2001

An Electromyographic and Motion Analysis Study of an Elliptical Trainer

Kristin Sweeney
University of North Dakota

Follow this and additional works at: https://commons.und.edu/pt-grad

Part of the Physical Therapy Commons

Recommended Citation
https://commons.und.edu/pt-grad/434

This Scholarly Project is brought to you for free and open access by the Department of Physical Therapy at UND Scholarly Commons. It has been accepted for inclusion in Physical Therapy Scholarly Projects by an authorized administrator of UND Scholarly Commons. For more information, please contact zeinebyousif@library.und.edu.
AN ELECTROMYOGRAPHIC AND MOTION ANALYSIS
STUDY OF AN ELLIPTICAL TRAINER

by

Kristin Nicole Sweeney
Bachelor of Science in Physical Therapy
University of North Dakota, 2000

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
2001
This Independent Study, submitted by Kristin Nicole Sweeney in partial fulfillment of the requirements of 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 Motion Analysis study of an Elliptical Trainer

Department Physical Therapy

Degree Master of Physical Therapy

In presenting this Independent Study Report in Partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Department of Physical Therapy shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my work or, in his absence, by the Chairperson of the department. It is understood that any copying or publication or other use of this Independent Study Report or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of North Dakota in any scholarly use which may be made of any material in my Independent Study Report.

Signature Kristin Sweeney

Date 12-08-00
# TABLE OF CONTENTS

- List of Figures ........................................................................................................ v
- List of Tables ......................................................................................................... vi
- Acknowledgements ............................................................................................... vii
- Abstract .................................................................................................................. viii
- Chapter I. Introduction ......................................................................................... 1
- Chapter II. Literature Review .............................................................................. 4
- Chapter III. Methods ............................................................................................. 11
- Chapter IV. Results ............................................................................................... 20
- Chapter V. Discussion ........................................................................................... 38
- Appendix ............................................................................................................... 41
- References ............................................................................................................. 48
LIST OF FIGURES

Figure 1. Electrode placement for lower extremity muscles .......... 17
Figure 2. Surface EMG electrode placement on subject .................. 18
Figure 3. Placement of the five reflective markers on the subject .......... 19
Figure 4. EMG activity in the gluteus maximus muscle during the experimental trials ............................................. 24
Figure 5. EMG activity in the semitendinosus muscle during the experimental trials ............................................. 25
Figure 6. EMG activity in the biceps femoris muscle during the experimental trials ............................................. 26
Figure 7. EMG activity in the vastus lateralis muscle during the experimental trials ............................................. 27
Figure 8. EMG activity in the vastus medialis muscle during the experimental trials ............................................. 28
Figure 9. EMG activity in the rectus femoris muscle during the experimental trials ............................................. 29
Figure 10. EMG activity in the anterior tibialis muscle during the experimental trials ............................................. 30
Figure 11. EMG activity in the gastrocnemius muscle during the experimental trials ............................................. 31
Figure 12. Forward striding at a 30 degree incline .......................... 32
Figure 13. Backward striding at a 30 degree incline .......................... 33
Figure 14. Range of motion during forward striding ......................... 34
Figure 15. Range of motion during backward striding ......................... 35
LIST OF TABLES

Table 1. Descriptive Statistics of Subjects ........................................... 11
Table 2. Origin, Insertion, and Action of Selected Muscles .................. .. 16
Table 3. Percent changes in muscle activity during experimental trials. The percent changes are in comparison to forward striding at 10 degrees ... 36
Table 4. Lower extremity joint range of motion during forward and backward striding ................................................................. 37
ACKNOWLEDGEMENTS

I would like to thank my parents, John and Ruth Ann Sweeney, for their support both financially and emotionally throughout my educational career. To my big brother, Grant, thank you for your support and belief that I will always succeed. Go Sioux!

I would also like to extend a special thank you out to my two research partners, Sarah Mannel and Jennifer Tveit, and my preceptor, Dr. Tom Mohr. It has been my pleasure to work with all of you.
ABSTRACT

Americans are increasingly interested in exercising to increase fitness and reduce the risks of disease. One of the latest machines used to accomplish this goal is the elliptical trainer, a combination stair stepper, treadmill, exercise cycle, and cross-country ski machine. The purpose of this study was to describe muscle activity and joint range of motion while moving both forward and backward on an elliptical trainer at different inclines.

Six subjects between the ages of twenty-two and twenty-five years rode an elliptical trainer backwards and forwards at different inclines for four trials. Electromyographic activity of eight lower extremity muscles was calculated along with lower extremity joint angles while performing the stride.

From our results, we concluded that with changing inclines and direction, the electromyographical data from the lower extremity muscles was variable. Neither changes in direction nor incline produced consistent changes in EMG activity. Range of motion of the hip and knee increased as the incline increased. No differences in range of motion were noted when changing from backward striding to forward striding.
CHAPTER I

INTRODUCTION

Americans have become increasingly interested in exercising to increase aerobic fitness and reduce the risk of disease.\(^1\) One of the latest pieces of exercise equipment designed to help accomplish this goal is the elliptical trainer. Manufacturers of the machine market it as a combination stair stepper, treadmill, exercise cycle, and cross-country-ski machine.\(^2\) They report that the elliptical trainer mimics the motion of running while nearly eliminating the problems faced by runners due to impact forces.\(^1\)

Manufacturers' product information claims that muscle involvement can be varied by changing ramp elevation, resistance, and direction.\(^3\) Literature for the Precor EFX5.17 Elliptical Fitness Crosstrainer suggests that this machine has a one-of-a-kind motion that targets the gluteus maximus at higher ramp settings and the quadriceps at medium-high settings.

This machine takes its name from its smooth elliptical shaped stride. The rider stands on two foot pedals, connected to a wheel gear and a roller that move along a smooth platform. The platform angle can be adjusted to change the motion from running or skiing at smaller grades to a more cyclical or stepping motion at higher inclines.\(^2\) Arms can be free or hands can be placed on support bars. Some varieties have arm poles which can be pulled back and forth.\(^1\)
**Problem Statement**

No peer reviewed studies have been performed to test the actual muscular activation patterns of persons riding an elliptical trainer. Claims made by manufacturers comparing the elliptical trainer to treadmills, steppers, cycle ergometers, and cross-country-ski machines have not been studied.

**Purpose of Study**

The purpose of this study is to describe muscle activity and joint range of motion while moving both forward and backward on an elliptical trainer at different inclines.

**Significance of Study**

The elliptical trainer is widely used in fitness centers as a possible closed-kinetic-chain lower extremity exercise option for gaining strength and range of motion (ROM) following trauma or a surgical procedure. Therefore, determining which muscles are activated by this machine at different inclines and directions may be beneficial in developing training and rehabilitation protocols for patients. In addition, a description of changes in range of motion will be important to therapists using the machine for patients.

**Research Questions**

1. Which lower extremity muscles are activated and to what extent during exercise on an elliptical trainer?
2. Which lower extremity muscles are activated during different points on the cycle during exercise on an elliptical trainer?
3. Which lower extremity muscles are activated at different grades and directions during exercise on an elliptical trainer?

4. How is lower extremity range of motion affected by changing inclines and directions on the elliptical trainer?

**Hypotheses**

**Null hypotheses:**

1. Changing inclines will not have a measurable effect on muscular activity.

2. Changing directions will not have a measurable effect on muscular activity.

3. Changing inclines will not have an effect on hip, knee, and ankle range of motion.

**Alternate hypotheses:**

1. Increasing incline will increase muscle activity.

2. Changing from forward to backward motion will reverse muscle activity.

3. Increasing the incline will increase hip, knee, and ankle range of motion.
CHAPTER II
LITERATURE REVIEW

Manufactures of elliptical trainers claim their machines produce similar muscle activation as stationary bicycles, treadmills, stair-steppers, and cross-country-ski machines. However, they offer little in the way of scientific research to backup their claims. This is especially evident with the cross-country ski machine where no relevant studies were found during a literature search.

Cycling Ergometry

There have been many studies published examining the lower extremity during cycling. Research has shown the biceps femoris and gluteus maximus to be active in hip extension during the down stroke portion of the pedal cycle. The biceps femoris, along with the semitendinosus, semimembranosus, and gastrocnemius, continued to be active to move the pedal by flexing the knee around the bottom of the cycle. The tibialis anterior acted to dorsiflex the foot during the upstroke portion of the cycle.

Some discrepancies have been noted with muscle activation timing in the quadriceps muscles. Mohr et al. and Suzuki et al. reported the rectus femoris was activated earlier than the vastus lateralis due to its hip flexor action during pedal upstroke. Houtz and colleagues however, reported different results showing that the rectus femoris and the vastus lateralis were active at the same time. Mohr et al. also showed that the rectus femoris, vastus lateralis, biceps
femoris, gluteus maximus, and gastrocnemius worked together during pedaling to extend the entire lower extremity, while Houtz et al.\(^7\) reported that the rectus femoris, vastus lateralis, and tibialis anterior were active during the bottom portion of the cycle while the biceps femoris and gastrocnemius were active during the top portion of the cycle. Neptune and colleagues\(^8\) also reported that the semitendinosus and semimembranosus were active through these transition regions at the top and bottom of the cycle.

Studies with a simulation model have been used to show that the muscles used in forward and backward cycling contribute to the same primary biomechanical functions.\(^8,9\) These studies found that the vastus muscles along with the gluteus maximus and adductor magnus muscles produced most of the muscle energy in the down stroke extension phase of both forward and backward cycling. During the upstroke flexion phase of both pedaling directions, the short head of biceps femoris and iliopsoas worked to accelerate the crank. The gastrocnemius, soleus, and tibialis anterior muscles worked together to transfer energy created from muscles in the leg to the crank in both pedaling directions. Differences in backward and forward pedaling were shown with muscle contributions from the medial hamstrings (long head of biceps femoris, semitendinosis, semimembranosis) and rectus femoris.\(^8,10\) In backward cycling, the hamstrings contributed by directly accelerating the crank posteriorly through the top transition region.\(^10\) Forward cycling displayed a timing shift of nearly 180 degrees to allow the hamstrings to propel the crank posteriorly through the bottom transition region. The rectus femoris worked eccentrically and then
concentrically to accelerate the crank through the bottom transition region during backward cycling. A timing shift of the rectus femoris allowed acceleration of the crank anteriorly through the top transition region during forward pedaling. Total integrated EMG data reported a decrease in biceps femoris by 32%, medial gastrocnemius by 11%, and soleus by 10% during backward pedaling. No change of the vastus medialis, tibialis anterior, rectus femoris, and semimebranosus total integrated EMG activity was seen with change in pedaling direction.

EMG studies from Mohr et al.\textsuperscript{4} reported increased activity level in the rectus femoris and vastus lateralis during standing cycling conditions. Decreased activity of the biceps femoris was also seen. Due to weight shifting during standing, a decreased amount of activity from the biceps femoris was needed to pull the pedal around the bottom of the cycle. Li et al.\textsuperscript{11} reported slightly different findings comparing seated at level, seated at 8% grade uphill, and standing at 8% grade uphill positions. They reported increased EMG activity in rectus femoris, gluteus maximus, and tibialis anterior in the standing condition. No increase in EMG activity was seen during the change from 0 to 8% grade in the seated position.

The construction of a cycle ergometer limits the ROM through which an extremity can move during a pedal cycle. Houtz et al.\textsuperscript{7} reported that the ROM in the hip, knee, and ankle varied with the change in position of the seat height during the cycle. In their study, subjects cycled with seat heights of 21 and 25 inches from the center of the pedal. They found that approximately 20 to 40
degrees of motion in the hip and 40 to 60 degrees of motion in the knee could be achieved. All of their subjects were able to demonstrate full ranges of dorsiflexion and plantar flexion. As the hip and knee cycled into full flexion, maximum dorsiflexion was achieved, and maximum plantar flexion was seen as the extremity completed extension and flexion began. The hip and knee did not reach full extension and both reached maximum extension at the same time in the cycle. Houtz and colleagues reported that the hip flexion does not exceed 90 degrees, but instead begins to internally rotate and adduct, because increased flexion would cause an unstable pelvis on the small supporting seat of the bicycle.

**Treadmill Walking**

Extensive research has been completed on gait analysis. During normal level walking, Ericson et al. reported that the gluteus maximus and hamstring muscles demonstrated peak activity at the beginning of stance phase, and worked together to extend the hip through the stance phase. The hamstrings were most active working to flex the knee during mid-swing and terminal-swing. Peak activity of the quadriceps was during initial contact working to extend the knee for stance phase. The gastrocnemius and soleus demonstrated peak activity at the beginning of push-off to provide acceleration to advance the limb for swing phase. Peak EMG activity of the anterior tibialis occurred during initial contact to lower the foot and at the beginning of acceleration in swing phase to provide dorsiflexion for toe clearance of swing phase.
Backward walking demonstrated different activity compared to forward walking. This change in activity is due to a difference in stance phase activity. Stance phase begins with heel contact and ends with toe-off during forward walking. During backward walking, stance phase begins with the toes contacting the ground and ends with the heel being lifted off last. The plantar flexors of the ankle provide forward thrust in forward walking, while the hip and knee extensors are used to provide backward thrust in retrograde walking.

Grasso and colleagues compared EMG activity in forward and backward walking. They discovered the mean EMG activity was higher for backward walking than forward walking. The gluteus maximus was reported to be most active at midstance for backward gait, while it was most active during heel contact and toe-off during forward gait. The rectus femoris and vastus lateralis displayed results showing peak activity during early stance and midstance in backwards gait and peak activity in swing and early stance with forward gait. The gastrocnemius was most active during early and late stance in backward walking. It was most active during midstance of forward walking. Backward gait showed greatest activity in the tibialis anterior during stance while it was most active during early stance and swing phase of forward gait.

As treadmill grades increased from 0% to 12% and 24%, Lange et al. reported an increase in average and peak EMG data for the vastus medialis, vastus lateralis, and biceps femoris. The average amplitude for vastus medialis increased by 125%, the vastus lateralis by 109%, and the biceps femoris by
53%. The average EMG data of the hamstring muscles were unaffected by this increase in grade.

Studies of retrograde walking on increased inclines have also been completed. Cipriani et al. reported a decrease in hamstring activity as the treadmill incline increased with retrograde walking. The anterior tibialis, gastrocnemius, and rectus femoris demonstrated an increase in activity with this increase in incline.

Level walking is shown to produce a range of 30 degrees of flexion to 20 degrees of hyperextension in the hip. The greatest amount of hip flexion occurs during initial contact and at the end of mid-swing. The greatest amount of hip hyperextension occurs at the end of terminal stance. The knee demonstrates 0 degrees at initial contact and at the end of terminal stance. It reaches the greatest amount of flexion, 60 degrees, at the end of initial swing. The ankle produces a range of 10 degrees dorsiflexion at the end of midstance to 20 degrees plantar flexion at the end of pre-swing.

Changes in treadmill inclines, will affect these joint range of motions. Lange et al. reported that an increase in grade from 0 to 24% produced an increase in ankle plantar flexion/dorsiflexion by 20% and hip flexion/extension by 59%. Maximum knee flexion with increased grades increased very little and extension decreased, producing an overall decrease in total knee ROM of 12%.

Backward walking with increased inclines of 5 and 10% produced greater knee flexion and ankle dorsiflexion. During stance phase and mid-swing, knee
flexion increased. Ankle dorsiflexion increased at the beginning of stance phase and no change was reported for the hip with increased inlines.

**Stair-Climbing Ergometry**

Stair-climbing ergometry has not been as extensively studied as cycling or walking. EMG studies of stair-climbing ergometry reported the gluteus maximus, rectus femoris, and vastus medialis to be most active at the beginning of the extension phase while the gastrocnemius was most active during the middle to end of the extension phase. The semimembranosus and semitendinosus activity remained fairly constant during the stepping cycle.

Zimmermann et al. studied the muscle activity comparing forward and retrograde stepping at 60 steps/minute. A slight, but non-significant increase in the rectus femoris, vastus medialis, and semimembranosus and semitendinosus muscles was observed for retrograde stepping. Gluteus maximus and gastrocnemius showed a slight decrease in mean EMG during retrograde stepping. This decrease in gastrocnemius activity could be attributed to a less plantar flexed position of the foot in retrograde stepping.

The hip, knee, and ankle ROM during forward stepping of the StairMaster 4000PT was studied by Asplund and colleagues. The subjects were instructed to take full steps without hitting top or bottom stoppers. Values of 32.4 degrees of total ankle motion, 12.7 to 72.8 degrees of knee flexion, and 15.2 to 51.4 degrees of hip flexion were reported.
CHAPTER III

METHODS

Subjects

Six healthy volunteers (3 females and 3 males) gave their informed consent to serve as subjects in this study (Table 1). Requirements for recruitment included age between 18 and 40 years, and no previous history of knee surgeries. One subject was eliminated from the study due to faulty electrodes causing irregular EMG data. The study was approved by the Institutional Review Board at the University of North Dakota, Grand Forks and was performed on campus in the Physical Therapy department within the School of Medicine and Health Sciences (See Appendix).

Table 1. Descriptive Statistics of Subjects

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>23 (years)</td>
<td>22-25</td>
</tr>
<tr>
<td>Height</td>
<td>162 (cm)</td>
<td>158-178</td>
</tr>
<tr>
<td>Weight</td>
<td>176 (lbs)</td>
<td>120-256</td>
</tr>
</tbody>
</table>
Instrumentation

All trials were performed on a Precor EFX544 model elliptical fitness crosstrainer (Precor, 20001 North Creek Parkway, Bothell, WA 98041-3004).

Electromyography

The electromyographic data was collected by a Noraxon Telemyo 8 telemetry unit (Noraxon USA, 13430 North Scottsdale Rd., Scottsdale, AZ 85254). This data was 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 and electromyographic data were synchronized using the Peak Event Synchronization Unit. A photoelectric cell was used to trigger the start of EMG collection. The photoelectric cell was activated each time the lower extremity made a full forward excursion. Upon full forward excursion of the right lower extremity the sensor was triggered and an LED light was illuminated in the video image.

Video

Five reflective markers were placed on each subject to represent various joint centers in the sagittal plane. The camera used to film the activity was a Peak High-Speed Video 60/120 Hz camera (Peak Performance Technologies, 7388 S. Revere Parkway, Suite 601, Englewood, CO 80112-9765). During the trials, a camera frequency of 60 Hz and a shutter speed of 1/250 of a second were used. Trials were taped on a JVC model BR-S378U videocassette recorder.
The videotape was encoded with a SMPTE time code generator.

After all trials were recorded, the video was 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 while digitizing the data.

**Electrode and Marker Placement**

The skin on the right lower extremity was shaved of any excess body hair and cleansed with alcohol to prepare the subject for placement of eight (8) surface EMG electrodes over the muscle groups chosen to be monitored (Table 2). The monitored muscles were chosen because of the likelihood that they would show activation changes during the various movements on the elliptical trainer based on research done on comparative machines. The eight muscles included were: 1) gluteus maximus (GM), 2) semitendinosus (ST), 3) biceps femoris (BF), 4) vastus lateralis (VL), 5) rectus femoris (RF), 6) vastus medialis (VM), 7) anterior tibialis (AT), and 8) gastrocnemius (GS).

The placement of the electrodes was determined by finding the muscle belly based on a previously identified measurement using anatomical landmarks (Figure 1). The ground electrode was placed on the right medial tibial plateau (Figure 2). The EMG signals were transmitted to a receiver unit and then fed into a computer for display and recording of data.

Five reflective markers were placed on each subject to designate joint centers of the lower extremity (Figure 3). Markers were placed at: one third of
the measured distance from the subjects right ASIS to right PSIS, the right
greater trochanter, midposition of the right lateral knee joint line, the right lateral
malleolus, and the distal end of the fifth metatarsal. The markers were
illuminated on the video screen and captured on tape during the trials. Marker
placements were digitized, thus allowing for analysis of the hip, knee, and ankle
motions.

Protocol

Subjects were allowed to warm-up on the elliptical trainer for 2 minutes at
10° incline prior to beginning the trials. Equal time was allotted for the subject to
become accustomed to both forward and backward motion. Prior to beginning
the trials, each subject was asked to voluntarily contract each muscle group to be
monitored in the study. The subject performed trials forward and backward for
each of two inclines, 10° and 30°. The subject’s pace was chosen to be 100
paces per minute, which was predetermined to be a typical pace for users of the
elliptical trainer. The machine was arbitrarily set at a resistance level of six out of
ten based on the comfort of previous user trials.

Each trial consisted of a six second bout of exercise on the elliptical
trainer. EMG and kinematic data were collected throughout each trial. Subjects
were allowed rest breaks between trials based on their own comfort level. The
order of trials were chosen randomly for each subject by drawing out of a hat.

Data Analysis

Before the subjects were recorded, the camera field was calibrated by
videotaping a meter stick with illuminated ends. The videotape of each trial was
captured onto the Peak system and cropped down to five completed cycles. The video was then digitized using the Peak system. Joint angles and segmental motion were calculated by the software and formed into reports that demonstrate the anthropometric representation of the joint motion and integrated EMG data for each trial. The EMG data was exported to Excel spreadsheet software for analysis and quantification of mean activity levels. All EMG was normalized to walking at 10° incline. Percent change from 10° incline was calculated by the following formula:

\[
\text{Percent change} = \frac{\text{EMG Activity During Trial} - \text{EMG Activity at 10° grade}}{\text{EMG Activity at 10° grade}}
\]
Table 2. Origin, Insertion, and Action of Selected muscles.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Origin</th>
<th>Insertion</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<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>Vastus Medialis</td>
<td>Medial lip of linea aspera</td>
<td>Medial surface, top of patella</td>
<td>Extend knee (leg)</td>
</tr>
<tr>
<td></td>
<td>Intertrochanteric line</td>
<td>Tibial tuberosity</td>
<td></td>
</tr>
<tr>
<td>Vastus Lateralis</td>
<td>Lateral lip of linea aspera</td>
<td>Lateral surface, top of patella</td>
<td>Extend knee (leg)</td>
</tr>
<tr>
<td></td>
<td>Greater trochanter</td>
<td>Tibial tuberosity</td>
<td></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>Semitendinosus</td>
<td>Ischial tuberosity</td>
<td>Medial surface of superior tibia</td>
<td>Flex knee</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extend thigh</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>Condyles of femur</td>
<td>Calcaneal tuberosity</td>
<td>Plantarflexion</td>
</tr>
<tr>
<td>Anterior Tibialis</td>
<td>Upper 1/2 of lateral surface of tibia</td>
<td>First metatarsal</td>
<td>Dorsiflexion</td>
</tr>
<tr>
<td></td>
<td>Interosseous membrane</td>
<td>First cuneiform</td>
<td>Inversion</td>
</tr>
</tbody>
</table>
Gluteus Maximus - midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter
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 Medialis - along a line \( \frac{1}{5} \) of the distance from the medial knee joint line to the ASIS
Vastus Lateralis - along a line \( \frac{1}{4} \) the distance from the lateral knee joint line to the ASIS and over the belly of the vastus lateralis
Anterior Tibialis - over the muscle belly \( \frac{1}{3} \) the distance from the inferior patellar pole to the lateral malleolus
Gastrocnemius - over the muscle belly \( \frac{1}{4} \) the distance of the leg (fibular head to calcaneous)

Figure 1. Electrode Placement for Lower Extremity Muscles.
Figure 2. Surface EMG electrode placement on subject.
Figure 3. Placement of the five reflective markers on the subject.
CHAPTER IV

RESULTS

The results of the EMG analysis are shown in Table 3 and Figures 4-13. The results of forward and backward striding ROM at 10° and 30° are shown in Table 4 and Figures 14-15.

Percent change in muscle activity

The percent change in muscle activity for all the muscles tested is shown in Table 3 and Figures 4-11.

Gluteus Maximus

The GM showed the highest level of activity during forward striding at 10° incline (Figure 4). The lowest activity was found in backward striding at 10° incline.

Semitendinosus

The ST was more active with forward striding than backward striding. The ST showed the greatest level of activity at forward striding with a 30° incline (Figure 5). Backward striding at 10° incline showed less activity than forward striding at 10° incline. Backward striding at 30° incline showed less activity than forward striding at 30° incline.
**Biceps Femoris**

Striding in the forward direction elicited more activity in the BF than backward striding regardless of incline (Figure 6). Forward striding at 30° incline produced more activity than forward striding at 10° incline.

**Vastus Lateralis**

The greatest activity in the VL occurred during forward striding at 30° incline (Figure 7). The least activity was found during forward striding at 10° incline. Forward striding at 30° elicited more EMG activity in the VL than did backward striding at 30°.

**Vastus Medialis**

The VM produced the most activity during backward striding at 10° incline (Figure 8). At 30° incline, the VM displayed equal activity during both forward and backward striding.

**Rectus Femoris**

The RF activity increased with increasing incline and was more active in backward striding than forward for both inclines (Figure 9).

**Anterior Tibialis**

Activity in the AT was greater during forward striding than backward striding (Figure 10). Forward striding at 10° incline exhibited the highest level of activity of all the conditions tested. The least activity was seen in backward striding at 30° incline.
**Gastrocnemius**

The GS activity was less during backward striding than forward striding regardless of incline (Figure 11). Backward striding at 30° incline produced the least amount of GS activity.

**Muscle Activity Patterns**

**Forward stride at 30 degrees**

During forward striding, the GM demonstrated the greatest activity during the first 45% of the cycle with the peak activity at 15% of the cycle (Figure 12).

The RF greatest activity was found during the first 50% of the stride cycle with a peak at 20% of the cycle.

VL and VM demonstrated a similar pattern of activity throughout the stride cycle. The maximum activity for both muscles occurred at 15% of the cycle.

The activity patterns of the BF and ST during forward striding was similar throughout the stride cycle. However, the peak activity for the ST was at 2% of the cycle and the peak activity for BF was at 70% of the cycle.

The AT and GS show very little activity during the first 60% of the cycle. The AT peak activity occurred at 86% of the stride cycle. The GS activity remained relatively steady throughout and peaked at 2% of the cycle.

**Backward stride at 30°**

During backward striding, the GM demonstrated the greatest activity at 40% of the cycle (Figure 13).

The RF muscle's maximum activity occurred from 20 to 75% of the backward cycle with a peak at 40-50% of the cycle.
The VL and VM demonstrated a similar pattern of activity throughout the cycle. The peak activity for the VL was at 35-40%, while the peak activity for the VM was at 30% of the cycle.

The activity of the BF during backward striding demonstrated a peak of activity at 95% of the cycle. The peak activity for the ST was at 35% of the cycle.

The AT and GS showed variable activity throughout the cycle. The AT peak activity occurred at 90% of the stride cycle. The GS peak activity was at 35% of the cycle.

**Range of Motion**

**Hip flexion**

At the hip, the total ROM decreased slightly with changes in direction. The total ROM increased with an increase in incline, regardless of direction.

**Knee flexion**

At the knee, total ROM stayed nearly the same for striding during all trials. Knee flexion was increased, however, as incline increased. Direction appeared to have no effect on the extent of knee flexion, with a decrease in flexion of only two to three degrees during backward striding.

**Ankle plantarflexion and dorsiflexion**

Total ROM at the ankle was greater during striding at 10° incline than at 30° incline. Direction did not have an effect on total ROM at the ankle. Most work on the elliptical trainer occurred with the ankle in a plantarflexed position. The ankle achieved a maximum of only four degrees of dorsiflexion during any of the trials.
Figure 4. EMG activity in the gluteus maximus muscle during the experimental trials.
Figure 5. EMG activity in the semitendinosus muscle during the experimental trials.
Figure 6. EMG activity in the biceps femoris muscle during the experimental trials.
Figure 7. EMG activity in the vastus lateralis muscle during the experimental trials.
Figure 8. EMG activity in the vastus medialis muscle during the experimental trials.
Figure 9. EMG activity in the rectus femoris muscle during the experimental trials.
Figure 10. EMG activity in the anterior tibialis muscle during the experimental trials.
Figure 11. EMG activity in the gastrocnemius muscle during the experimental trials.
Figure 12. Forward striding at a 30 degree incline.
Figure 13. Backward striding at a 30 degree incline.
Figure 14. Range of motion during forward striding.
Figure 15. Range of motion during backward striding.
Table 3. Percent change in muscle activity during experimental trials. The percent changes are in comparison to forward striding at 10 degrees.

<table>
<thead>
<tr>
<th></th>
<th>GM</th>
<th>ST</th>
<th>BF</th>
<th>VL</th>
<th>RF</th>
<th>VM</th>
<th>AT</th>
<th>GS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW 10</td>
<td>-21.82%</td>
<td>-4.84%</td>
<td>-11.11%</td>
<td>2.04%</td>
<td>6.25%</td>
<td>20.19%</td>
<td>-7.41%</td>
<td>-9.52%</td>
</tr>
<tr>
<td>FW 30</td>
<td>-10.91%</td>
<td>9.68%</td>
<td>14.81%</td>
<td>11.22%</td>
<td>25.00%</td>
<td>15.38%</td>
<td>-1.85%</td>
<td>-9.52%</td>
</tr>
<tr>
<td>BW 30</td>
<td>-10.91%</td>
<td>4.84%</td>
<td>-9.26%</td>
<td>7.14%</td>
<td>28.75%</td>
<td>15.38%</td>
<td>-14.81%</td>
<td>-14.29%</td>
</tr>
</tbody>
</table>
Table 4. Lower extremity joint range of motion during forward and backward striding.

<table>
<thead>
<tr>
<th>Joint</th>
<th>10° forward</th>
<th>10° backward</th>
<th>30° forward</th>
<th>30° backward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>Min value</td>
<td>-1°</td>
<td>5°</td>
<td>5°</td>
</tr>
<tr>
<td></td>
<td>Max value</td>
<td>30°</td>
<td>32°</td>
<td>43°</td>
</tr>
<tr>
<td></td>
<td>Total Range</td>
<td>31°</td>
<td>27°</td>
<td>38°</td>
</tr>
<tr>
<td>Knee</td>
<td>Min value</td>
<td>15°</td>
<td>16°</td>
<td>20°</td>
</tr>
<tr>
<td></td>
<td>Max value</td>
<td>75°</td>
<td>72°</td>
<td>82°</td>
</tr>
<tr>
<td></td>
<td>Total Range</td>
<td>60°</td>
<td>56°</td>
<td>62°</td>
</tr>
<tr>
<td>Ankle</td>
<td>Min value</td>
<td>2° dorsiflexion</td>
<td>2° dorsiflexion</td>
<td>4° dorsiflexion</td>
</tr>
<tr>
<td></td>
<td>Max value</td>
<td>18° plantarflexion</td>
<td>24° plantarflexion</td>
<td>6° plantarflexion</td>
</tr>
<tr>
<td></td>
<td>Total Range</td>
<td>20°</td>
<td>26°</td>
<td>10°</td>
</tr>
</tbody>
</table>
CHAPTER V

DISCUSSION

The results from this study do not support the manufacturer’s claims for the Precor EFX elliptical trainer. The Precor EFX manufacturer reports that the gluteals are targeted at higher ramp settings and the quadriceps at medium-high settings. The results of this study do not confirm those claims. The results of this study showed that the change in muscle activity was inconsistent with a change in direction or a change in incline.

It is impossible to compare the results of this study with those of other fitness machines. The motion of the elliptical trainer is unlike any other machine. It is not true cycling, walking, or stepping. Backward striding on the elliptical trainer is comparable to backward walking down a hill, while retrograde activity on a treadmill or stair-stepper is similar to backward walking up a hill or staircase.

Clinical Implications

All muscles tested displayed activity during the trials. The EMG activity was variable and one should use caution when using this machine for strengthening because consistent results may not be achieved. The results of this study show that the gluteus maximus can be activated the most during forward striding at the 10° incline. The hamstring muscles are most active during forward striding at the 30° incline. The VM and VL appeared to be active with both forward striding and backward striding at both inclines. The RF displays
more activity with backward striding and produces increased activity with increased incline. More activity was seen during forward striding than backward striding for the AT and GS.

With increased incline, the amount of total ROM required for the hip and knee also increased. Total Ankle ROM decreased with an increased incline. The use of the elliptical trainer to increase hip and knee ROM in patients may be indicated, however there are other pieces of low impact closed kinetic chain exercise machines that may provide a greater increase in ROM and strength.

**Limitations**

A number of limitations were identified that impacted the results of this study. This study had a limited number of subjects. With only six subjects, no statistical analysis could be performed. Also, one subject had to be dropped out due to poor adherence of the electrodes. When assessing hip ROM, the trunk was not used and this provided for a smaller lever arm that may not have been as accurate. A baseline of muscle activity was not recorded on each muscle of each subject. This impaired us from comparing the amount of activity for each muscle. A comparison between muscles could not be made. The resistance level may also have been too low to achieve maximal muscle activity.

Future studies completed on the elliptical trainer would help to enhance the benefits of this machine. A future study should increase the resistance level to elicit more muscle recruitment. Subjects should be asked to face backwards on the machine or be tested on several other types of exercise equipment to allow comparison between them. An increase in the number of subjects tested
along with using similar training level and same gender may be beneficial. A study determining a baseline muscle activity to allow comparison of muscles or comparing the same subject on the elliptical trainer and other exercise machines such as the stair-stepper, stationary bicycle, cross-country ski machine, and treadmill may also be completed.

**Conclusion**

We were unable to confirm any of the hypotheses. The elliptical trainer did elicit activity from all tested muscles, however the EMG activity appears to be variable. It is felt that physical therapists should use caution when using this machine for patient intervention because they may not achieve consistent results. Until further research is completed, it would be difficult to justify the use of this machine for patient intervention.
APPENDIX
1. ABSTRACT: [LIMIT TO 200 WORDS OR LESS AND INCLUDE JUSTIFICATION OR NECESSITY FOR USING HUMAN SUBJECTS.]

Rehabilitation facilities are always trying new approaches to post operative rehabilitation on anterior cruciate (knee) injuries. One such approach is to have the patients walk both forward and backward (retro) on an elliptical training device as part of their rehabilitation protocol. The elliptical training device is a cross between a cross country (Nordic Trac) trainer and a stair stepper machine. The person performs the exercise in a standing position. Although this a commonly used mode of exercise in the clinic, there is little scientific information on elliptical training devices.

The purpose of this research project is to describe muscle activity and joint motion while walking both forward and backward on an elliptical trainer at different inclines. The muscle activity will be collected via electromyographic (EMG) 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 patients.

Normal, healthy, adult subjects will be used in this research project. Human subjects are needed for this research study in order to determine when the selected muscles are active while walking 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 subjects (both male and female) between the ages of 18 and 40. The subjects for the study will be recruited from university students and clients presently involved in training at the facility in Fargo. These subjects will participate voluntarily. These subjects will be chosen because of their age and health status. Only healthy subjects with no history of knee surgeries will be used in the study. The project will be completed at the UND Physical Therapy Department. Prior to walking, each subject will be asked to complete a consent form. The subjects will not be compensated.

Methods:
Prior to the walking trials, each subject's age, height, and weight will be recorded. During the trial, we will measure electromyographic (EMG) activity in selected lower extremity muscles. We will measure activity in the following muscles while the subjects are walking on the treadmill: 1) gluteus maximus, 2) vastus medialis, 3) vastus lateralis, 5) biceps femoris, 6) gastrocnemius, 7) anterior tibialis, and 8) semitendinosus. The study will be performed by Thomas Mohr, chairman of the physical therapy department and three graduate students: Jennifer Tveit, Kristin Sweeney, and Sarah Mannel.

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 subject will walk both forwards and backwards at 100 strides per minute at each of the elliptical rider inclines of 0%, 10%, and 20%. At each incline, the athlete will walk for a total of 10 seconds in order to obtain the necessary data for analysis. A typical trial would consist of the subject walking at 0% incline for 10 seconds, followed by a two minute rest period. The order of the walking 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 subject is walking both forward and backward at the various inclines. The body angles will also be analyzed to examine the walking strategies at the various inclines. The data should provide information on which muscles are active during forward and backward walking, and this information will provide the basis for developing protocols specifically for postoperative patients. The benefit to the participant will be the experience of being involved in a scientific study, and knowing that they will be contributing to the body of knowledge in exercise physiology and physical therapy.

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 healthy subjects will be used, at walking speeds the risk of any injury is extremely low. The participant will be closely observed throughout the activity on the elliptical trainer to decrease the potential of harm. 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 of the skin following removal of the electrodes, but this will only be temporary.

In the event that this research activity (which will be conducted at UND Physical Therapy) 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 the subject’s third party payor, 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.

All of the raw data will be stored in electronic format (computer files/video tapes), in the Department of Physical Therapy for a period of five (5) years. After that time, the data will be erased. Some of the processed data and the consent forms will be in stored in paper format, in the Department of Physical Therapy for a period of five (5) years. After that time they will be shredded.
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 five (5) 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  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 Elliptical Trainer

You are being invited to participate in a study conducted by Jennifer Tveit, Kristin Sweeney, Sarah Mannel 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 lower extremity while you are walking both forwards and backwards at different inclines on the elliptical trainer. We will also be measuring the angles of the joints of the upper extremity, lower extremity and trunk while you are walking. We hope to describe the muscle activity and the different angles that you employ during walking. Only normal, healthy subjects will be asked to participate in this study. If you have any previous knee surgeries you will not be eligible for this study. The benefit to you, as a participant, will be the experience of being involved in a scientific study and knowing that you will be contributing to the body of knowledge in exercise physiology and physical therapy.

You will be asked to walk on the elliptical trainer for a total of six (6) trials consisting of the following: 1) Walking forwards and backwards on the elliptical trainer at 100 strides per minute with 0% grade, 2) Walking forwards and backwards on the elliptical trainer at 100 strides per minute with 10% grade, 3) Walking forwards and backwards on the elliptical trainer at 100 strides per minute with 20% 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 Physical Therapy Department at the University of North Dakota 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 walk on the elliptical trainer at the three different inclines.

Although the process of physical performance testing always involves some degree of risk, the investigators in this study feel that the risk of injury or discomfort is minimal. In order for us to record the muscle activity, we will be placing 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 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. The computer files, video tapes, and consent forms are kept in the physical therapy department for a period of five (5) years. After that time, the electronic media is erased and the paper files 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 UND Physical Therapy) 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 payor, 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


