator. The skin of the lower extremity of each subject will be prepared by cleansing the skin with alcohol before attachment of the EMG adhesive electrodes over the motor point. Adhesive surface electrodes will be placed on the subject's skin over the motor point. The EMG signals will be transmitted to a receiver unit and then fed into a computer for display and recording of data. Prior to beginning the experimental trial, the researcher will apply manual resistance to the subject's lower extremity in order to elicit a maximal voluntary contraction from each muscle being monitored in this study. The muscle activity recorded during the maximal voluntary contraction will be considered as a 100% EMG activity level to which the EMG activity during exercise on the treadmill can be compared. This procedure is done to normalize the EMG data for later analysis.

Video analysis will be used to measure upper extremity, lower extremity and trunk range of motion during the activity. Reflective markers will be attached to the trunk and lower extremity using double-sided adhesive tape. We anticipate placing markers on the shoulder, elbow, wrist, hip, knee, and ankle. Video cameras will be placed on the side of the subject and will film the subject's trunk and lower extremity markers and motion during the experimental trial. This will be recorded on videotape and will be transferred to a computer for analysis.

The athlete will run at 20 mph with 0%, 10%, 20%, 30%, and 40% grade of the treadmill incline. At each incline, the athlete will run for a total of six seconds in order to obtain the necessary data for analysis. The subjects will be given a three minute rest period between trials.

Data analysis:
Descriptive statistics describing the subjects' anthropometric profiles will be provided. The mean activity of each monitored muscle will be calculated. The EMG data collected during the experimental trials will be expressed as a percentage of the EMG activity recorded during the maximal contraction prior to the experimental trials (i.e. normalized). The video image will be converted to a stickman-like figure, from which we can determine joint angles and limb velocity. The EMG data is synchronized with the video data to determine the level of EMG activity during the various running trials.
3. **BENEFITS:** (Describe the benefits to the individual or society.)

The data collected throughout this research study will be analyzed to determine which muscles are active when the athlete is running at high speeds and various inclines. The body angles will also be analyzed to examine the running strategies at these various speeds and inclines. The data should provide information on which muscles are active during running, and this information will provide the basis for developing protocols specifically for training athletes. It will also further the available knowledge base of research in this area.

4. **RISKS:** (Describe the risks to the subject and precautions that will be taken to minimize them. The concept of risk goes beyond physical risk and includes risks to the subject's dignity and self-respect, as well as psychological, emotional or behavioral risk. If data are collected which could prove harmful or embarrassing to the subject if associated with him or her, then describe the methods to be used to insure the confidentiality of data obtained, including plans for final disposition or destruction, debriefing procedures, etc.)

The risks involved in this research project are minimal. The subjects may experience a tingling discomfort while the investigator is using the electrical stimulator to elicit a muscle contraction in order to locate the motor point of the muscle to be monitored. The EMG and video analysis equipment causes no discomfort to the subject, since they are both monitoring devices. Because the video information is converted to stickman-like diagrams, the actual subject's video is not used in data reporting. Therefore, the subject is not recognizable.

The process of physical performance testing does impose a potential risk of injury to the muscle. The testing will occur in a controlled setting, and because only subjects who have already been trained on the treadmill at the proposed speeds and inclines, the risk of injury is minimal. The participant will be closely observed throughout the activity on the treadmill to decrease the potential of harm. However, the activity that this athlete will be performing carries with it the same amount of risk as running at the elite levels to which the participant is accustomed. The investigator or participant may stop the experiment at any time if the participant is experiencing discomfort, pain, fatigue, or any other symptoms that may be detrimental to his/her health.

The subjects' names will not be used in any reports of the results of this study. Any information that is obtained in connection with this study and that can be identified with the subject will remain confidential and will be disclosed only with the subject's permission. The data will be identified by a number known only by the investigator.
5. **CONSENT FORM:** A copy of the **CONSENT FORM** to be signed by the subject (if applicable) and/or any statement to be read to the subject should be attached to this form. If no **CONSENT FORM** is to be used, document the procedures to be used to assure that infringement upon the subject's rights will not occur.

Describe where signed consent forms will be kept and for what period of time.

Consent forms will be kept in the Physical Therapy Department at the University of North Dakota for a period of 3 years.

6. For **FULL IRB REVIEW** forward a signed original and thirteen (13) copies of this completed form, and where applicable, thirteen (13) copies of the proposed consent form, questionnaires, etc. and any supporting documentation to:

Office of Research & Program Development
University of North Dakota
Grand Forks, North Dakota 58202-7134

On campus, mail to: Office of Research & Program Development, Box 7134, or drop it off at Room 105 Twamley Hall.

For **EXEMPT** or **EXPEDITED REVIEW** forward a signed original and a copy of the consent form, questionnaires, etc. and any supporting documentation to one of the addresses above.

The policies and procedures on Use of Human Subjects of the University of North Dakota apply to all activities involving use of Human Subjects performed by personnel conducting such activities under the auspices of the University. No activities are to be initiated without prior review and approval as prescribed by the University's policies and procedures governing the use of human subjects.

**SIGNATURES:**

[Signatures]

(Revised 3/1996)
INFORMATION AND CONSENT FORM

TITLE: An Electromyographic and Video Motion Analysis Study of Elite Sprinters at Varying Speeds and Inclines.

You are being invited to participate in a study conducted by Carrie Anderson, Samantha Gould, Anna Hillig, Teri Parker and Thomas Mohr from the physical therapy department at the University of North Dakota. The purpose of this study is to study muscle activity in your trunk and lower extremity while you are running at different speeds and inclines on the treadmill. We will also be measuring the angles of the joints of the upper extremity, lower extremity and trunk while you are exercising. We hope to describe the muscle activity and the different angles that you employ during this bout of exercise. Only trained, normal, healthy subjects will be asked to participate in this study.

You will be asked to run on the treadmill for a total of five (5) trials consisting of the following:
1) Running on the treadmill at 20 miles per hour with 0% grade. 2) Running on the treadmill at 10% grade. 3) Running on the treadmill at 20% grade. 4) Running on the treadmill at 30% grade. 5) Running on the treadmill at 40% grade. Each trial will last approximately six seconds. You will be given a rest period between trials.

The study will take approximately one hour of your time. You will be asked to report to the Acceleration Training Department at Orthopedic Associates in Fargo, ND, at an assigned time. You will then be asked to change into gym shorts for the experiment. We will first record your age, gender, height and weight. During the experiment, we will be recording the amount of muscle activity and the angles of your joints that is present when you run on the treadmills on the five different settings.

Although the process of physical performance testing always involves some degree of risk, the investigator in this study feels that, because of your prior training, the risk of injury or discomfort is minimal. In order for us to record the muscle activity, we will be placing nine electrodes on your trunk and lower extremity. Before we can apply the electrodes, we will use a small stimulator to electrically stimulate the muscles to locate the best spot to place the electrodes. The stimulator will cause a mild tingling sensation. The recording electrodes are attached to the surface of the skin with an adhesive material. We will also attach reflective markers at various points on your arm, leg and trunk. These devices only record information from your muscles and joints, they do not stimulate the skin. After we get the electrodes attached, we will give you a brief training session to refamiliarize you on the treadmill. The amount of exercise you will be asked to perform will be moderate.

Your name will not be used in any reports of the results of this study. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. The data will be identified by a number known only by the investigator. The investigator or participant may stop the experiment at any time if the participant is experiencing discomfort, pain, fatigue, or any other symptoms.
that may be detrimental to his/her health. Your decision whether or not to participate will not prejudice your future relationship with the Physical Therapy Department or the University of North Dakota. If you decide to participate, you are free to discontinue participation at any time without prejudice.

The investigator involved is available to answer any questions you have concerning this study. In addition, you are encouraged to ask any questions concerning this study that you may have in the future. Questions may be asked by calling Dr. Thomas Mohr at (701) 777-2831. A copy of this consent form is available to all participants in the study. A copy of the consent form will be retained in the Physical Therapy Department for a period of three years.

In the event that this research activity (which will be conducted at Orthopedic Associates) results in a physical injury, medical treatment will be available, including first aid, emergency treatment and follow up care as it is to a member of the general public in similar circumstances. Payment for any such treatment must be provided by you and your third party payment, if any.

ALL OF MY QUESTIONS HAVE BEEN ANSWERED AND I AM ENCOURAGED TO ASK ANY QUESTIONS THAT I MAY HAVE CONCERNING THIS STUDY IN THE FUTURE. MY SIGNATURE INDICATES THAT, HAVING READ THE ABOVE INFORMATION, I HAVE DECIDED TO PARTICIPATE IN THE RESEARCH PROJECT.

I have read all of the above and willingly agree to participate in this study explained to me by Shannon Owens or Erica Fretland

Participant's Signature Date

Witness (not the scientist) Date
DATE: April 9, 1998

TO: IRB, University of North Dakota

FROM: Thomas Mohr, PT, PhD
Chairman, UND Physical Therapy

RE: Sprinting Study

I am writing to request a continuation of the study entitled "An Electromyographic and Video Motion Analysis Study of Elite Sprinters at Varying Speeds and Inclines". The study had been approved last year (project "IRB-9706-285"). We were able to collect data on 5 subjects, but we would like to run additional subjects this year to strengthen the data. With the flood last summer, we did not have enough time to complete the study as we had intended. The data we did collect was fine and we did not have any problems that would have presented a risk to the subjects. We have received verbal approval to continue the study from John Frappier of Acceleration Products.

I am resubmitting the same IRB and Consent forms as last year with the following changes:

The student researchers will change this year (the two from last year will graduate this year).

I have added the required information regarding retention of the consent forms to the consent form.

We anticipate that we would collect data from 10 subjects this year.

If you have any questions, please do not hesitate to contact me.
June 12, 1997

Thomas Mohr Phd.
UND School of Medicine
PT Dept. Box 9037
Grand Forks, ND 58202

Dear Mr. Mohr,

I have had the opportunity to review the research proposal “An Electromyographic and Video Motion Analysis Study of Elite Sprinters at Various Speeds and Inclines”. I am in agreement and approve of this study. The Red River Valley Sports Medicine Institute has also approved of this study. We look forward to working with you.

Sincerely,

John Frappier
President

JF/jlf
September 17, 1997

Dr. Tom Mohr, Chairman
UND School of Medicine
PT Dept. Box 9037
Grand Forks, ND 58202

Dear Dr. Mohr,

I have had the opportunity to review the research proposal “An Electromyographic and Video Motion Analysis Study of Elite Sprinters at Various Speeds and Inclines”. As Medical Director of the Red River Valley Sports Medicine Institute, I approve and support this research endeavor. We look forward to working together with you.

Sincerely,

Mark A. Lundeen, MD
Medical Director RRVSMI
REFERENCES


10. Swanson SC, Frappier JP, Caldwell GE. Muscular Coordination During Incline and Level Treadmill Running. Presented at the North American Congress on Biomechanics; August 14-18;1998; Waterloo, Ontario, Canada.

