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An electromyographic and video motion analysis study of sprinters at varying speeds and inclines

Marc Sondreal
University of North Dakota

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

by

Marc Peter Sondreal
Bachelor of Science in Physical Therapy
University of North Dakota, 1999

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
2000
This Independent Study, submitted by Marc Peter Sondreal 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 Sprinters at Varying Speeds and Inclines

Department Physical Therapy

Degree Master of Physical Therapy

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Date 12/15/99
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ABSTRACT

Athletes desire to succeed in their respective sport. Several training programs claim to enhance athletic performance by loading specific muscles and joints needed for increased speed, power, and strength in a sport specific manner. One such training regimen is the Frappier Acceleration® program, in which the core element involves sprinting on a treadmill at varying 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.

Eleven males between the ages of eighteen and twenty-two years of age ran on a treadmill at five different conditions at varying speeds and inclines. One of these trials consisted of the subject walking at 2.4 mph and a 0 percent grade in order to obtain a baseline for comparison of the other four trials. Surface electrodes and joint markers were used to analyze electromyographic activity of eight muscles and calculate joint angles while running. A descriptive analysis was then performed comparing the five trials.

From our results we conclude that the sprinter does adopt different strategies and muscle recruitment patterns to compensate for increases in slope. There is an increase in EMG activity in the Vastus Lateralis, Rectus Femoris, Gluteus Maximus, and Tibialis Anterior when running at 8 mph and 25 percent grade when compared to the level condition, and an increase in the EMG activity of all recorded muscles when running at 13 mph and 25 percent grade vs. level running. Examination of range of motion revealed
that there was greater overall motion of the hip on the incline trials while displacements of the knee and ankle were relatively similar.
CHAPTER 1

INTRODUCTION

Many athletes desire to succeed in their respective sport. The increasing technology of human performance enhancement has given athletes an outlet to become bigger, faster, and stronger than conventional methods of training. These athletes yearn for ways to optimize their potential above their competitors. Several programs claim to enhance athletic performance by loading of the specific muscles and joints needed for increased speed, power, and strength within a sport specific manner. One such training regimen is the Frappier Acceleration® program, in which the core element involves sprinting on a treadmill at varying speeds and inclines.

Problem Statement

The problem lies in the limited amount of research available to attest to the efficacy of this training technique. Further research is needed to validate the use of this training method in order to endorse its use in training athletes. Although research regarding treadmill training is available, there is a need to evaluate whether differences, if any, exist between level treadmill running and incline treadmill running at speeds above 8mph.

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 level treadmill, and on an
incline causes particular muscles to work harder or the sprinter to change their running technique to accommodate the workload of the varying conditions.

Significance of Study

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

Research Questions

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

Hypothesis

Null: Muscles recruited and joint kinematics do not change while running on an incline compared to level treadmill running.

Alternate: Muscle recruitment and joint angles change with increased speed and incline.
CHAPTER 2
LITERATURE REVIEW

Kinematics of Sprinting

The biomechanics of running have been well documented. These studies have helped provide information necessary to understand the mechanisms of the neuromusculoskeletal system, recognize efficient running mechanics and establish training regimens to optimize performance for all individuals.\textsuperscript{1-4} Other aspects evaluated have been comparisons of different speed and slopes\textsuperscript{5}, training differences of overground running versus a treadmill\textsuperscript{6}, and analysis of muscle activity in sprinting\textsuperscript{7-10}. However, there have been few studies that have examined treadmill incline sprint training above a 20\% grade and over 10mph (4.5m/sec).\textsuperscript{11-13}

The gait cycle is the period from initial contact to initial contact of the same foot.\textsuperscript{3} It can be further subdivided into a stance and swing phase. The stance phase, a period when the foot is in contact with the ground, includes four components: loading response, midstance, terminal stance, preswing.\textsuperscript{3} The swing phase, a period when the foot is not in contact with the ground, includes three stages: initial swing, midswing, terminal swing.\textsuperscript{3} In a walking gait cycle, a period of double limb support occurs where both feet are in contact with the ground.\textsuperscript{2}

Running involves the same cycle as walking, only faster. Running is differentiated by a float phase in which both feet are airborne.\textsuperscript{3} The stance phase of
running can be divided into two subphases, an absorption and propulsion phase. The swing phase also has two subphases, an initial and terminal swing phase.

As running velocity increases both stride length and stride frequency increase. Although as maximum speed is reached, stride frequency undergoes the most change. When comparing Olympic sprinters, Mann and Herman found that more successful sprinters had higher stride frequencies with the decrease in the support phase being the determining factor. A study conducted by Chapman and Caldwell found the major limitation in increasing sprint speed is the inability to elevate the peak eccentric muscle contraction at the knee prior to initial contact. This suggests that quick leg recovery in sprinting is essential to increasing speed.

**Muscle Activity During Sprinting**

There have been several studies published examining the lower extremity during sprinting. These have included electromyographic (EMG) activity, joint kinematics, and differences in running grade. Numerous muscles are active throughout the sprint cycle. With an increase in running speed, there is an increase in muscle activity and joint range of motion for selected muscles.

The rectus abdominus (RA) is most active during toe-off to initial contact. This occurs during hip flexion as the RA appears to act as a stabilizer for the forward and backward pelvic movement during sprinting. With incline treadmill running, there is a greater amplitude of activity compared to that of a level running surface.

The tibialis anterior (TA) shows a two-peak activation. The maximal activity occurs at the beginning of swing as the foot begins to dorsiflex. The second activation occurs just prior to footstrike while the acting as an antagonist to the gastrocnemius (GA)
muscles. There is a two-peak activation with incline running as well, however maximal activity occurs prior to initial contact rather than after toe-off with level running.12

The GA activity begins just prior to initial contact and continues until maximum activity at toe-off. The activity just prior to initial contact is most likely to prevent a dorsiflexion moment at the ankle joint. Incline running shows maximal activity of the GA muscle during the middle of stance rather than continuing until toe-off.11,12 This corroborates with Mann et al, as he states there is little or no activity at toe-off. The decreased response at toe-off may be a result of rapid hip flexion of the swing limb in order to propel the body forward.

The gluteus maximus (GM) shows a peak activity at the end of terminal swing.10 It functions to decelerate the swinging limb just prior to initial contact. Its second activation occurs at the end of stance into early swing acting concentrically for hip extension. These findings corroborate well with incline sprinting conditions11-13

The medial and lateral hamstring (HS) muscle activity is similar to that of the GM. The HS is most active from mid to terminal swing lasting into the stance phase.17 There is minor activity at midswing resulting in increased knee flexion needed for hip clearance. At terminal swing, the HS acts eccentrically to control hip flexion and the rapid knee extension that occurs prior to initial contact. The HS then concentrically contracts during stance contributing to hip extension.7,11,12 With incline running, the timing for the biceps femoris muscle activity is consistent with level conditions.11,12 However, Owens found more activity on the incline trial suggesting more force is needed to extend the hip in order to propel the body up the incline.
Studies show that the HS contributes most at the highest levels of speed. Because of the forceful knee extension and hip flexion, a large percentage of HS strains occur between terminal swing and stance phase. Research shows the bicep femoris is the most prone to injury at this point because of its orientation and because it has the shortest muscle length of the HS muscle group.

The rectus femoris (RF) has a two-peak activity with the first occurring during the support phase. At this point, the RF works eccentrically to control hip extension and knee flexion. The second peak is found during the swing phase. During swing, the muscle concentrically contracts to flex the thigh forward while not being very active extending the lower leg prior to initial contact. Therefore, the RF seems to be a more important hip flexor than knee extensor. With incline running, the RF maximal activity occurs during midswing. However, it is interesting to note that Swanson found the RF becomes active after initiation of hip flexion and peaks after concentric hip flexion power occurs, suggesting that hip flexion is assisted by the mono-articular hip flexors. The data supports research by Piazza and Delps that the primary function of the RF is to control the amount of knee flexion during swing not hip flexion.

High Velocity Treadmill Training

In supramaximal speed training or overspeed training, the individual is able to run at speeds faster than he is physically able by artificial means. Studies show that the supramaximal method could be an advantageous training tool for sprint training by adapting human neuromuscular performance during training. One way to achieve this phenomenon is high velocity treadmill training.
The Frappier Acceleration® program utilizes treadmills with an incline capability of a 40% grade and a top speed of 28mph (12.5m/sec). Upon completion of this program, results from the clinic show an average drop in 40yd dash time by 0.2sec with an average increase of two to four inches in vertical jump. The training protocols incorporated are designed to enhance muscular loading at the hip, knee, and ankle during sprinting. Studies show that these muscle groups are primarily responsible for propulsion in sprinting. Therefore, research analyzing joint kinematics and EMG above a 20% grade and over 10mph (4.5m/sec) would be helpful in understanding changes in the musculoskeletal system while gaining insight into the effectiveness of the Frappier Acceleration® program.
CHAPTER 3
METHODS

Subjects

Twelve, healthy males gave their informed written consent to serve as subjects in this study (See Table 1). Two subjects were eliminated from this study due to faulty electrodes and irregular EMG data. 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>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Range</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>19.1 (years)</td>
<td>18-22</td>
<td>1.60</td>
</tr>
<tr>
<td>Height</td>
<td>70.6 (inches)</td>
<td>69-74</td>
<td>1.87</td>
</tr>
<tr>
<td>Weight</td>
<td>164.2 (pounds)</td>
<td>150-195</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 transmitted 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 placed in the subject's shoe. Another switch composed of three piezo-resistive sensors was mounted under the bed of the treadmill and allowed the investigators an additional means to identify when initial contact was occurring. Upon contact of the left foot with the treadmill, an LED light was illuminated in the video image via the footswitch, and a small lamp was activated via the treadmill switch. A switch controlled by the investigator allowed the footswitch circuit to be closed only during the EMG collection period.

**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 videocassette recorder (JVC of America, 41 Slater Drive, Elmoood Park, MF 07407). The videotape 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) videocassette recorder for the purpose of digitization.
Electrode and Marker Placement

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 eight (8) 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).

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 electrode was placed on the iliac crest.

The electromyographic signals from the electrodes were input directly to a receiver, which then transmitted 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 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 illuminated during the trials and captured on tape. The marker locations were digitized to allow the sagittal motion of the neck, trunk, arm, forearm, thigh, leg and foot to be analyzed.
Table 2. Origin, Insertion, and Action of Selected muscles for Sprinting.

<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</td>
<td>Xiphoid process</td>
<td>Flex trunk</td>
</tr>
<tr>
<td></td>
<td>Pubic Crest</td>
<td>5th to 7th Intercostal cartilage</td>
<td>Stabilize pelvis during walking</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>Posterior Crest of Ilium</td>
<td>Iliotibial Tract</td>
<td>Extend thigh</td>
</tr>
<tr>
<td></td>
<td>Sacrotuberous ligament</td>
<td>Gluteal Tuberosity</td>
<td>Laterally rotate thigh</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extend trunk</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>Anterior Inferior Iliac Spine</td>
<td>Base of the Patella</td>
<td>Extend leg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tibial Tuberosity</td>
<td>Flex thigh</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>Ischial Tuberosity</td>
<td>Head of Fibula</td>
<td>Flex knee</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extend thigh</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extend trunk</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>Condyles of Femur</td>
<td>Calcaneal Tuberosity</td>
<td>Plantarflexion</td>
</tr>
<tr>
<td>Anterios Tibialis</td>
<td>Upper ½ lateral surface of tibia Tendon</td>
<td>1st Metatarsal</td>
<td>Dorsiflexion</td>
</tr>
<tr>
<td></td>
<td>Interosseus membrane</td>
<td>1st Cuneiform</td>
<td>Inversion</td>
</tr>
<tr>
<td>Vastus Medialis</td>
<td>Medial lip of linea aspera</td>
<td>Medial surface, top of patella</td>
<td>Extends knee (leg)</td>
</tr>
<tr>
<td></td>
<td>Intertrochanteric line</td>
<td>Tibial tuberosity</td>
<td></td>
</tr>
<tr>
<td>Erector Spinae</td>
<td>Posterior iliac crest and sacrum</td>
<td>Fibers run superiorly to angles of lower ribs</td>
<td>Maintain posture</td>
</tr>
<tr>
<td></td>
<td>Sacral and inferior lumbar spinous processes, and supraspinous</td>
<td>cervical transverse processes</td>
<td>Extend trunk, bilaterally</td>
</tr>
<tr>
<td></td>
<td>ligament</td>
<td></td>
<td>Rotates trunk, unilaterally</td>
</tr>
</tbody>
</table>
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
Semitendinosus - midpoint of a line from the ischial tuberosity to the medial femoral condyle
Rectus Femoris - midpoint of a line from the ASIS to superior pole of patella (minimum of 10 cm above the patella)
Vastus Lateralis - along a line ¼ the distance from the lateral knee joint line to the ASIS and over the belly of the vastus lateralis
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.
Protocol

Conditions

Table 3. Description of Protocol Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Speed</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition 1</td>
<td>Walking at 2.4 mph</td>
<td>0% grade</td>
</tr>
<tr>
<td>Condition 2</td>
<td>8 mph</td>
<td>25% grade</td>
</tr>
<tr>
<td>Condition 3</td>
<td>PSF of 8 mph/25% grade</td>
<td>0% grade</td>
</tr>
<tr>
<td>Condition 4</td>
<td>13 mph</td>
<td>25% grade</td>
</tr>
<tr>
<td>Condition 5</td>
<td>PSF of 13 mph/25% grade</td>
<td>0% grade</td>
</tr>
</tbody>
</table>

Calculation of Preferred Stride Frequency

Subjects were allowed to warm-up on the treadmill for 1-2 minutes prior to beginning their trials. Following the completion of the warm-up, the subjects were required to perform 3-4 bouts of exercise on the treadmill at the same speed and incline of condition 2 (8 mph and +25% grade). During each exercise bout, the investigator recorded with a stopwatch the time it took the subject to complete five complete stride cycles. The subjects were allowed to take as much rest as needed between each of the bouts of exercise. The investigator then ran the subject on a 0% grade for condition 3 at a speed that would allow the same preferred stride frequency (PSF) as in condition 2. For condition 3, the investigator timed how long it took the subject to complete five complete stride cycles. The speed for condition 3 at 0% grade was adjusted up or down until the time it took to complete 5 stride cycles for condition 3 was within .2 seconds of the time it took the subject to complete 5 stride cycles for condition 2. Once this was established,
the speed was recorded as the speed that would be utilized for condition 3 in the trials. The subjects then ran 3-4 five second bouts of exercise on the treadmill at the same speed and incline of condition 4 (13 mph and +25% grade) in order to determine the PSF estimation used to dictate the speed that was used in condition 5 on a 0% grade using the same procedure.

**Trials**

After successful completion of the pre-testing bouts of exercise, each subject completed a total of 5 trials of EMG and kinematic data in only one trial of each condition (C1, C2, C3, C4, C5). Each trial consisted of a six-second bout of exercise on the treadmill. Kinematic and EMG data were collected throughout the trial. The subjects were allowed to take as much rest as needed between trials to minimize any effect of fatigue. Walking was the first trial recorded for all subjects. The four running conditions were performed in a random order determined by blindly drawing out of a hat.

**Data Analysis**

Prior to videotaping, the camera field was calibrated by videotaping a meter stick. The video footage for each sprinting trial was cropped down to five completed strides 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 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 data was transferred into the Microsoft Excel program to determine the percent change from walking of each muscle from the ensemble averages of each sprinting condition.

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

For each psf/0% grade condition, the speed of the treadmill is increased in an effort to replicate stride frequency of the incline conditions. In Condition 3, the speeds range from 12mph to 13.5mph. In Condition 5, the speeds range from 17mph to 18.5mph. Also, two subjects are eliminated from this study due to faulty electrodes and poor recording of EMG activity. Therefore, nine subjects are used to evaluate EMG and motion analysis.

13psf/0% grade (Condition 5) vs. 8psf/0% grade (Condition 3)

Figure 3 shows the ensemble average curves for hip, knee, and ankle ROM during these two conditions. At the hip joint, Condition 5 has greater total ROM than Condition 3. Differences in total knee and ankle ROM are smaller. At the ankle, Condition 5 elicits the highest degree of plantarflexion peak whereas Condition 3 causes the greatest dorsiflexion.

Figure 4 and 5 show the ensemble average curves for EMG activity of the eight muscles selected. Condition 5 exhibits a higher EMG activity total for all muscles selected compared to Condition 3. In Figure 2, the four muscles showing the largest difference in percent change from walking are RF (340%), RA (288%), VL (221%), GM (219%). The muscle showing the least difference is the GA (91%).

13mph/25% grade (Condition 4) vs. 8mph/25% grade (Condition 2)
Figure 6 shows the ensemble average curves for hip, knee, ankle, ROM during these two conditions. Little difference is noted in hip and knee ROM. At the ankle, Condition 6 displays a greater degree of plantarflexion throughout the entire stride length when compared to Condition 2.

In Figure 7 and 8, the GM, GA, and VL elicit a higher peak in EMG activity during Condition 4 than in Condition 2. However, Condition 4 displays a higher average EMG activity for all muscles selected. The four muscles showing the largest difference in percent change from walking are the RF (654%), RA (522%), BF (371%), and ST (318%), as shown in Figure 2. The muscle showing the least difference is the GA (96%)

8mph/25%grade (Condition 2) vs. 8psf/0%grade (Condition 3)

Figure 9 shows the ensemble average curves for hip, knee, ankle ROM during these two conditions. At the hip, Condition 2 exhibits a greater degree of hip flexion throughout the entire stride when compared to its counterpart. Condition 3, however, attains a higher peak of ROM in both knee flexion and extension. At the ankle, Condition 2 achieves the highest peak of ROM for dorsiflexion.

Figure 10 and 11 show EMG activity for these two conditions. During Condition 2, the VL, RF, GM, GA, and TA exhibit a greater average EMG activity when compared to the level condition. During Condition 3, the RA, BF, and ST are higher in average EMG activity. The muscles that show the largest difference in percent change from walking are the VL (186%), RF (133%), and GM (121%). The muscle showing the least percent change is the TA (13%).

13mph/25%grade (Condition 4) vs. 13psf/0%grade (Condition 5)
Figure 12 shows the ensemble average curves for hip, knee, and ankle ROM during these two conditions. At the hip, Condition 4 exhibits a greater degree of hip flexion throughout the entire stride cycle when compared to Condition 5. However, the level condition elicits the highest peak in ROM for both knee flexion and extension. At the ankle, Condition 5 achieves the highest peak of ROM for dorsiflexion.

In Figure 13 and 14, Condition 5 elicits a higher peak in EMG activity for the GM, VL, BF, ST, GA, and TA when compared to this incline condition. However, Condition 4 shows higher average EMG activity for all eight muscles examined compared to the level condition. The four muscles showing the largest difference in percent change from walking are RF (447%), VL (222%), RA (152%), and GM (136%) as shown in Figure 2. The muscle showing the least is the GA (33%). In addition, Condition 4 displays the greatest average EMG activity for all the muscles tested when compared with the other conditions.
Figure 2. Average EMG activity during treadmill sprinting expressed as a percent change from treadmill walking.
Figure 3.
EMG Activity for Condition 5 vs. Condition 3

*Figure 4.*
Figure 5.
Figure 6.
Figure 7.

EMG Activity for Condition 4 vs. Condition 2

- Rectus Abdominus 13/25% (C4) vs. Rectus Abdominus 8/25% (C2)

- Gluteus Maximus 13/25% (C4) vs. Gluteus Maximus 8/25% (C2)

- Rectus Femoris 13/25% (C4) vs. Rectus Femoris 8/25% (C2)

- Vastus Lateralis 13/25% (C4) vs. Vastus Lateralis 8/25% (C2)
Figure 8.
Figure 9.
EMG Activity for Condition 2 vs. Condition 3

Figure 10.
Figure 11.
Figure 12.
Figure 13.
Figure 14.
Figure 15.
Figure 16.
Figure 17.
CHAPTER 5

DISCUSSION

Overall the results support our hypothesis, that the high speed incline conditions revealed a higher muscle activity when compared to the subjects preferred stride frequency (psf) at the level condition. This study finds that 13mph/25% grade (Condition 4) elicits more average EMG activity for all eight muscles selected when compared to the other sprinting conditions. Differences in EMG and joint kinematics are not only found when comparing incline versus level conditions. Changes in joint ROM and increases in EMG activity are dependent on the condition at which the subject was sprinting.

13psf/0%grade (Condition 5) vs. 8psf/0%grade (Condition 3)

Our results show EMG and joint ROM changes are similar to other studies during level sprinting conditions. As velocity increases, stride length and stride frequency increases. This explains why peak and average EMG are higher with Condition 5 when compared to Condition 3. Mero and Komi found that in the leg muscles, EMG activity increases with greater running speed. Condition 3 exemplifies that training at higher speeds at a constant grade increases muscle activity secondary to the increase in stride frequency. Muscles that achieved the greatest difference in percent change of walking are the RF, RA, VL, GM. According to the results of this study, these are the primary muscles needed for speed generation as the velocity is increased.

We agree with Jönhagen that with a higher speed there is greater activity in the BF and ST at initial contact as this activity carries throughout the stride cycle. This
increase in activity is related to deceleration of the leg as the hamstrings act to
eccentrically control the powerful knee extensors. Also, joint ROM at the hip, knee, and
ankle increased in Condition 5. This corroborates with Thordarson\textsuperscript{3} that the body lowers
its center of gravity with increased speed by increasing flexion of the hips and knees and
by increasing dorsiflexion at the ankle joint.

**13mph/25\% grade (Condition 4) vs. 8mph/25\% grade (Condition 2)**

Overall these two incline conditions have greater hip, knee, and ankle ROM when
compared to the level sprinting conditions. Swanson\textsuperscript{13} agreed, finding a significant
difference in ROM at the hip, knee, and ankle joint during swing phase when compared
to their level condition counterpart. Changes are seen at the hip joint where the incline
conditions 2 and 4 exhibits a greater hip flexion moment throughout the stride cycle when
compared to the level conditions 3 and 5. We suggest that the increased ROM at the hip
occurs during the incline conditions to allow adequate clearance of the limb from the
incline. This finding is consistent in research.\textsuperscript{11-13}

Condition 4 displays a greater degree of plantarflexion throughout the entire stride
compared to Condition 2. As speed increases, we feel it is necessary for the ankle to be
ready for an earlier initial contact and quicker toe off in order to propel body forward
through the gait cycle. Another reason an increase in the degree of plantarflexion will
assist speed is that it prevents the knee from fully extending. Mann, Moran, and
Dougherty\textsuperscript{7} supported this finding that the knee never fully extends throughout the
sprinting cycle inferring that the increase in knee flexion will aid in quicker leg recovery
during the swing phase.
Swanson\textsuperscript{13} found that as velocity increases so does EMG activity at the same incline. We find similar results. It is interesting to note that peak EMG is higher in the GM, VL, and GA within Condition 2. However, average EMG is higher in all muscles throughout Condition 4 showing that muscles are required to work harder to maintain position on the incline with increased speed. At Condition 4 the RA, RF, ST, and BF display the largest difference in percent change from walking.

8mph/25\% grade (Condition 2) vs. 8psf/0\% (Condition 3)

Condition 2 causes greater hip flexion and dorsiflexion while Condition 3 had increased plantarflexion and hip extension throughout the gait cycle. Again, we agree with supporting research that the incline conditions need increased hip flexion to clear foot during swing phase.\textsuperscript{11-13} Swanson\textsuperscript{13} found that the increased dorsiflexion at the incline was needed to clear the foot during swing phase. It helped prepare for quicker impact as the vertical displacement for initial contact was much less in the incline condition compared to the level condition. Knee flexion is less in Condition 2 contributing to the increase in hip flexion and dorsiflexion to compensate.

Between these two conditions, EMG show conflicting results. In Condition 3 the GM, RF, VL, show the largest increased difference in percent change from walking. However, the opposite is shown when examining the RA, BF, and ST. This finding infers that these latter muscles are working harder at level surfaces than at an incline surface with stride frequency remaining constant. This phenomenon is not found in previous studies. We postulate the speed may have been too slow for our subjects and
therefore would cause a disruption in normal, consistent cadence rhythm allowing for the possible difference in EMG activity between the two trials.

The role of the RF in sprinting is not clearly defined. In Condition 2 and 3, it appears to stabilize the extremity upon initial contact through stance and not primarily aid in hip flexion. Increased hip flexion is related to increased power generation in sprinting. Hillig and Owens found that the role of the RF appears to act primarily in hip flexion and not in stabilization of stance or knee extension. On the other hand, Swanson and Piazza found the RF primarily contracted eccentrically to control the amount of knee flexion in swing. We did not examine the role of the mono-articular hip flexors, although studies have shown the iliacus and psoas major, not the RF, appear to be the most important in bringing rapid hip flexion and therefore an increase in speed.

13mph/25% grade (Condition 4) vs. 13psf/0% grade (Condition 5)

The review of these two conditions proves to be the most important as the speed is closer to maximal effort and is more sport specific than the other conditions tested. Once again the incline trial causes greater hip flexion throughout the entire stride length to allow for swing limb clearance at the incline. Swanson found the swing phase at the incline condition was shorter in length with an increased hip flexion. He attributed this to an increase in concentric flexion power by the mono-articular hip flexors. In our study the hip flexion angle is less in Condition 5, however it compensates by achieving the highest peak in knee flexion and dorsiflexion ROM.

Swanson found large differences in EMG amplitude between incline and level surfaces with stride frequency remaining constant, again suggesting changes in muscle
loading unique to incline conditions. Our results show that Condition 4 achieved the highest difference in percent walking in the RA, RF, VL, and GM compared to Condition 5. These are among the key muscles needed for increased speed generation.\textsuperscript{11,13,19}

The activity of the RA is greatly increased in Condition 4 and 5 compared to Conditions 2 and 3 as seen by Figure 2. The activity in this muscle during sprinting increases with speed as well as incline to control anterior and posterior rotation of the pelvis in the sagittal plane.\textsuperscript{7} An increase in speed seems to be the chief predictive factor for an increase in abdominal activity coupled with an increase in sprinting grade. Similarities in BF and ST function support Swanson's\textsuperscript{13} findings. These muscles contribute more to energy generation at the hip with Condition 4, while serving more to absorb energy at the knee during Condition 5 as seen by the location of the peak EMG amplitude in Figure 14.

**Limitations**

Our study was limited in three ways. First, the foot switch used to synchronize the EMG data with motion analysis was not consistent for all subjects. Therefore event markers of initial contact and toe off needed to be marked manually in some of the trials. The second limitation was that two subjects were excluded during computation of data. One subject was eliminated secondary to poor adhesive electrodes, which caused poor recording of EMG activity. The other subject was not used because some of the leads were not connected during several of the trials. Our final limitation was the sample size and inability to run descriptive statistics. Even though we had eleven elite sprinters that successfully completed all trials, more subjects are always better for a more efficient and accurate sample size.
Clinical Implications

The incline condition generally elicited higher levels of EMG in both stance and swing phases as compared to level running at the same stride frequency. From our results, it is more beneficial to train at faster speeds with varying grades to increase muscle activity and in return to improve power and speed. This implies that incline and high speeds are both needed to achieve these results.

We agree with Swanson\textsuperscript{13} that the general pattern of EMG and joint motion is similar between incline and level running of the same stride frequency. Thus, incline running seems beneficial and sport specific for athletes to include it into a training protocol to increase muscle loading, power generation, and speed during sprinting. However, treadmill sprinting may differ from overground sprinting. Furthermore, there is a need for continued research to examine the differences and similarities that may exist between incline treadmill and overground sprinting.

Conclusion

From our results, we accept our alternate hypothesis that muscle recruitment and joint angles change with increased speed and incline. Sprinting at 13mph/25\% grade produces the greatest EMG activity in all eight muscles tested when compared to the other three sprinting conditions in Figure 2. This would imply that these muscles should be targeted for increasing speed training. Also, our results indicate that the sprinter creates greater muscle recruitment in response to the increase in grade.
REPORT OF ACTION: EXEMPT/EXPEDITED REVIEW
University of North Dakota Institutional Review Board

DATE: June 7, 1999  PROJECT NUMBER: IRB-9906-261

Thomas Mohr, Marc Sondreal, Christy Rygh, Jeremy Zimney

NAME: Department/College: Physical Therapy

PROJECT NUMBER: IRB-9906-261

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

The above referenced project was reviewed by a designated member for the University’s Institutional Review Board on June 11, 1999 and the following action was taken:

☑ Project approved. EXPEDITED REVIEW No. 4
☑ Next scheduled review is on June 2000

☑ 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: T. Mohr, Adviser

Signature of Designated IRB Member
UND’s Institutional Review Board

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)
**University of North Dakota Human Subjects Review Form**

**Principal Investigator:** Thomas Mohr, Marc Sondreal, Christy Rygh, Jeremy Zimney

**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  **Project Dates:** 5/1/99 to 5/1/00

**Project Title:** An Electromyographic and Video Motion Analysis Study of Sprinters at Varying Speeds and Inclines

**Funding Agencies (If Applicable):** None

**Type of Project (Check All That Apply):**

- [X] New Project
- [ ] Continuation
- [ ] Renewal
- [ ] Thesis Research
- [X] Student Research Project
- [ ] Change in Procedure for a Previously Approved Project

**Dissertation/Thesis Advisor, or Student Advisor:** 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
- [X] 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 [X] Approved; Date 5/6/99  __________ Pending

**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. The subjects for the study will be recruited from the present UND track team. These subjects will participate voluntarily. These subjects will be chosen due to their 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, which included treadmill running. The project will be completed at Orthopedic Associates in Fargo, ND. Prior to performing, each subject will be asked to complete a consent form. The subjects will not be compensated.

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, 6) gastrocnemius, 7) vastus medialis and 8) erector spinae. The study will be performed by Thomas Mohr, chairman of the physical therapy department and three graduate students: 1) Marc Sondreal, 2) Christy Rygh, and 3) Jeremy Zimney.

To record EMG activity, adhesive electrodes will be placed over each muscle. The precise electrode placement will be determined from standard electrode placement charts. Prior to placing the EMG electrodes, the skin over each placement site will be prepared by cleansing the skin with alcohol. 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 walk at 0% treadmill incline, and then run at approximately 8.0 and 13.0 mph with 0% and 25% grades of the treadmill incline. At each incline the athlete will walk and then run for a total of six seconds at each level in order to obtain the necessary data for analysis. A typical trial would consist of the subject walking at 0% incline for six seconds, followed by a three minute rest period. The subject would run for six seconds at one of the four speeds and grades (i.e. 8.0 mph @ 0%, 13.0 mph @ 0%, 8.0 mph @ 25%, 13.0 mph @ 25%). The subjects will be given a three minute rest period between trials. The order of the running trials will be determined by random assignment.

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 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. Since the electrodes are used for recording only, there is no risk of injury from them. There may be a slight redness following removal of the electrodes, but this will only be temporary.

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.

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, after which time they will be shredded.

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:**

- **Principal Investigator**  
  
- **Project Director or Student Adviser**

- **Training or Center Grant Director**

  
  
  
  **Date**

(Revised 3/1996)
May 6, 1999

Dr. Tom Mohr, Chairman
UND School of Medicine
P.T. Department, Box 9037
Grand Forks, ND 58202-9037

Dear Dr. Mohr,

This is to inform you that I have read the research proposal titled “An Electromyographic and Video Motion Analysis Study of Elite Sprinters at Varying Speeds and Inclines”. I support this study and look forward to working together with you and the research team. Thank you for the opportunity to participate in this study.

Sincerely,

John Frappier
President of API
May 6, 1999

Dr. Tom Mohr, Chairman
UND School of Medicine
P.T. Department, Box 9037
Grand Forks, ND 58202-9037

Dear Dr. Mohr,

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

Sincerely,

Mark A. Lundeen, MD
Medical Director RRVSMI
INFORMATION AND CONSENT FORM

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

You are being invited to participate in a study conducted by Marc Sondreal, Christy Rygh, Jeremy Zimney 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. Your participation, as a member of the UND track team constitutes the proper level of training required for this study.

You will be asked to run on the treadmill for a total of five (5) trials consisting of the following: 1) Walking on the treadmill at 3.4 mph with 0% grade, 2) Running on the treadmill at approximately 8 miles per hour with 0% grade, 3) Running on the treadmill at approximately 8 mph with 25% grade, 4) Running on the treadmill at approximately 13 mph with 0% grade, and 5) Running on the treadmill at approximately 13 mph with 25% grade. 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 at 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. 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 and markers attached, we will give you a brief training session to re-familiarize you with the treadmill. The amount of exercise you will be asked to perform will be moderate. There may be a slight redness following removal of the electrodes, but this will only be temporary.

Your name will not be used in any reports of the results of this study. The video taped data will be analyzed by a computer and the markers placed on your body will be used to construct a "stick man" like figure. Your real, photographic image will not be used in reporting of the findings of the study. After analysis, the video tapes are erased. The consent forms are kept in the physical therapy department for three years and then are shredded. 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.

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 one of the investigators.

Participant's Signature Date
REFERENCES


