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

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

by

Teri Parker
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This Independent Study, submitted by Teri Parker 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 Jeri Parker

Date 12/17/98

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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 (mph) 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 in the incline trial, motion of the knee was greater during level surface running, while ankle motion remained relatively the same. EMG data showed greater overall activity when sprinting at 13 mph on a 30% incline than when sprinting at 20 mph on a 0% incline.

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.[1]

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

Several articles have been published examining lower extremity function during sprinting. Often, the focus is on electromyographic (EMG) activity of the lower extremity muscles, joint kinematics, and the effects of different training methods.

The majority of authors and researchers are in agreement regarding the muscle activity and joint kinematics that take place during swing and stance phases of the running cycle. Mann et al,[2] found that the majority of EMG activity in examined muscles was during foot descent of swing and mid-support of stance and that in the last 30% of support, there was little or no muscle activity. Both Mann et al[2] and Johagen et al[3] found activity in the lower extremity muscles to be greater at the transition from swing to stance, rather than vice versa. Novacheck[4] feels the body's need to prepare for ground contact is more than what is needed when the extremity leaves the ground. This may the reason for the greater activity from swing to stance rather than stance to swing.

The hip extensors, particularly the hamstrings and gluteus maximus, are active in the second half of swing and the first part of stance with the dominate activity just before and just after initial contact.[2,3,4] During swing, these muscles contract eccentrically to decelerate the thigh before initial contact. Just after initial contact, the eccentric contraction of the hamstrings is functioning to decrease the momentum of the tibia moving over the foot.[4] Mann et al,[2] found that EMG activity increased around the hip during swing. The hip extensors are most active at the end of stance phase, concentrically extending the hip. The hip flexors are most active during the second half of stance and the first half of swing.[4] These muscles, especially the iliacus, are said to be the main muscle group responsible for increasing speed during sprinting.[2,3,4] Mann et al[2], found an increase in iliacus activity during swing as speed and ROM increased. Increasing the velocity increases maximum hip flexion causing a longer step length.[4] The longer step length increases knee extension which is important in propelling the body in a forward progression.[2] Both the hip flexors and extensors are responsible for increasing power generation.[4]

Johagen et al,[3] have shown the quadriceps to have two peak activation times; one during swing and the other at the middle of stance. Early in swing, the rectus will contract eccentrically, preventing excess knee flexion.[4] During mid-swing, the rectus is working independently to restrain posterior movement of the tibia as the knee flexes. Towards terminal swing, these muscles contract concentrically, extending the knee and preparing the lower extremity for initial contact and absorption of the shock of impact.[2,3,4] During stance, the quadriceps show eccentric activity at initial contact which continues through early mid-support, controlling knee flexion and absorbing shock.[2,4]

The hamstrings are most active in the second half of swing.[4] They act to control rapid knee extension, control the momentum of the tibia, and prevent knee hyperextension.

Activity of the gastrocnemius during swing phase begins when the foot is starting its descent.[2,3] Both Mann et al[2] and Jonhagen et al[3] feel that this activation is to provide stability and avoid dorsiflexion as the foot prepares for initial contact. The gastrocnemius contracts eccentrically from initial contact to midstance, controlling forward movement of the tibia.[2] The contraction becomes concentric at the beginning of terminal swing to initiate plantar flexion. There is disagreement whether or not this muscle is active during pre-swing (toe-off). Mann et al,[2] states that there is little or no activity and a push-off "per-se" does not happen. They feel that the majority of forward propulsion is brought on by rapid hip flexion of the swing limb, not push-off of the stance limb. Johagen et al,[3] reported activity throughout the stance phase, including toe-off. They found that the gastrocnemius actually peaked at this time.

The tibialis anterior is active throughout swing.[2] Concentric contraction causes dorsiflexion to stabilize the ankle and enable foot clearance.[2,4] Just before initial contact, this muscle will act as an antagonist to the gastrocnemius and help prepare the foot for ground contact.[3]

The ability to assess muscle coordination through kinematics, kinetic, and EMG studies helps identify mechanisms responsible for neuromuscular adaptations that take place during certain types of training.[5]

Swanson et al,[5,6,7] have researched different training protocols used in the Frappier Acceleration™ program. This program utilizes high-speed treadmills at incline grades over 25% and speeds over 10 mph.[5,6] The main goal is development of muscle power during stance and recovery phases of the sprinting cycle.[6] The researchers found that use of training protocols such as these are effective in enhancing maximum sprinting speeds and quickness.[4]

Another training mechanism utilized by Frappier Acceleration™ is the use of sprintcords. These patented sprintcords are loading devices which will load the hip flexors and knee extensors during the recovery phase.[7] This method is based in part on the findings of Chapman and Caldwell[8] who have shown that sprinting success depends on the ability of the hip flexors to forcefully contract in the recovery phase.[7] Swanson et al,[7] also researched this training method in order to verify its effectiveness in loading the hip flexors and knee extensors. They found that sprintcords are effective in loading the hip flexors in a "sport-specific manner" and that they can "closely mimic the crucial swing phase of sprinting".

Other training methods focus on improving the power output of muscles. They aim at hypertrophy of the muscles or specific adaptations of the nervous system.[9] Christophe Delecluse,[9] has documented the effects of strength training on sprinting performance.

Hypertrophy is the increase in mean cross-section area of muscle fibers. Often, this type of training is used as a preparatory period to improve the quantity of muscle mass before training for speed of neuromuscular activation and/or muscle contraction.[9] Fast twitch muscles will hypertrophy quickly when overloaded with a large number of sets consisting of repetitions at submaximal loads of 60-80% of a one repetition maximum (1 RM). This type of training must be limited and combined with other strength training methods.

Hypertrophy training will develop into neuronal activation in which specific adaptations of the nervous system are made.[9] The amount of force that can be generated by the muscle groups depends on the extent to which the nervous system can activate the muscle. By rapidly recruiting motor units and increasing the firing rate of the motor neurons, an improved intra- and intermuscular coordination will be seen. A training method utilized to accomplish this is using short and very fast maximal actions against near maximal loads (90-100% of 1 RM.). A maximum of three repetitions is done as fast as possible when the muscle is in a rested state.

Utilizing the stretch-shortening cycle for training, a higher velocity and decreased deceleration phase is used to load the neuromuscular system.[9] Exercises such as plyometrics will place demands on the athlete that they can just manage in a reactive ballistic way with a high velocity movement. These are considered essential exercises for top level spring preparation.

Sprint associated exercises are also used to reproduce fast running including a strength component.[9] Overload exercises use a high resistance mechanism to improve the acceleration phase, increasing speed endurance and stride length. Overspeed or facilitated running force the athlete to run faster than what is normal by using artificial means. The higher stride rate that is involved causes a change in the nervous system.

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

	Mean	**Range**	**Standard Deviation**
Age	22.67 (years)	21 – 27	2.21
Height	72.33 (inches)	67 – 78	3.86
Weight	191.67 (pounds)	173 – 215	14.44

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 2. Origin, Insertion, and Action of Selected Muscles for Sprinting

Muscle	Origin	Insertion	Action
Rectus Abdominus	Pubic Symphasis Pubic Crest	Xiphoid process 5^{th} to 7^{th} Intercostal cartilage	Flex trunk Stabilize pelvis during walking
Gluteus Maximus	Posterior Crest of Ilium Sacrotuberous ligament	Iliotibial Tract Gluteal Tuberosity	Extend thigh Laterally rotate thigh Extend trunk
Rectus Femoris	Anterior inferior iliac spine	Base of the patella Tibial Tuberosity	Extend leg Flex thigh
Biceps Femoris	Ischial Tuberosity	Head of Fibula	Flex Knee Extend thigh Extend trunk
Gastrocnemius	Condyles of femur	Calcaneal tuberosity	Plantarflexion
Anterior Tibialis	Upper ½ lateral surface of tibia Interosseous membrane	1^{st} metatarsal 1^{st} cuneiform	Dorsiflexion Inversion

The placement of the electrodes was determined by finding each muscle by a previously identified measurement from anatomical landmarks.[10] 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.

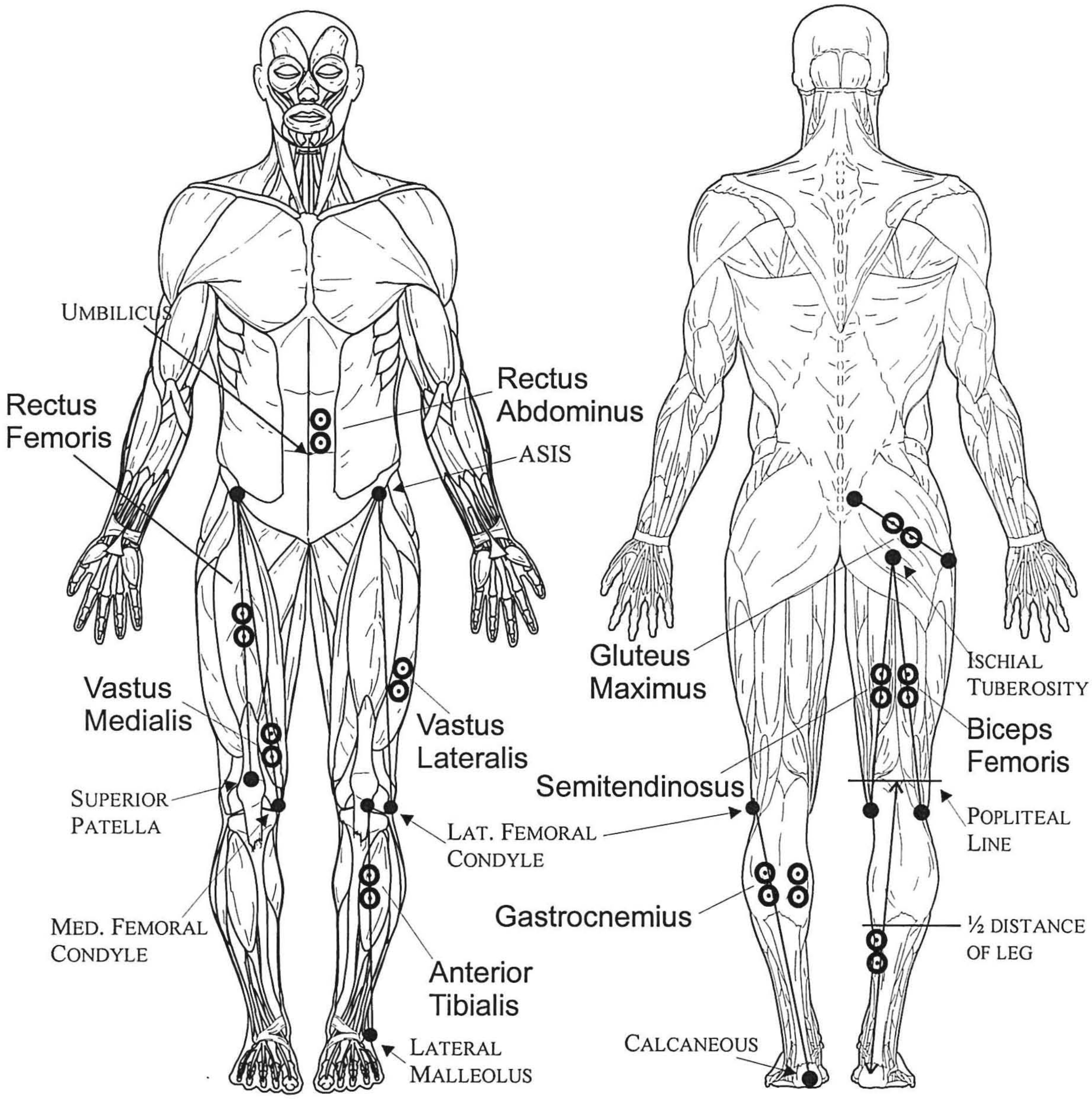
The electromyographic signals from the electrodes were transmitted to a receiver, which sent the signals into a computer for display and recording of the data. This information was stored on the computer hard drive for future analysis.

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 sprint 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 sprint 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. Also, at 20 mph, the dorsiflexion moment decreased more quickly during stance as 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.

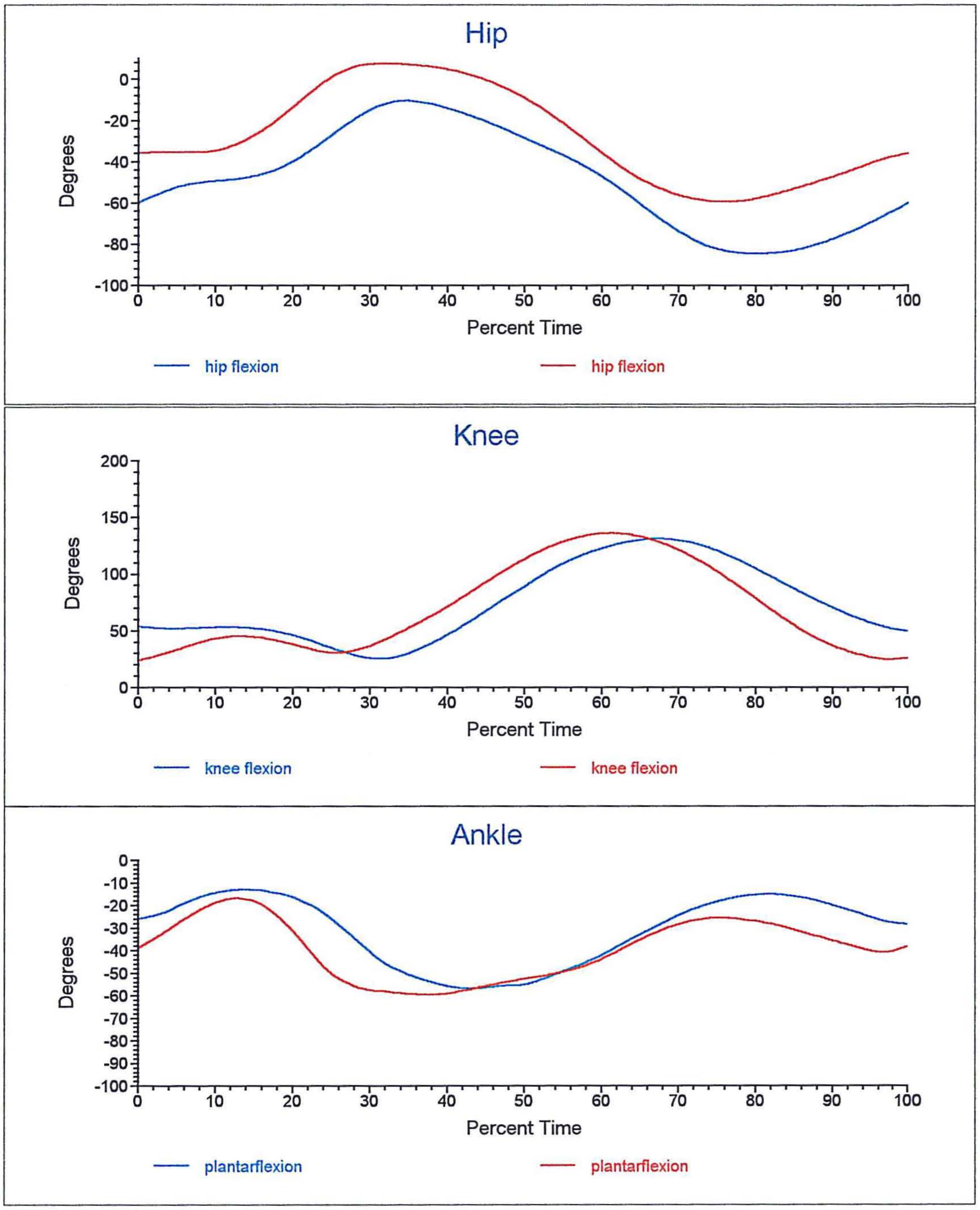


Figure 2. Ensemble averaged curves for range of motion. Red line is sprinting at 20 mph and 0%. Blue line is sprinting at 13 mph and 30%.

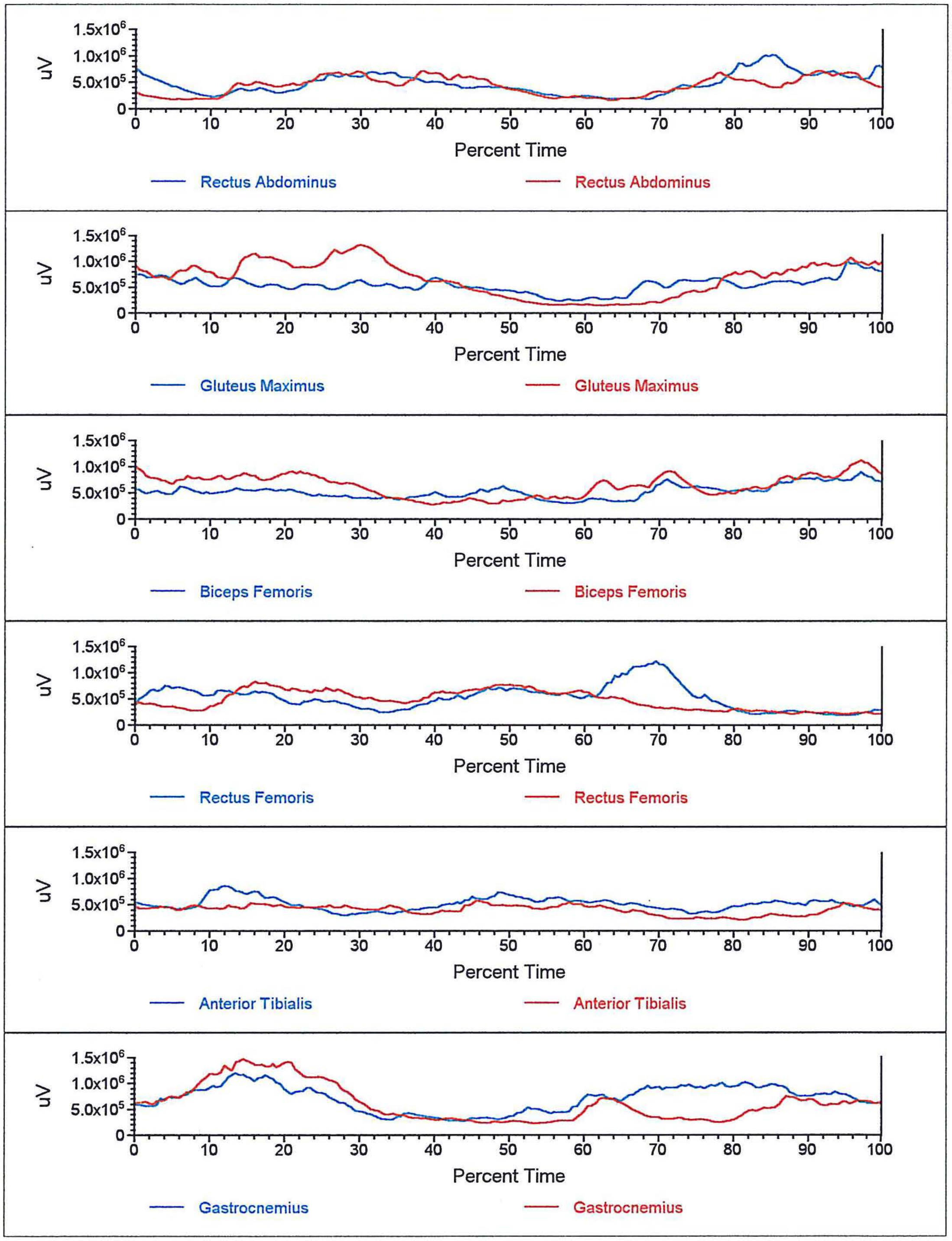


Figure 3. Averaged EMG activity for 13 and 20 mph. Thirteen mph is shown in blue and 20 mph is shown in red.

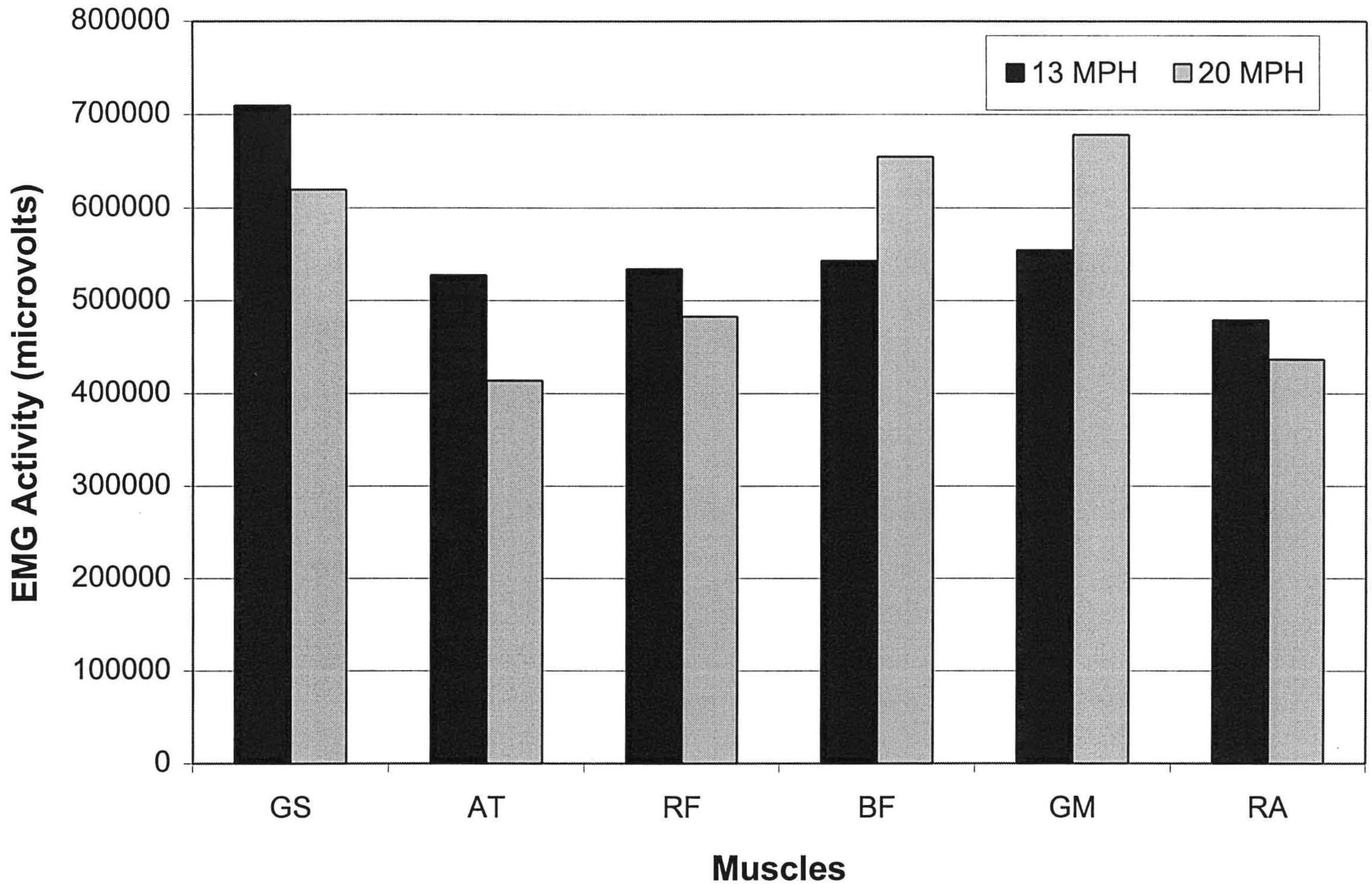


Figure 4. EMG activity during sprinting.

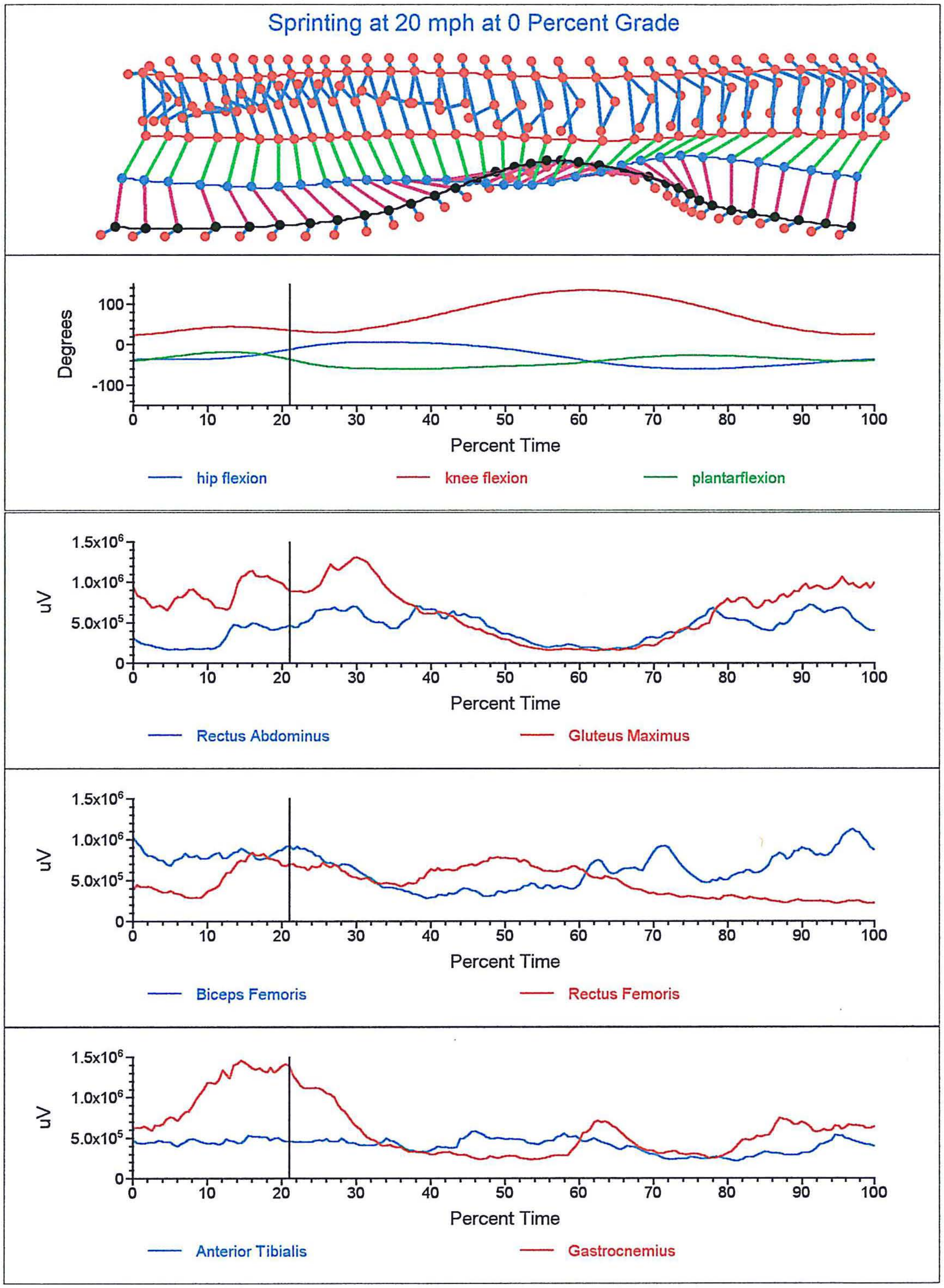


Figure 5. Ensemble averaged kinematic and electromyographic data for all subjects sprinting at 20 mph and 0% grade. The vertical line represents toe off.

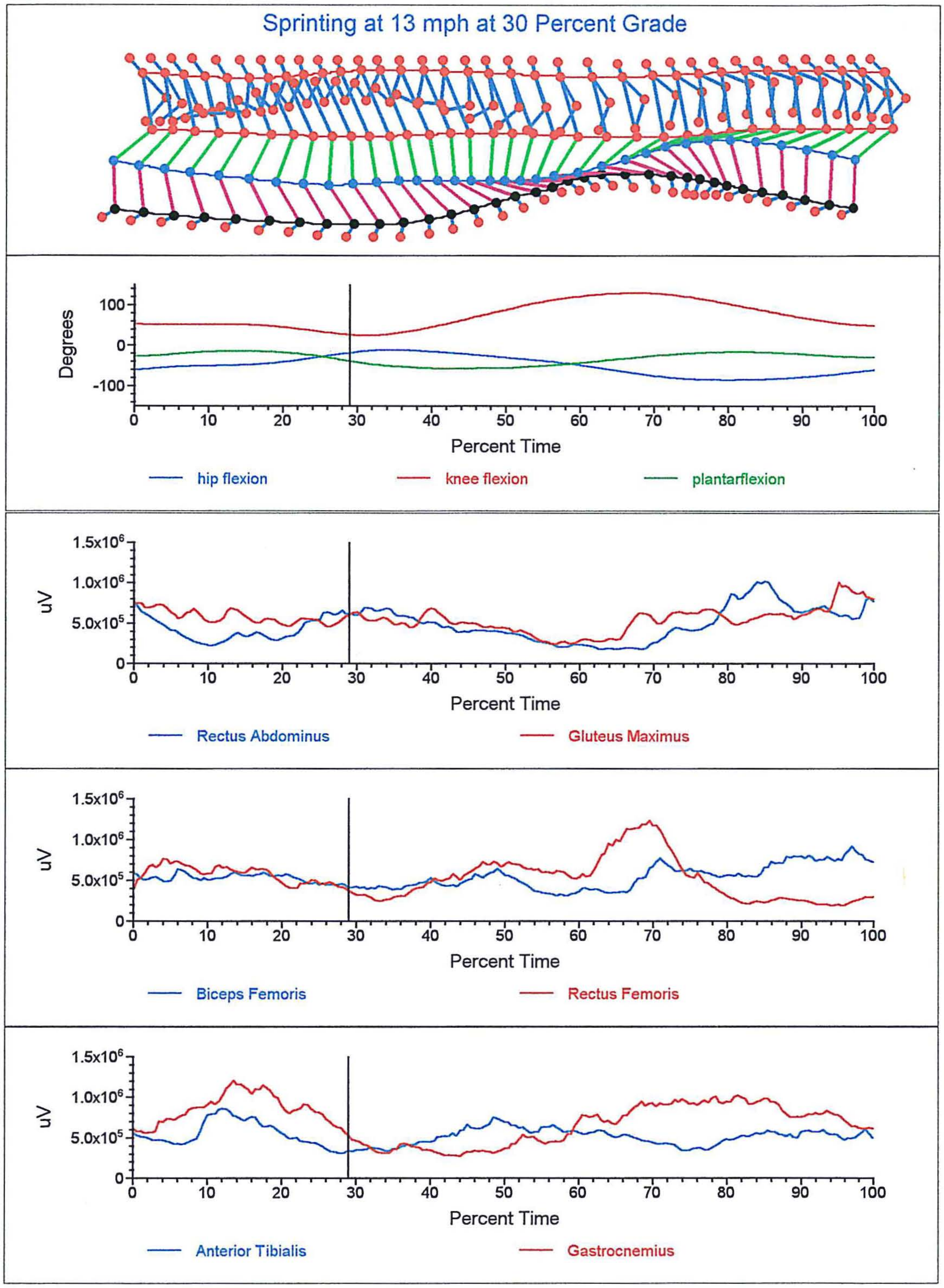


Figure 6. Ensemble averaged kinematic and electromyographic data for all subjects sprinting at 13 mph and 30% grade. The vertical line represents toe off.

Table 3. Muscle Activation Patterns.

	Sprinting at 20 mph and 0% grade			Sprinting at 13 mph and 30% grade		
	Maximal Activation	Moderate Activation	Minimal Activation	Maximal Activation	Moderate Activation	Minimal Activation
Gastrocnemius	10-29%	0-10% 29-34% 63-69% 86-100%	34-63% 69-86%	10-26% 69-89%	0-10% 26-33% 53-69% 89-100%	33-53%
Anterior Tibialis	0-66% 94-100%	66-94%		11-22% 46-55%	0-11% 22-46% 55-100%	
Rectus Femoris	15-31% 41-63%	0-15% 31-41% 63-79%	79-100%	66-74%	0-30% 41-66% 74-80%	30-41% 80-100%
Biceps Femoris	0-27% 88-100%	27-38% 54-88%	38-54%	71-77% 86-100%	0-71% 77-86%	
Gluteus Maximus	16-37% 91-100%	0-16% 37-48% 79-91%	48-79%	0-6% 96-100%	6-56% 68-96%	56-68%
Rectus Abdominus	24-49% 78-100%	14-24% 49-55% 71-78%	0-14% 55-71%	82-90%	0-8% 23-55% 74-82% 90-100%	8-23% 55-74%

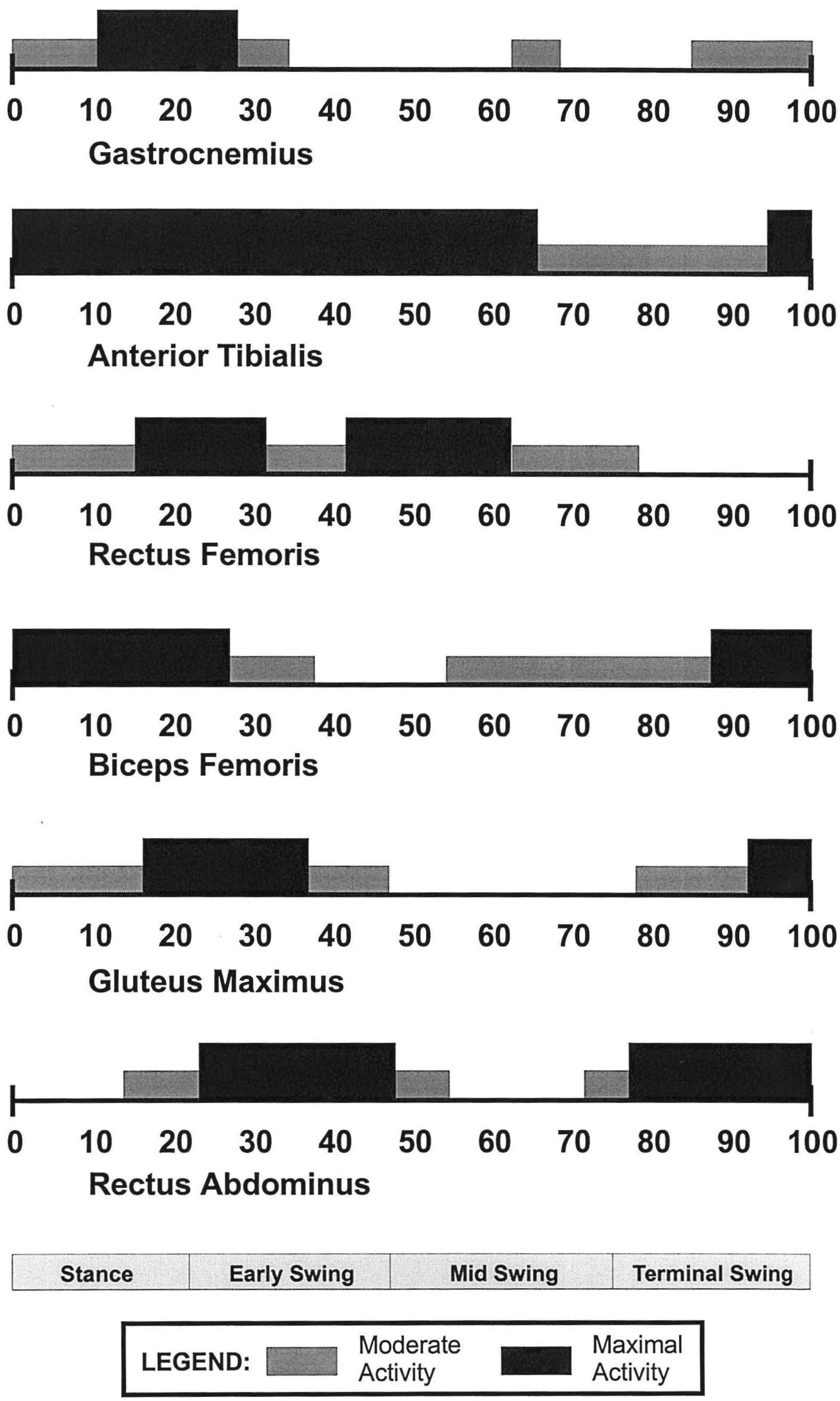


Figure 7. Muscle activation for sprinting at 20 mph and 0 percent grade.

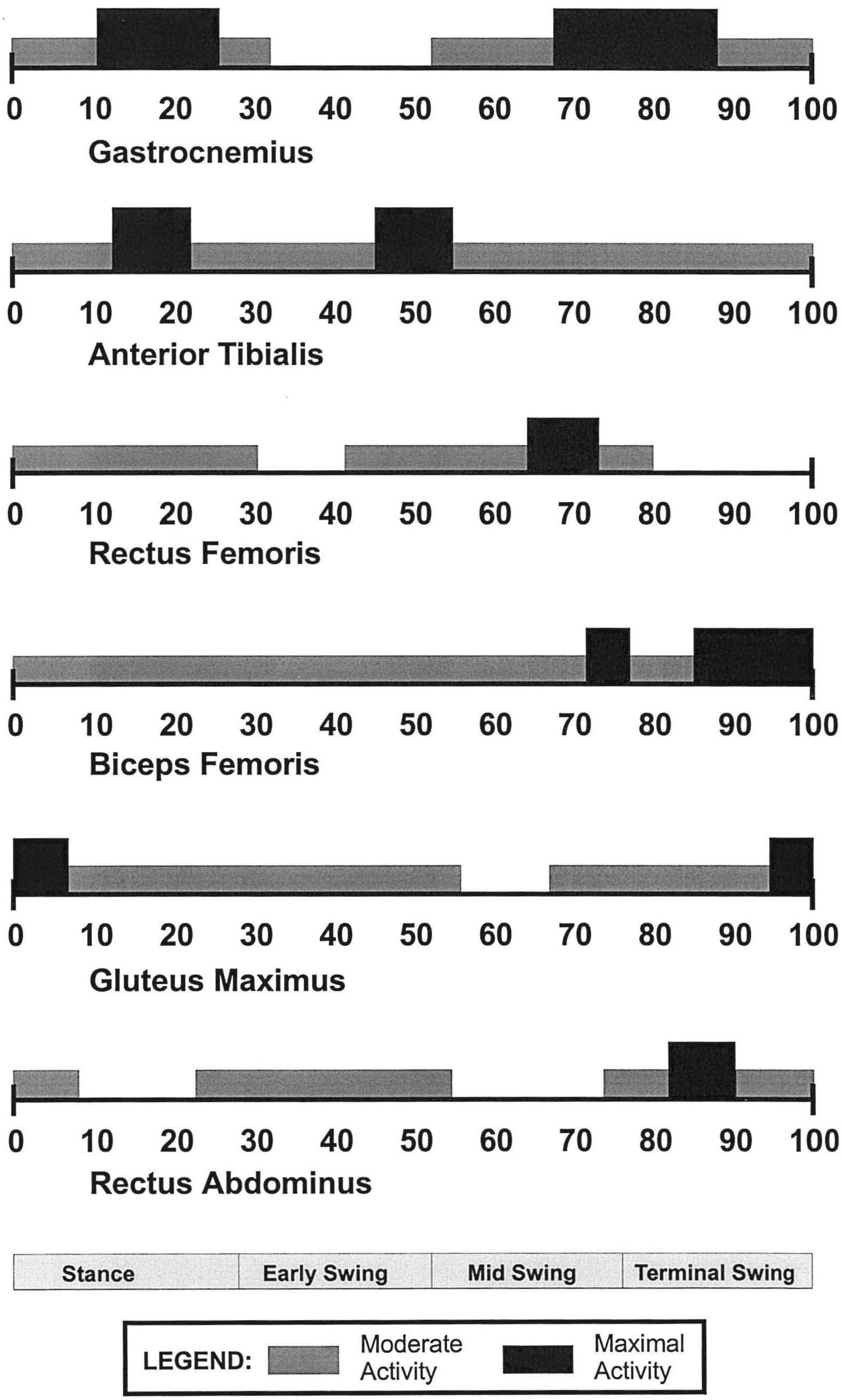


Figure 8. Muscle activation for sprinting at 13 mph and 30 percent grade.

CHAPTER 5

DISCUSSION

Kinematics

The hip showed 12° more ROM during the 13 mph incline trial than in the 20 mph level trial. During the 20 mph trial there was 66° of excursion compared to 74° during the 13 mph trial. Another similar study done by Owens,[11] found 52° of excursion at 20 mph at 0% incline and 75° of excursion at 13 mph and 30% incline. We hypothesized that the increase in hip ROM functions to allow the lower extremity to clear the incline of the treadmill.

Conversely, knee ROM was 6° greater during the 20 mph trial than the 13 mph trial. We found 112° of excursion during the 20 mph trial, whereas there was 106° of excursion during the 13 mph trial. Owens,[11] found there to be 100° of excursion during both trials. Generally, at higher speeds, a shorter lower extremity lever arm is required to decrease the arc of motion. This may explain the greater knee flexion seen at 20 mph.

Our study found ROM at the ankle to remain fairly consistent. At 20 mph there was 43° of excursion and at 13 mph there was 44° of excursion. Owens found more variation between the two trials. At 20 mph, she found 34° of excursion and 41° of excursion at 13 mph.

Our results of hip and knee ROM during level-surface sprinting are supported by those of Mann et al.[1] Although their measurements of ROM differ from ours, the amount of excursion is very similar. They found the hip to have an excursion of 65° and the knee to have an excursion of 110° whereas, our findings were 66° and 112°, respectively. Range of excursion at the ankle differed between our study and theirs. They found excursion to be 27° whereas, we found it to be 43°. The difference may be due to sprinter individuality. Each sprinter will vary in his level of training, technique of sprinting, efficacy, and body build. The differences found between our study and the one conducted by Owens may also be due to the individuality of the sprinters as stated above.

EMG

In general, all the muscles except the biceps femoris and gluteus maximus showed more overall average activity at 13 mph and 30% incline grade. In this study, it appears that both speed and incline have an impact on EMG activity depending on the muscle.

Although the gastrocnemius had greater overall activity during incline sprinting, its greatest amplitude of activity was during stance of the 20 mph trial. This is in disagreement with Swanson et al,[6] who found the gastrocnemius to have significantly greater EMG activity during the stance phase of incline sprinting. The difference could relate back to sprinter individuality. Our subjects may have used the gastrocnemius during push-off for power generation when sprinting on a level surface and the hip flexors for power generation during incline sprinting. This theory is supported by Johagen et al,[3] who found the gastrocnemius to have continual activity during the stance phase with a peak that correlates to push-off.

During the 20 mph trial, maximal activity of the anterior tibialis was seen from the end of terminal swing, through stance, into the first half of mid swing. Most of the activity is eccentric, controlling the plantarflexion moments and acting as a stabilizer for the ankle. Johagen et al,[3] also found a peak in activity at the end of terminal swing, functioning as an agonist to the gastrocnemius and preparing the lower extremity for initial contact. Activity changed to concentric during mid-swing in order to dorsiflex the ankle and clear the foot over the treadmill. Two periods of maximal activation were seen during the 13 mph incline trial. First, an eccentric contraction was seen at the end of stance acting to stabilize the ankle and control movement into plantarflexion. The second period of maximal activation happened at the beginning of mid-swing with a concentric contraction to dorsiflex the ankle in order to clear the foot.

The rectus femoris displayed two periods of maximal activation during the 20 mph trial. From late stance to early swing the muscle contracted eccentrically to control the hip as it moved into extension and the knee as it moved into flexion. The second period of maximal activity happened early in mid-swing. At this time, the rectus contracted concentrically to begin flexing the hip and extending the knee. These findings are in agreement with those of Jonhagen et al[3], but in disagreement with Mann et al,[2] who found only one period of maximal activity during stance. During the incline trial at 13 mph there was a burst of maximal concentric activity acting to flex the hip. This burst of activity was much higher in amplitude compared to mid-swing activity at 20 mph. This is because the hip must flex to a much greater degree in order to clear the lower extremity from the treadmill.

The biceps femoris showed both eccentric and concentric periods of maximal activity during the 20 mph trial. In stance, the muscle contracted eccentrically in order to control knee extension. Toward the end of stance into early swing, the contraction changed to concentric. This concentric contraction extended the hip and flexed the knee as the lower extremity began its swing phase. During terminal swing, the contraction changed to eccentric once more acting to decelerate extension of the knee and flexion of the hip. Our findings are supported by Johagen et al,[3] who found the hamstring muscles to become active just before maximum hip flexion and just after knee extension, restraining the hip joint in terminal flexion then helping to modulate rapid extension of the knee. During the 13 mph trial, one period of eccentric maximal activity was observed during terminal swing. This eccentric contraction functioned to slow knee extension and hip flexion.

During the 20 mph trial, the gluteus maximus contracted concentrically from the end of stance to early swing, extending the hip. At terminal swing, the contraction changed to eccentric in order to control hip flexion and decelerate the thigh as it moved forward. Similar eccentric activity is seen during the 13 mph trial. An eccentric contraction began at the end of terminal swing and lasted into early swing. This contraction also served to decelerate the thigh as it moved forward. Mann et al,[2] also found the gluteus maximus to function eccentrically to decelerate the swinging thigh just before initial contact and concentrically, beginning in stance, to extend the hip.

Two periods of maximal activation were seen in the rectus abdominus during the 20 mph level trial. First, concentric activity was seen during early swing, functioning to limit anterior pelvic tilt occurring with hip flexion. Mann et al,[2] found this muscle to be consistently active during terminal stance and early swing, but did not state whether the contractions were concentric or eccentric. During the 13 mph incline trial, a concentric contraction occurred during terminal swing in order to pull the pelvis posteriorly with hip flexion. The amplitude of this maximal contraction was greater than what was seen during the 20 mph trial. This is because of the greater hip flexion that is seen when running on an incline.

Limitations of Study

The limitations of our study were related to the training of the sprinters, intra-researcher reliability, and sample size. First, some of the sprinters were in a more trained state than others and were more accustomed to the treadmill and the training protocol. This may have lead to different muscle activation patterns between sprinters. Next, electrode placements were done by more than one researcher so, placement may not have been consistent between the sprinters. Also, due to the small sample size, deviation of EMG activity in any one subject could cause a much larger change in the overall average than what would be seen with a larger sample. Finally, a baseline of EMG activity during walking was not collected which limited the amount of quantitative data.

Conclusion

This study showed that there is greater motion at the knee when sprinting at 20 mph on a level surface and greater motion at the hip when sprinting at 13 mph on an incline surface of 30% grade. EMG activity was greater in the gastrocnemius, anterior tibialis, rectus femoris, and rectus abdominus at 13 mph and 30% incline and at 20 mph, activity was greater in the biceps femoris and gluteus maximus. The largest difference in muscle activity levels between the two speeds was seen in the gluteus maximus and the least was in the rectus abdominus

Clinical Implications

Different protocols have been used for training in order to enhance sprinting performance. Our study shows that incline training may be useful to increase hip ROM and to increase EMG activity of the gastrocnemius, anterior tibialis, rectus femoris, and rectus abdominus. Level surface sprinting may also be useful for increasing ROM at the knee and EMG activity of the biceps femoris and gluteus maximus.

APPENDIX

REPORT OF ACTION: EXEMPT/EXPEDITED REVIEW
University of North Dakota Institutional Review Board

DATE: September 16, 1998 **PROJECT NUMBER:** IRB-9706-285

NAME: Thomas Mohr, Carrie Anderson, Samantha Gould, 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

Richard Ferraro 9-17-98

Signature of Designated IRB Member
UND's Institutional Review Board

Date

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)

_X_ EXPEDITED REVIEW REQUESTED UNDER ITEM _3_ (NUMBER[S]) OF HHS REGULATIONS
___ EXEMPT REVIEW REQUESTED UNDER ITEM ____ (NUMBER[S]) OF HHS REGULATIONS

UNIVERSITY OF NORTH DAKOTA HUMAN SUBJECTS REVIEW FORM FOR NEW PROJECTS OR PROCEDURAL REVISIONS TO APPROVED PROJECTS INVOLVING HUMAN SUBJECTS

PRINCIPAL INVESTIGATOR: Thomas Mohr, Carrie Anderson, Samantha Gould, Anna Hillig, Teri Parker **TELEPHONE:** 777-2813 **DATE:** 4/15/98

ADDRESS TO WHICH NOTICE OF APPROVAL SHOULD BE SENT: PO Box 9037, Dept. Of Physical Therapy, UND

SCHOOL/COLLEGE: Medicine & Health Sciences **DEPARTMENT:** Physical Therapy **PROPOSED PROJECT DATES:** 5/1/98 to 5/1/99 (Month/Day/Year)

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

FUNDING AGENCIES (IF APPLICABLE): None

TYPE OF PROJECT (Check ALL that apply):

___ NEW PROJECT _X_ CONTINUATION ___ RENEWAL ___ DISSERTATION OR THESIS RESEARCH _X_ STUDENT RESEARCH PROJECT

___ CHANGE IN PROCEDURE FOR A PREVIOUSLY APPROVED PROJECT

DISSERTATION/THESIS ADVISER, OR STUDENT ADVISER: Thomas Mohr, PT, Phd

PROPOSED PROJECT: ___ INVOLVES NEW DRUGS (IND) ___ INVOLVES NON-APPROVED USE OF DRUG _X_ INVOLVES A COOPERATING INSTITUTION

IF ANY OF YOUR SUBJECTS FALL IN ANY OF THE FOLLOWING CLASSIFICATIONS, PLEASE INDICATE THE CLASSIFICATION(S):

___ MINORS (<18 YEARS) ___ PREGNANT WOMEN ___ MENTALLY DISABLED ___ FETUSES ___ MENTALLY RETARDED

___ PRISONERS ___ ABORTUSES ___ UND STUDENTS (>18 YEARS)

IF YOUR PROJECT INVOLVES ANY HUMAN TISSUE, BODY FLUIDS, PATHOLOGICAL SPECIMENS, DONATED ORGANS, FETAL MATERIAL, OR PLACENTAL MATERIALS, CHECK HERE ____

IF YOUR PROJECT HAS BEEN\WILL BE SUBMITTED TO ANOTHER INSTITUTIONAL REVIEW BOARD(S),PLEASE LIST NAME OF BOARD(S): Red River Sports Medicine, Fargo, ND

Status: ____ Submitted; Date 6/11/97 Approved; Date 6/12/97 Pending____

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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 electromygraphic (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 psycho-logical, 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:

Thomas Mohr, Carrie Anderson, Anna Hellig, Jami Gould, Kelli Parker — 4/9/98

Principal Investigator — Date

____________________ — ________

Project Director or Student Adviser — Date

____________________ — ________

Training or Center Grant Director — Date

(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 be 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

UNIVERSITY OF UND NORTH DAKOTA

SCHOOL OF MEDICINE & HEALTH SCIENCES
DEPARTMENT OF PHYSICAL THERAPY
501 NORTH COLUMBIA ROAD
P.O. BOX 9037
GRAND FORKS, NORTH DAKOTA 58202-9037
(701) 777-2831
FAX (701) 777-4199

MEMO

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.

ACCELERATION PRODUCTS, INC.

2301 25th Street South, Suite E, Fargo, North Dakota 58103
(701) 241-9018 Fax: (701) 232-0119 E-mail: accelr8@corpcomm.net

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/jlh

Red River Valley
Sports Medicine Institute

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

2301 25th Street South • Suite C
Fargo, North Dakota 58103
Tel 701-280-2406
Fax 701-237-0922

REFERENCES

1. Nelson RC, Osterhoudt RG. Effects of Altered Speed and Slope on the Biomechanics of Running. *Medicine and Sport.* 1971;6:220-224

2. Mann RA, Moran GT, Dougherty SE. Comparative Electromyography of the Lower Extremity in Jogging, Running, and Sprinting. *Am J Sports Med.* 1986;14:501-509.

3. Jonhagen S, Ericson MO, Nemeth G, Eriksson E. Amplitude and timing of Electromyographic Activity during Sprinting. *Scan J Med and Sci in Sports.* 1996;6:15-21.

4. Novacheck TF. The Biomechanics of Running. *Gait and Posture.* 1998;7:77-95.

5. Swanson SC, Frappier JP, Caldwell GE. Muscular Coordination During Incline Sprint Training. Unpublished Data.

6. 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.

7. Swanson SC, Frappier JP, Caldwell GE. A Biomechanical Assessment of the Effectiveness of the Sprintcord Training Device. Unpublished Data.

8. Chapman AE, Caldwell GE. Kinetic Limitations of Maximal Sprinting Speeds. *J Biomech.* 1983;16:78-83.

9. Delecluse C. Influence of Strength training on Sprint Running Performance. *Sports Med.* 1997;24:147-155.

10. Zipp P, Recommendations for the Standardization of Lead Position in Surface Electromyography. *Eur J Appl Physiol.* 1982;50:41-54.

11. Owens S. An electromyographic and video motion analysis study of elite sprinters at varying speeds and inclines. Unpublished Data. May 1998.