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An Electromyographic and Motion Analysis Study of an Elliptical Trainer

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AN ELECTROMYOGRAPHIC AND MOTION ANALYSIS STUDY OF AN ELLIPTICAL TRAINER

by

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This Independent Study, submitted by Sarah Virginia Mannel 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)

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Title	An Electromyographic and Motion Analysis study of an Elliptical Trainer
Department	Physical Therapy
Degree	Master of Physical Therapy

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Signature Sarah Warner

Date 12-11-00

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ACKNOWLEDGEMENTS

I would like to thank Dr. Tom Mohr for all his help, advice, and guidance through the completion of this paper. Thank you to Kristin and Jen for their tremendous work and effort. Thank you to Michael, Ruth, my parents, and the rest of my family who helped support and encourage me. All of the people recognized have contributed to the accomplishment of my goals.

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 activitiy. 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

Walking

Gait is a complex activity that has been studied at length by many different researchers. Investigators have studied range of motion (ROM) and electromyographic (EMG) activity during gait under certain conditions such as changes in inclines and speeds. They have also studied the effects of backward gait patterns. Lower extremity muscles that are active during gait include the gluteus maximus, rectus femoris, vastus medialis, vastus lateralis, the hamstrings, gastrocnemius, soleus, and tibialis anterior.[4, 5]

Ericson and colleagues[4] investigated muscular activity during normal level walking. The gluteus maximus and the hamstrings, demonstrated peak activity at the beginning of stance phase, working together to extend the hip through the stance phase. The hamstrings were also active during mid-swing and terminal-swing, working together to flex the knee. The quadriceps showed peak activity during initial contact to extend the knee during the stance phase. The gastrocnemius and soleus peak activity occurred at the beginning of push-off to help provide acceleration to advance the limb during swing phase. Anterior tibialis peak EMG activity occurred during two important phases of gait. The first peak was during initial contact to help lower the foot. The second peak was at the beginning of acceleration in swing phase to provide adequate dorsiflexion that is required for toe clearance during swing phase.

Backward walking offers a different pattern of muscle activity from forward walking.[6] The change in the muscle activity pattern is due to the difference in strategies between the two directions. In backward walking, the toes, instead of the heels, begin stance phase at initial contact. The foot progresses to heel-off at the end of stance phase.

The different tactics of the two walking directions helps to explain the results of research conducted by Grasso et al.[6] Grasso et al. discovered higher mean EMG activity during backward walking compared to forward walking. Maximum EMG activity of the gluteus maximus occurred at mid-stance during backward walking; whereas, heel contact and toe-off was the point of highest activity during forward walking. The anterior tibialis displayed the greatest activity at early stance and swing phase during forward walking. In contrast, the anterior tibialis's greatest activity during backward walking occurred during the stance phase. The gastrocnemius, showed the most activity during mid-stance in forward walking, and produced more activity during early and late stance in backward walking.

Lange et al.[7] investigated the difference in muscle activity during forward treadmill walking with changes in incline (0, 12, & 24%). The results of their study concluded that the vastus medialis, vastus lateralis, and biceps femoris activity increased as grade increased. The average increase for the vastus medialis was by 125%, the vastus lateralis by 109%, and the biceps femoris by 53%. The medial hamstrings showed no significant difference in average amplitude with an increase in incline.

In contrast to forward walking, backward walking showed a decrease in hamstring activity as the treadmill incline increased.[8] The anterior tibialis, gastrocnemius, and rectus femoris all showed increases in activity with an increased incline.

During normal level walking, the hip demonstrates the greatest flexion (30 degrees) during initial contact/end of terminal swing and end of mid-swing.[9] The greatest hip extension (10-20 degrees of hyperextension) occurs at the end of terminal stance. The knee moves from 0 degrees at initial contact/terminal swing and end of terminal stance, to 60 degrees of flexion at the end of initial swing. The ankle produces 5-10 degrees of dorsiflexion at the end of mid-stance and 20 degrees of plantarflexion achieved at the end of pre-swing. Lange et al.[7] reported that increasing the grade from 0 to 24% during forward walking increased ankle dorsiflexion by 20 percent. Raising the incline also produced greater knee and hip flexion, increasing hip ROM by 59 percent. Even though increasing the incline produced greater knee flexion, total knee ROM decreased by 12 percent. The decreased knee ROM was a result of the knee remaining in more of a flexed position throughout the cycle.

During backward walking with increases in incline (0, 5, and 10% grades), greater knee flexion and ankle dorsiflexion was noted.[8] Knee flexion increased during stance phase and mid-swing, while ankle dorsiflexion increased at the beginning of stance phase (toe strike). The results showed no change in the joint position of the hip with increases in incline.

Stepping

The stair-stepping machine has become a popular exercise in recent years. Although research on stair-stepping machines is minimal, there are a couple of studies that were found on EMG activity of lower extremity muscles. Like gait, the cycle of a stair-stepping machine can also be broken down into two phases. The extension phase begins as the lower extremity pushes down on the step. The flexion phase starts when the lower extremity begins to step up.

During forward stepping, gluteus maximus was most active during the extension phase.[10, 11] The rectus femoris and vastus medialis showed the greatest activity at the beginning of the extension phase, while the gastrocnemius was mostly active during mid to end of the extension phase. The activity of the hamstrings remained fairly constant throughout the cycle.

When comparisons were made between forward stepping and retrograde stepping at 60 steps/minute, only minor differences in muscle activity were apparent.[11] The rectus femoris, vastus medialis, and medial hamstrings increased slightly as the gluteus maximus and gastrocnemius decreased slightly during retrograde. The medial hamstrings showed greater activity in retrograde stepping than in forward stepping.

Cycling

Research has been done on cycling in a variety of forms, including forward vs. retrograde cycling and sitting vs. standing. Similar to stepping and walking, cycling can be broken down into two phases, a flexion phase as the upstroke and extension phase as the down stroke.

Mohr et al.[12] measured EMG activity in the gluteus maximus, biceps femoris, rectus femoris, vastus lateralis, gastrocnemius, and anterior tibialis during various conditions. During forward seated pedaling, all of these muscles, except the anterior tibialis, displayed activity during the extension phase. The biceps femoris was the most active muscle throughout forward pedaling, acting as a knee flexor at the bottom of the cycle and assisting the gluteus maximus to extend the hip during the down stroke. The anterior tibialis, active only during the last half of the upstroke phase, was activated to dorsiflex the foot. The rectus femoris, which was active just prior to vastus lateralis activation, performed a double role during cycling. The rectus femoris contributed to two actions during cycling, hip flexion and knee extension. Researchers concluded that the rectus femoris's role of a hip flexor might be the reason why it was active earlier in the pedal cycle than the vastus lateralis.

Backward pedaling, compared to forward pedaling, showed no difference in phasing activity for the vastus medialis, vastus lateralis, gluteus maximus, gastrocnemius, and anterior tibialis.[13, 14] However, the rectus femoris and the hamstrings did exhibit different timing when the pedaling direction changed. Instead of hamstring activity during the transition from extension to flexion, the hamstrings were activated during the flexion to extension transition. The hamstrings may have changed their role from a knee flexor to a hip extensor. The biceps femoris EMG activity decreased by 32% when the pedaling direction was switched from forward to backward.[13] The rectus femoris activity was delayed, producing a shorter amount of activity during the extension phase. The medial gastrocnemius also showed a decrease in activity during backward pedaling by 11%.

When comparing seated pedaling to standing pedaling, the gluteus maximus, rectus femoris, and vastus lateralis displayed longer periods of activity during standing.[12] In addition to the prolonged period of activity, the rectus femoris and vastus lateralis exhibited an increase in signal amplitude during standing. In contrast, the biceps femoris and gastrocnemius showed durations of shorter activity during standing.[12, 15] In regards to changes of cycling grade from 0% to 8%, no significant change in lower extremity neuromuscular coordination was found.[15]

Houtz and colleagues[16] monitored ROM during cycling with seat heights of 21 and 25 inches from the center of the pedal. Total ROM of the hip consisted of 20 to 40 degrees, never reaching full extension and not exceeding 90 degrees of hip flexion. The knee demonstrated 40 to 60 degrees of total ROM, also never reaching full extension. Full range of dorsiflexion was seen at maximum hip and knee flexion. Full plantar flexion was also achieved and seen as flexion of the extremity began.

Ericson et al.[17] compared activity in mean EMG peak activity of the lower extremity during cycling and walking. They found that the vastus medialis and vastus lateralis muscle activity was four to five times greater during cycling. In contrast, the anterior tibialis showed three times more activity during walking than cycling. Ericson et al. split the gastrocnemius into separate entities, medial gastrocnemius and lateral gastrocnemius. The medial gastrocnemius was more active during walking and the lateral gastrocnemius was more active during cycling. The gluteus maximus, rectus femoris, and hamstrings showed relatively similar activity between the two exercises.

Cross-Country Skiing

At this time, no relevant studies about the cross-country ski machine were found in the literature.

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

	Mean	**Range**
Age	23 (years)	22-25
Height	162 (cm)	158-178
Weight	176 (lbs)	120-256

Instrumentation

All trials were performed on a Precor EFX544 model elliptical fitness crosstrainer (Precor, 20001North 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 eah 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

(JVC of America, 41 Slater Drive, Elmood Park, NJ 07407). 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.

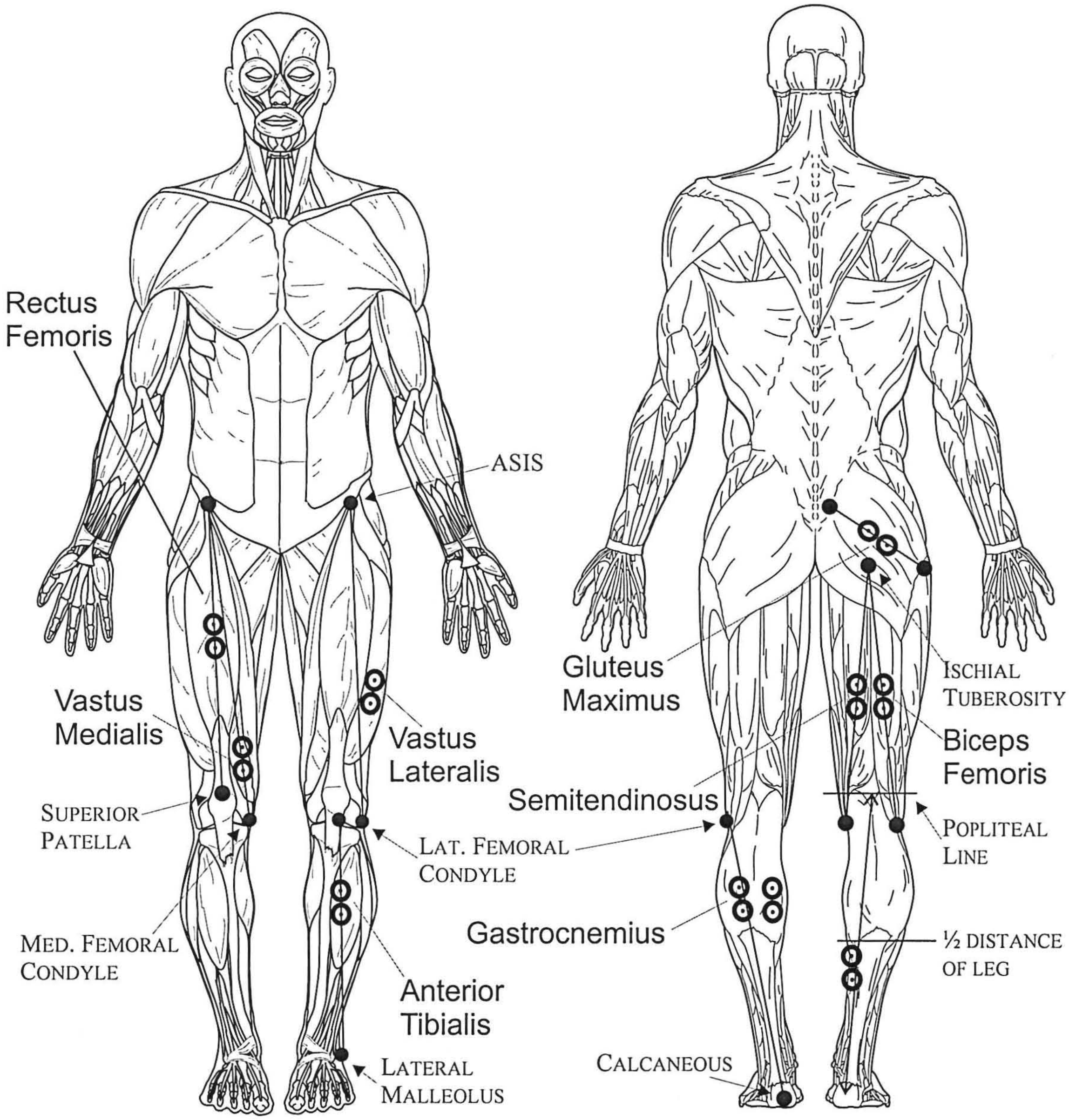
Data Analysis

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:

$$\text{Percent change} = \frac{\text{EMG Activity During Trial} - \text{EMG Activity at } 10^{\circ} \text{ grade}}{\text{EMG Activity at } 10^{\circ} \text{ grade}}$$

Table 2. Origin, Insertion, and Action of Selected muscles.

Muscle	Origin	Insertion	Action
Gluteus Maximus	Posterior crest of ilium Sacrotuberous ligament	Iliotibial tract Gluteal tuberosity	Extend thigh Laterally rotate thigh Extend trunk
Rectus Femoris	Anterior inferior iliac spine	Base of the patella Tibial tuberosity	Extend leg Flex thigh
Vastus Medialis	Medial lip of linea aspera Intertrochanteric line	Medial surface, top of patella Tibial tuberosity	Extend knee (leg)
Vastus Lateralis	Lateral lip of linea aspera Greater trochanter	Lateral surface, top of patella Tibial tuberosity	Extend knee (leg)
Biceps Femoris	Ischial tuberosity	Head of fibula	Flex knee Extend thigh
Semitendinosus	Ischial tuberosity	Medial surface of superior tibia	Flex knee Extend thigh
Gastrocnemius	Condyles of femur	Calcaneal tuberosity	Plantarflexion
Anterior Tibialis	Upper 1/2 of lateral surface of tibia Interosseous membrane	First metatarsal First cuneiform	Dorsiflexion Inversion



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 $^{1}/_{5}$ of the distance from the medial knee joint line to the ASIS
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
Anterior Tibialis - over the muscle belly 1/3 the distance from the inferior patellar pole to the lateral malleolus
Gastrocnemius - over the muscle belly ¼ 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.

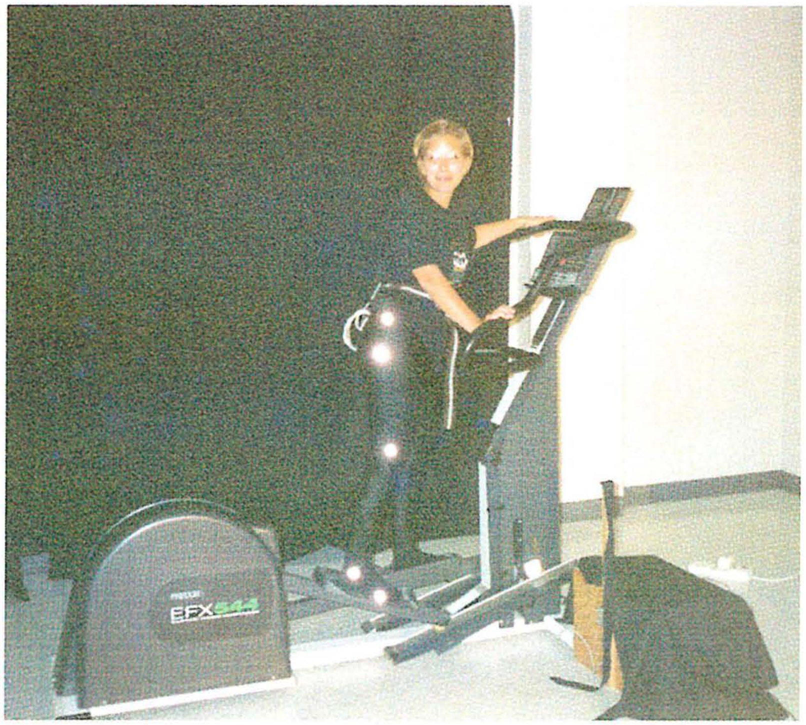


Figure 3. Placement of the five reflective markers on the subject.

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 stride 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.

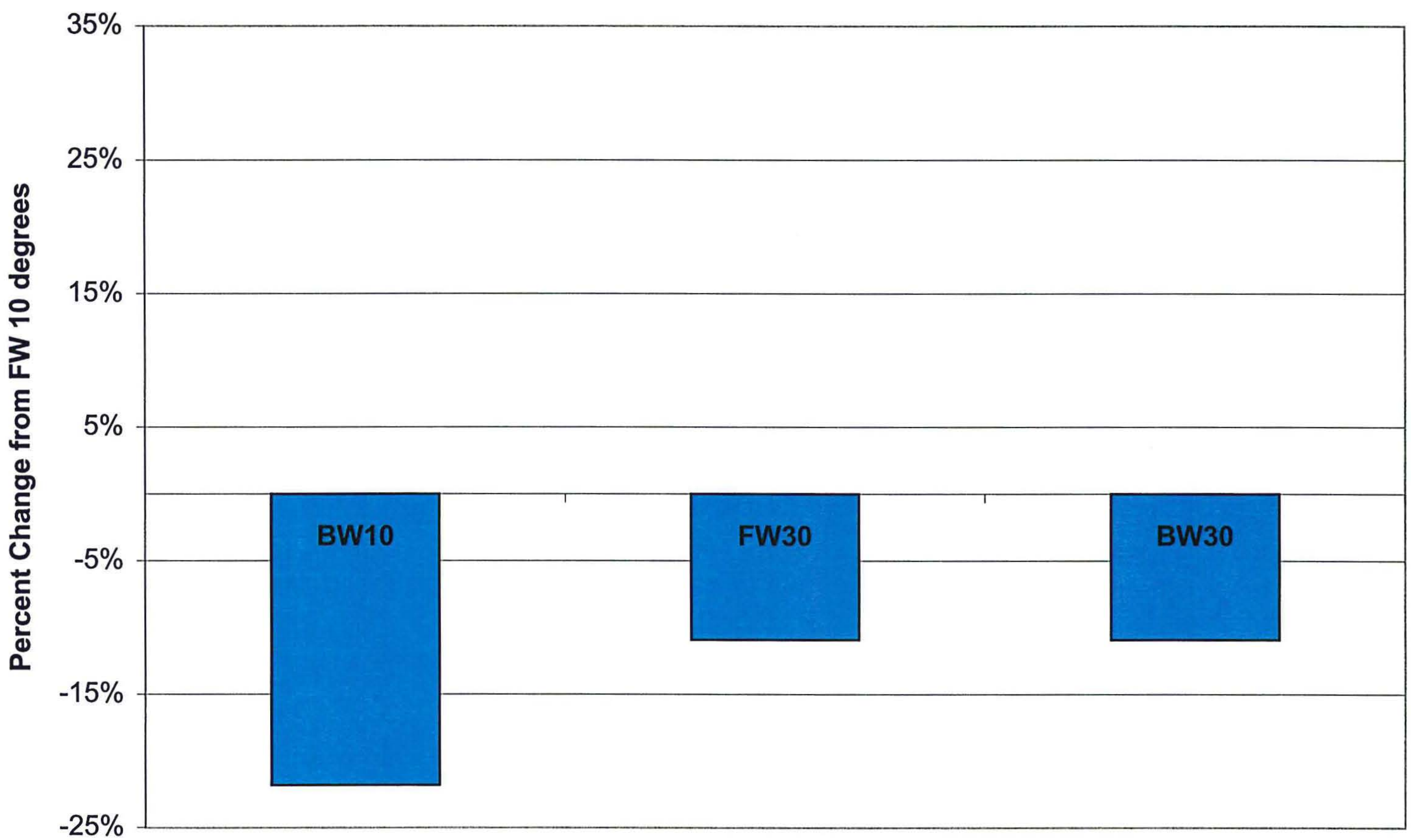


Figure 4. EMG activity in the gluteus maximus muscle during the experimental trials.

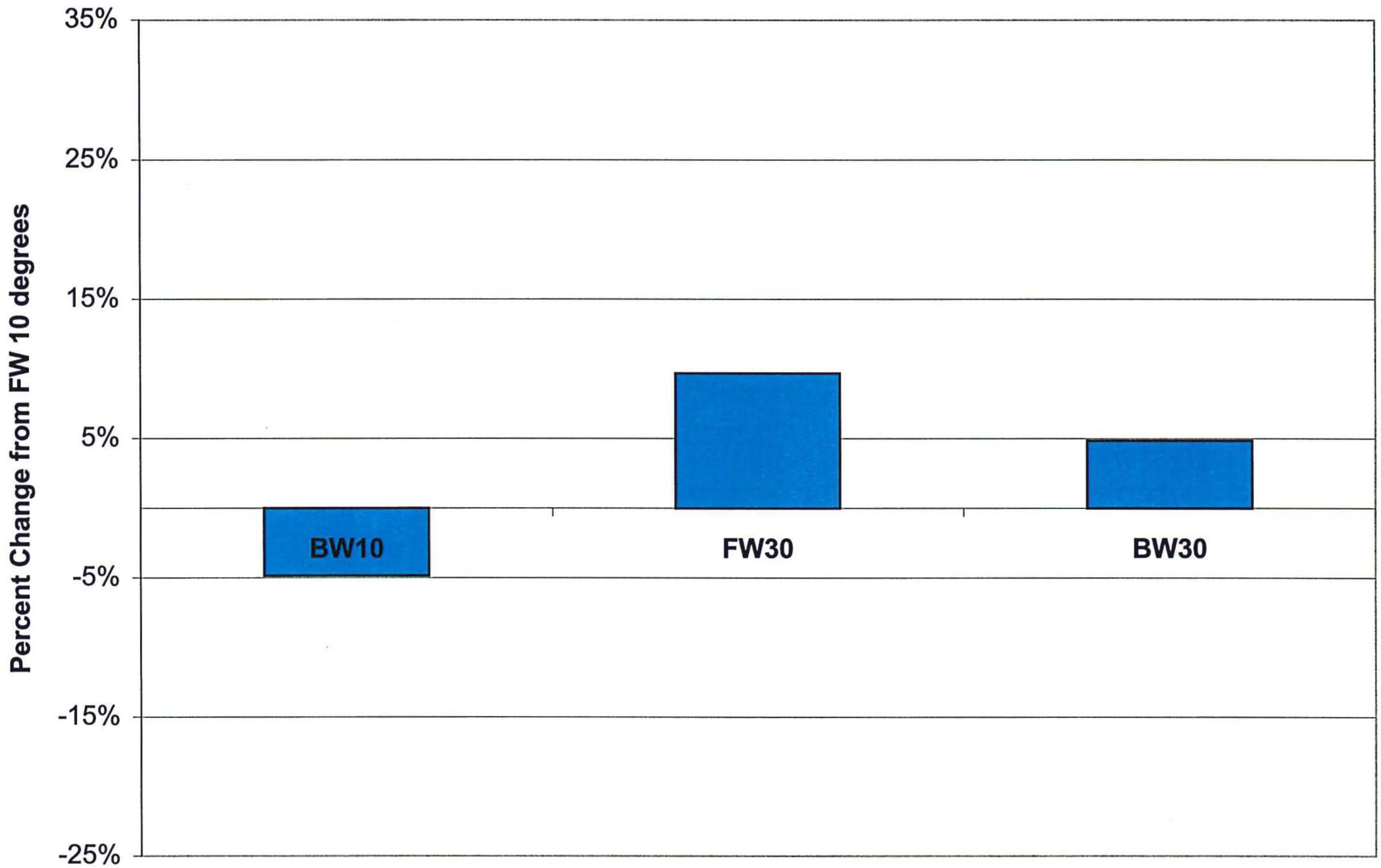


Figure 5. EMG activity in the semitendinosus muscle during the experimental trials.

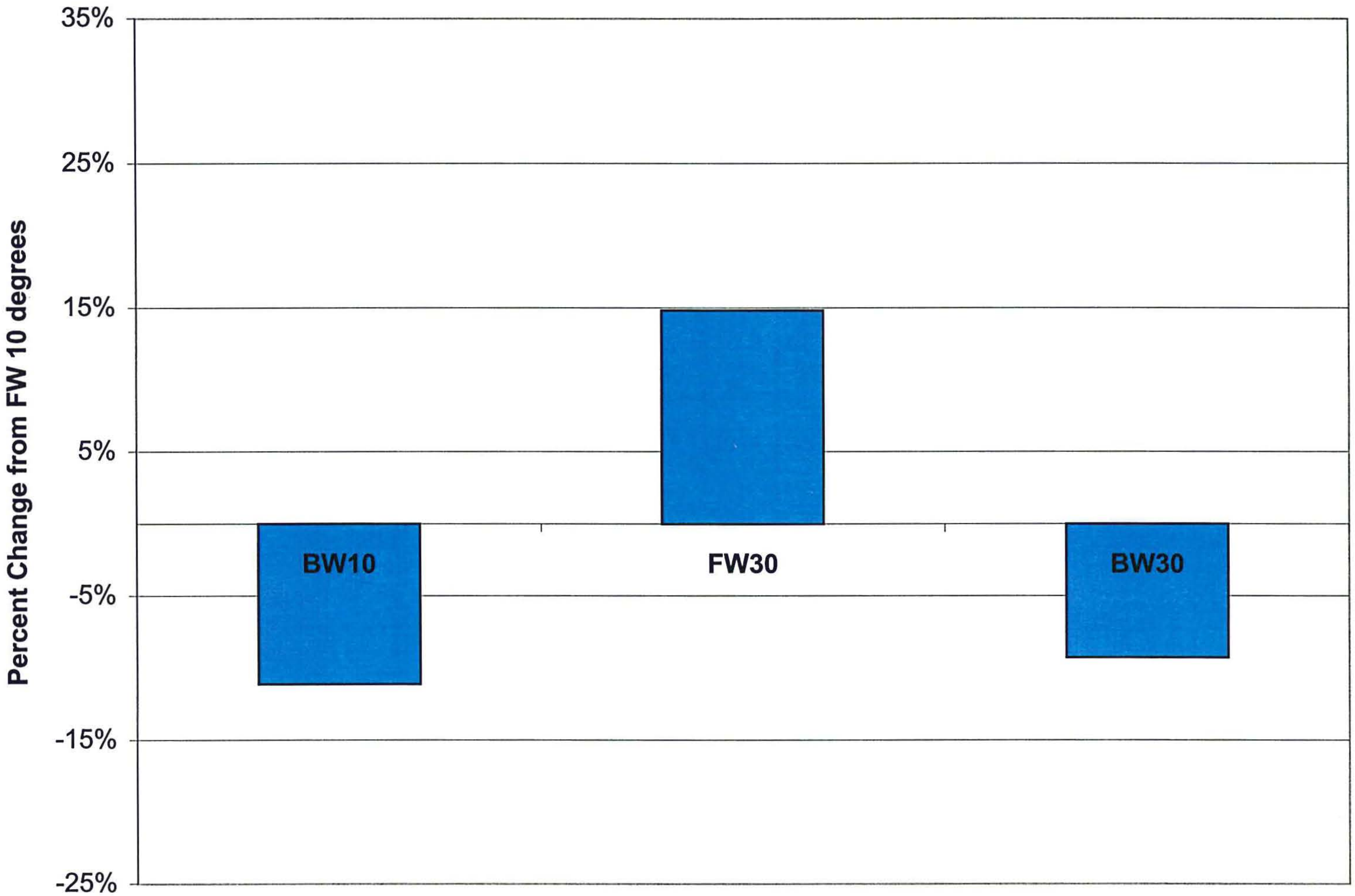


Figure 6. EMG activity in the biceps femoris muscle during the experimental trials.

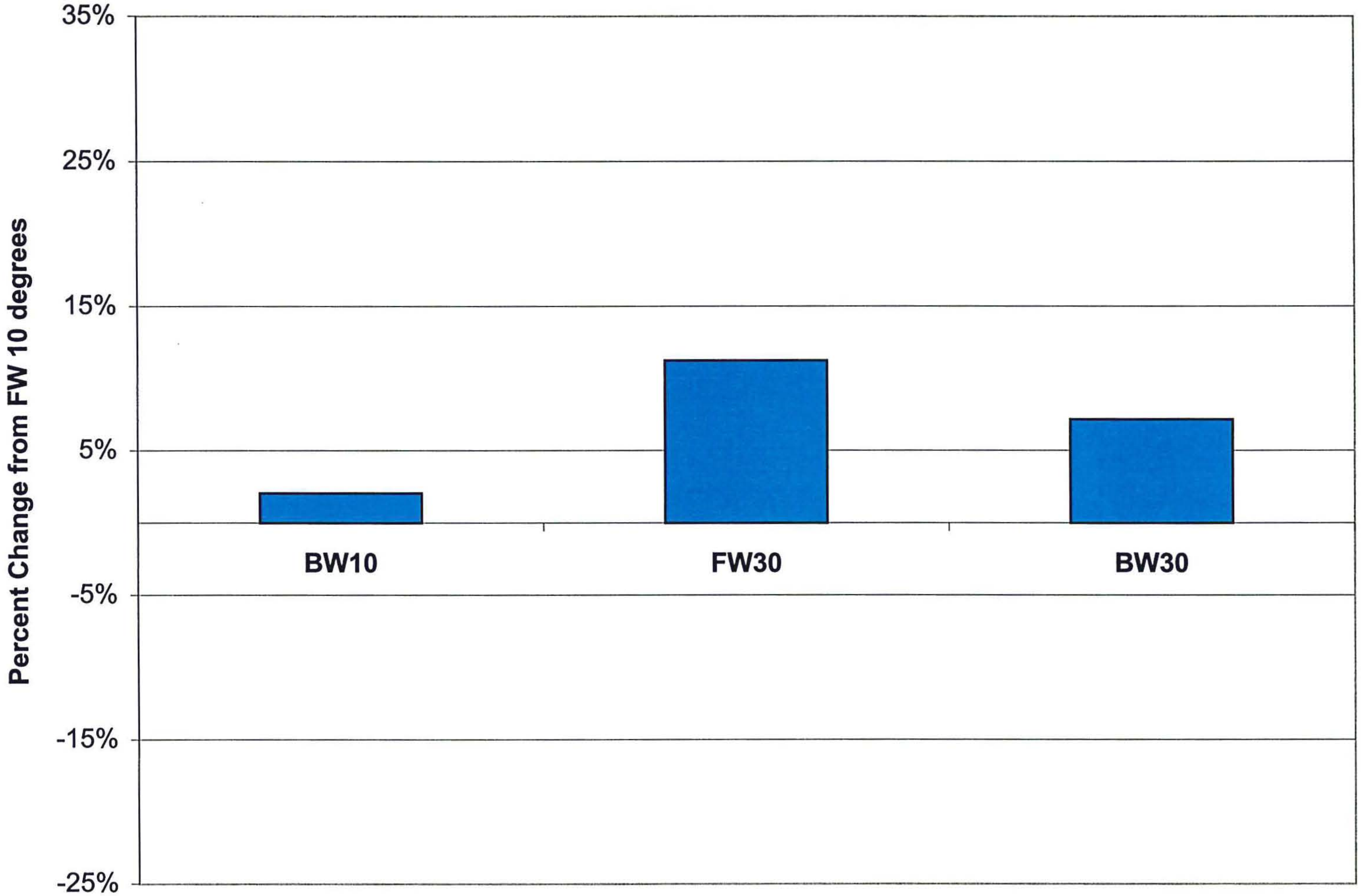


Figure 7. EMG activity in the vastus lateralis muscle during the experimental trials.

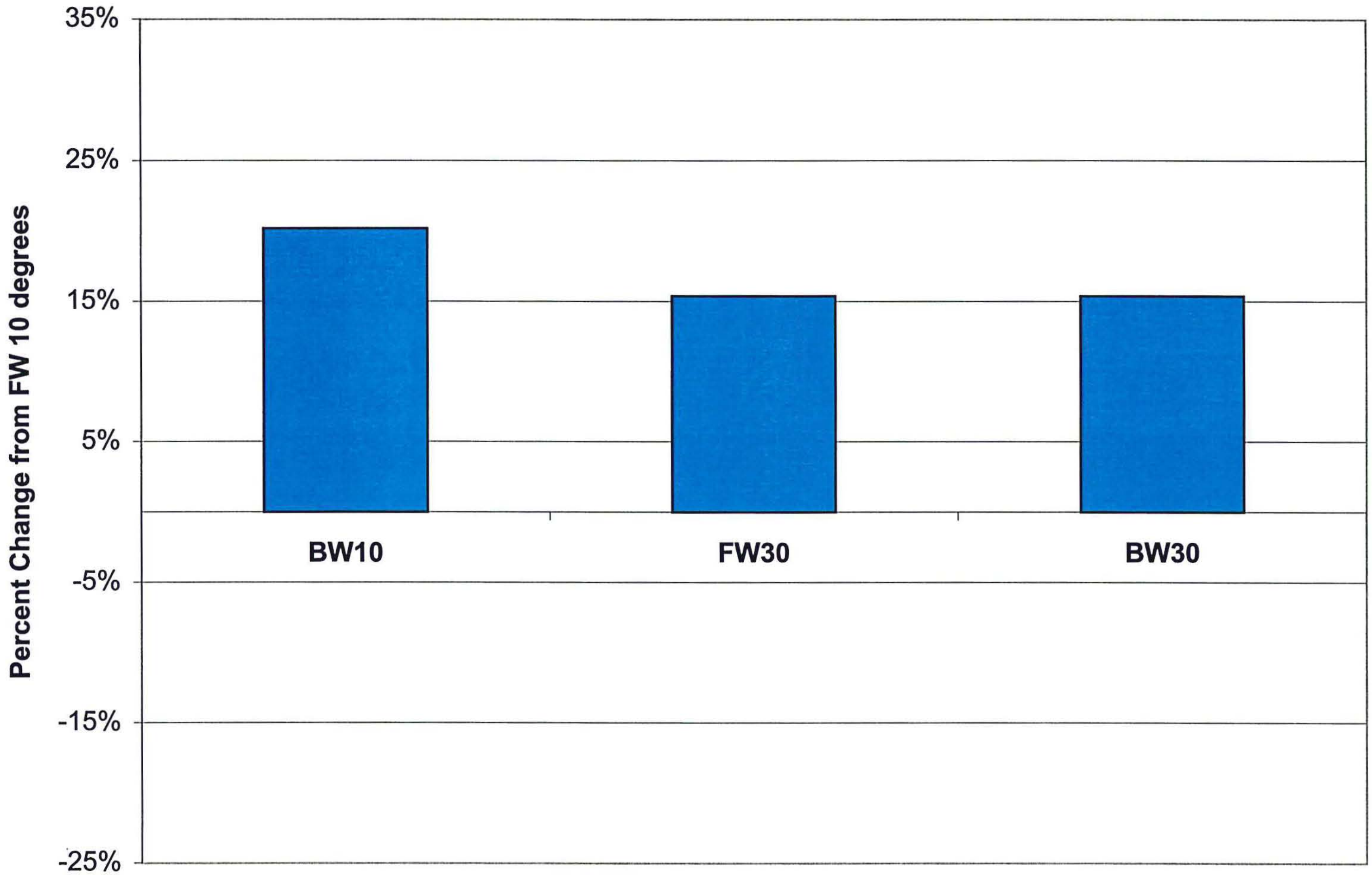


Figure 8. EMG activity in the vastus medialis muscle during the experimental trials.

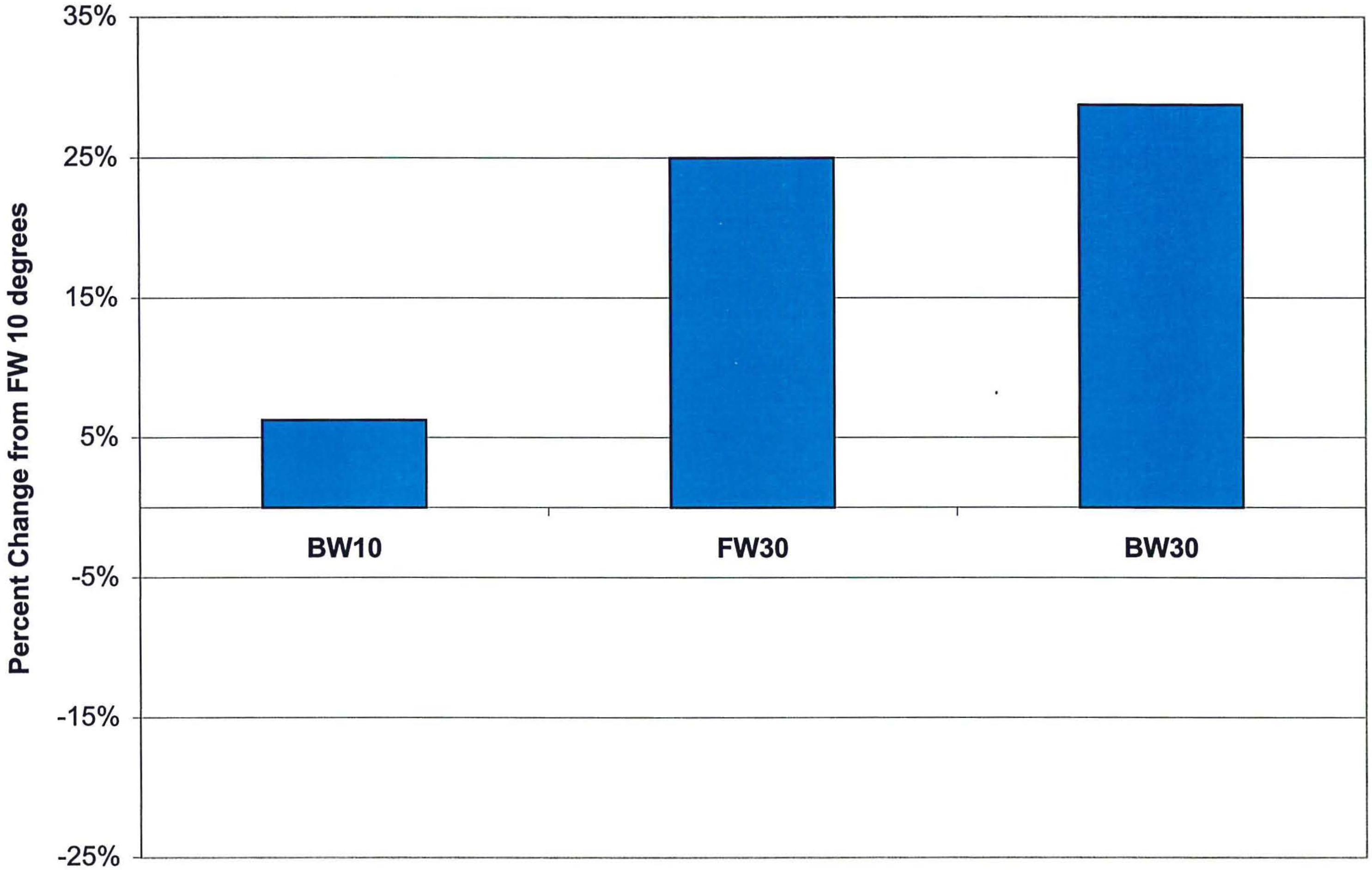


Figure 9. EMG activity in the rectus femoris muscle during the experimental trials.

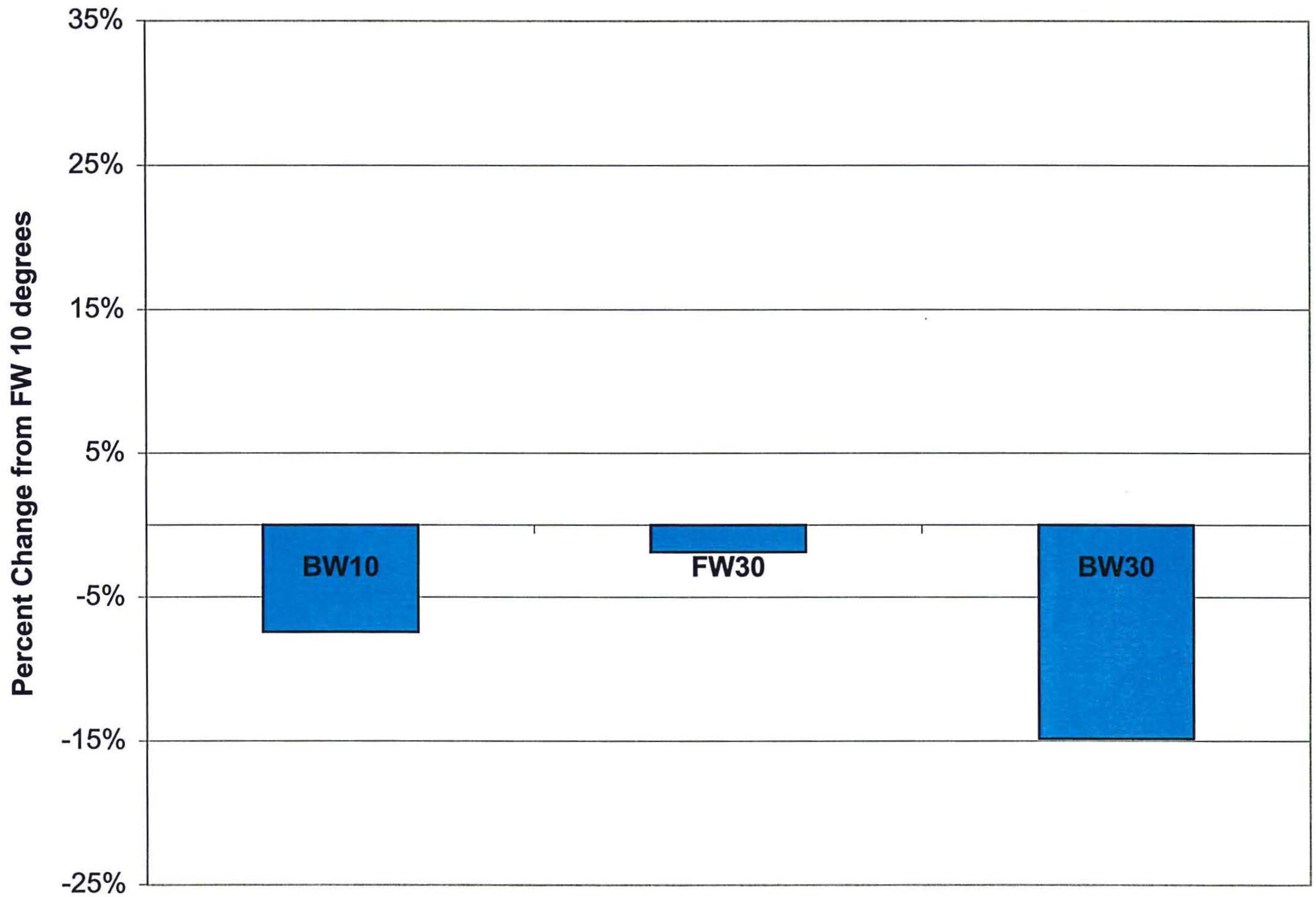


Figure 10. EMG activity in the anterior tibialis muscle during the experimental trials.

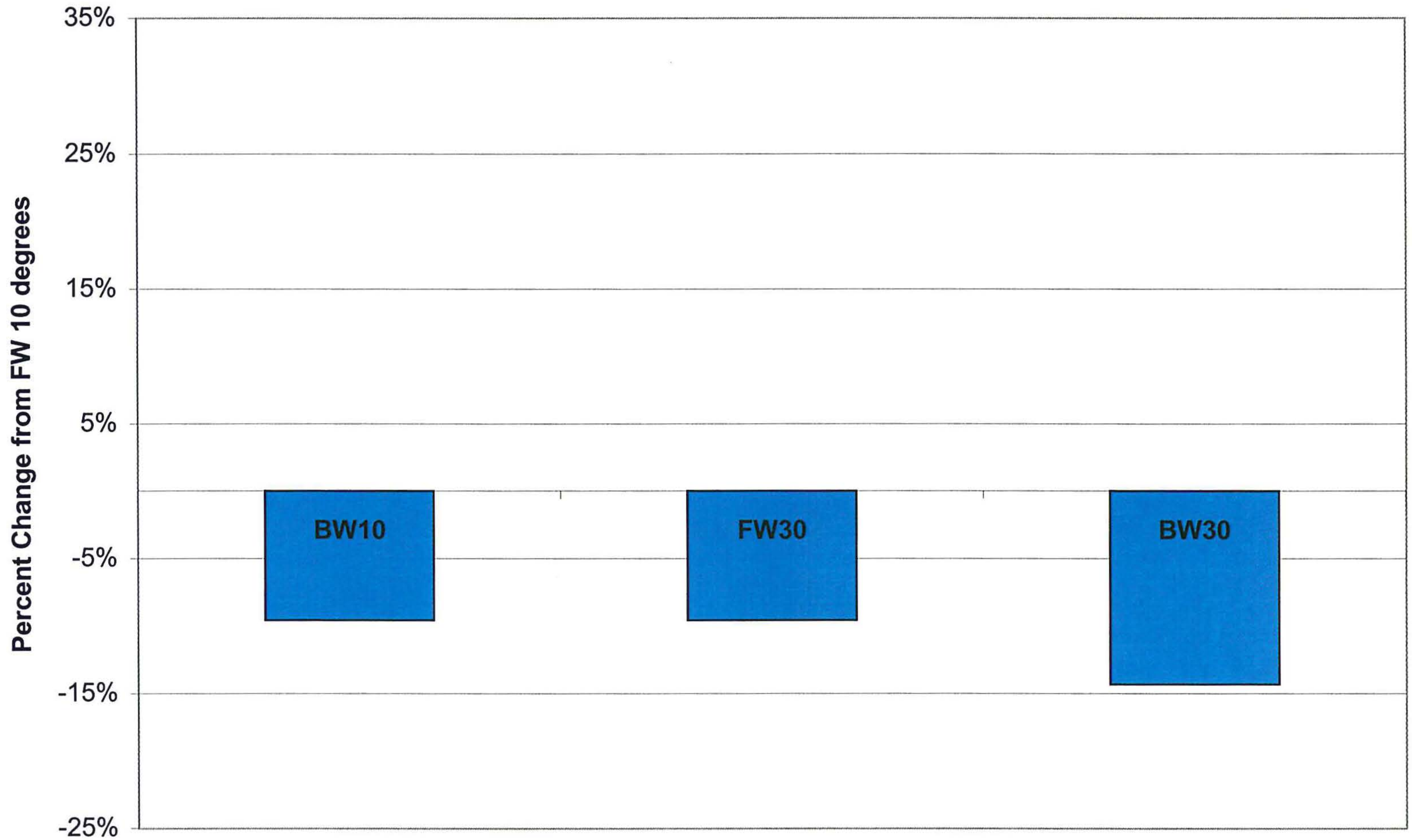


Figure 11. EMG activity in the gastrocnemius muscle during the experimental trials.

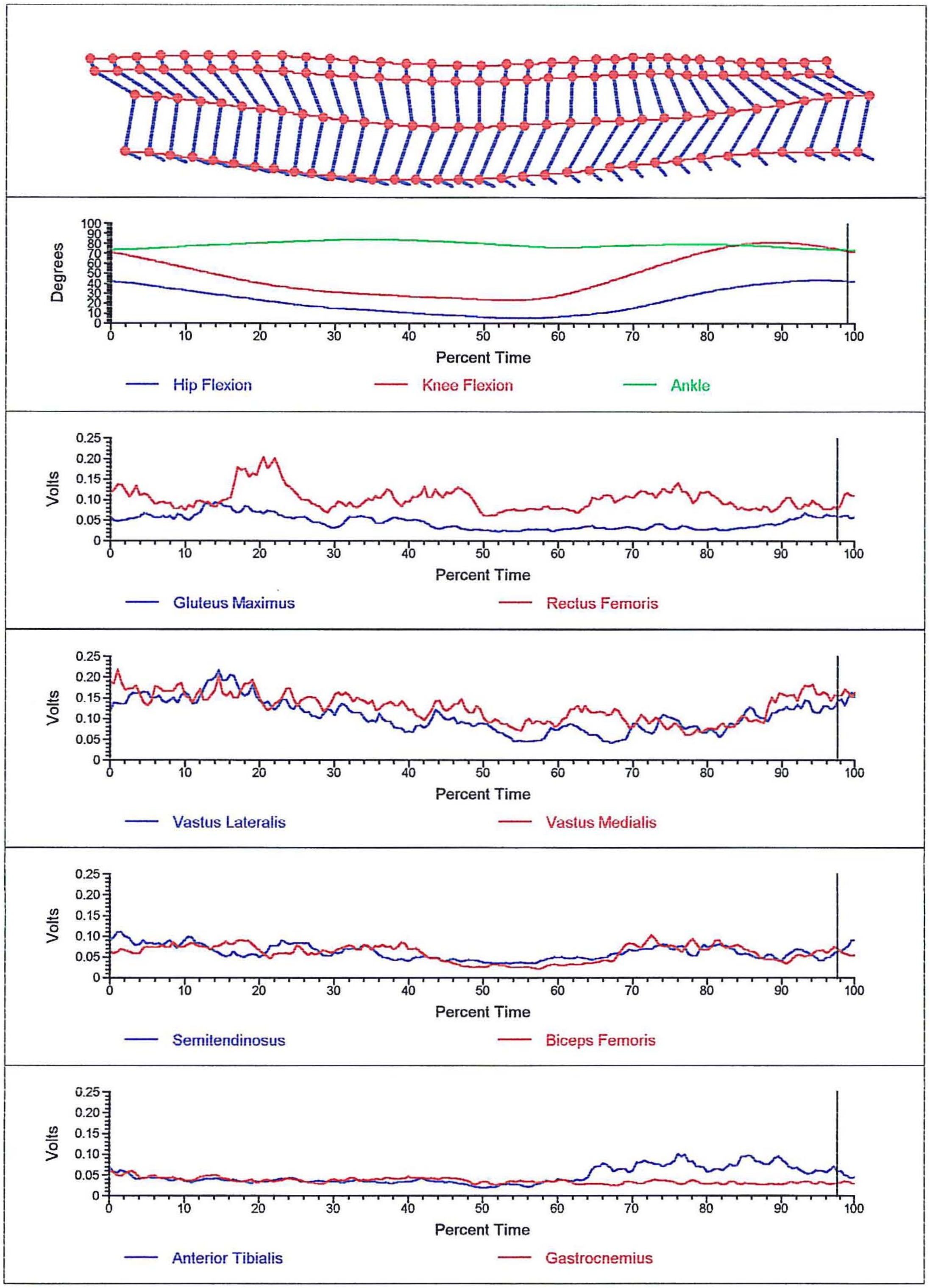


Figure 12. Forward striding at a 30 degree incline.

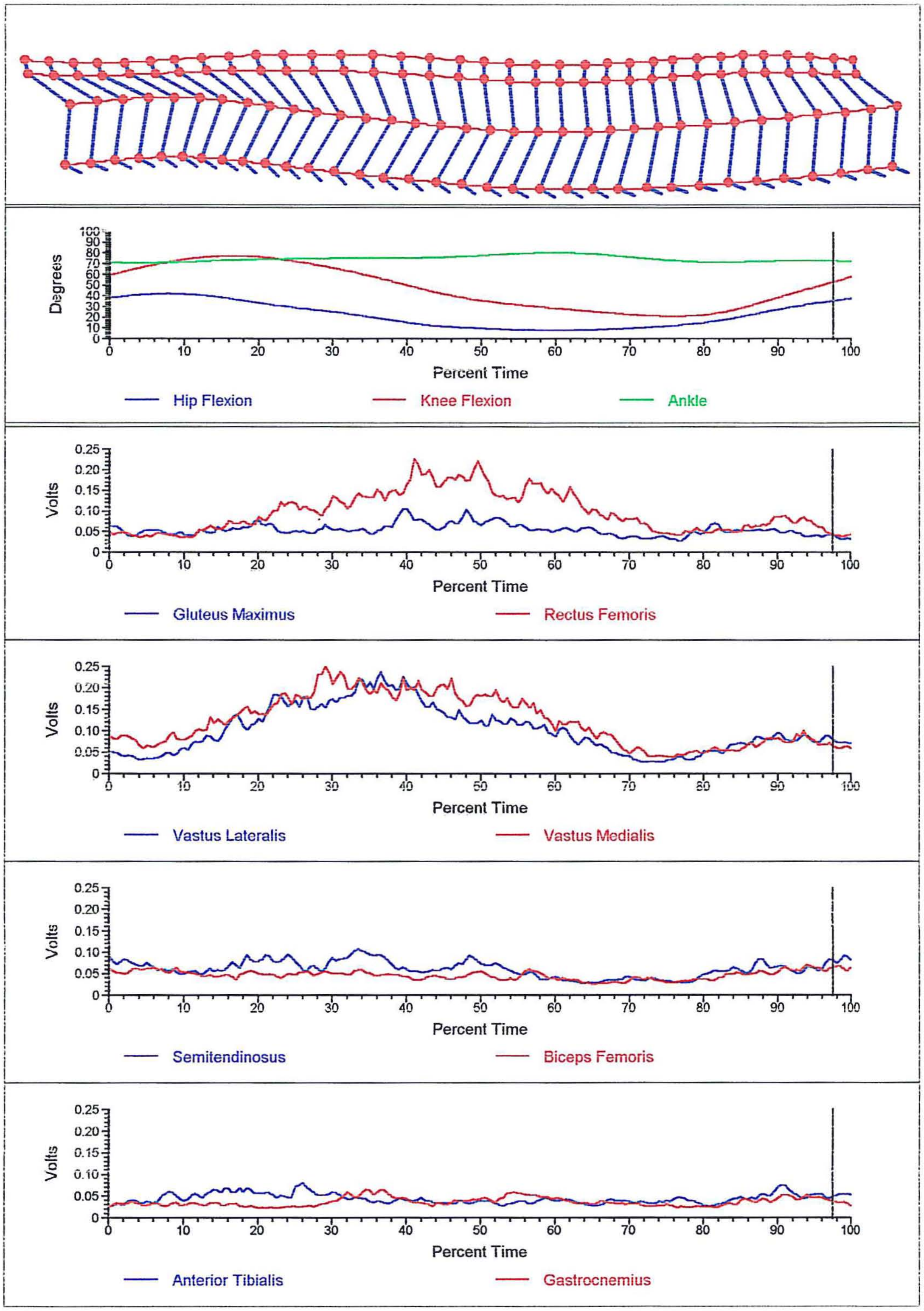


Figure 13. Backward striding at a 30 degree incline.

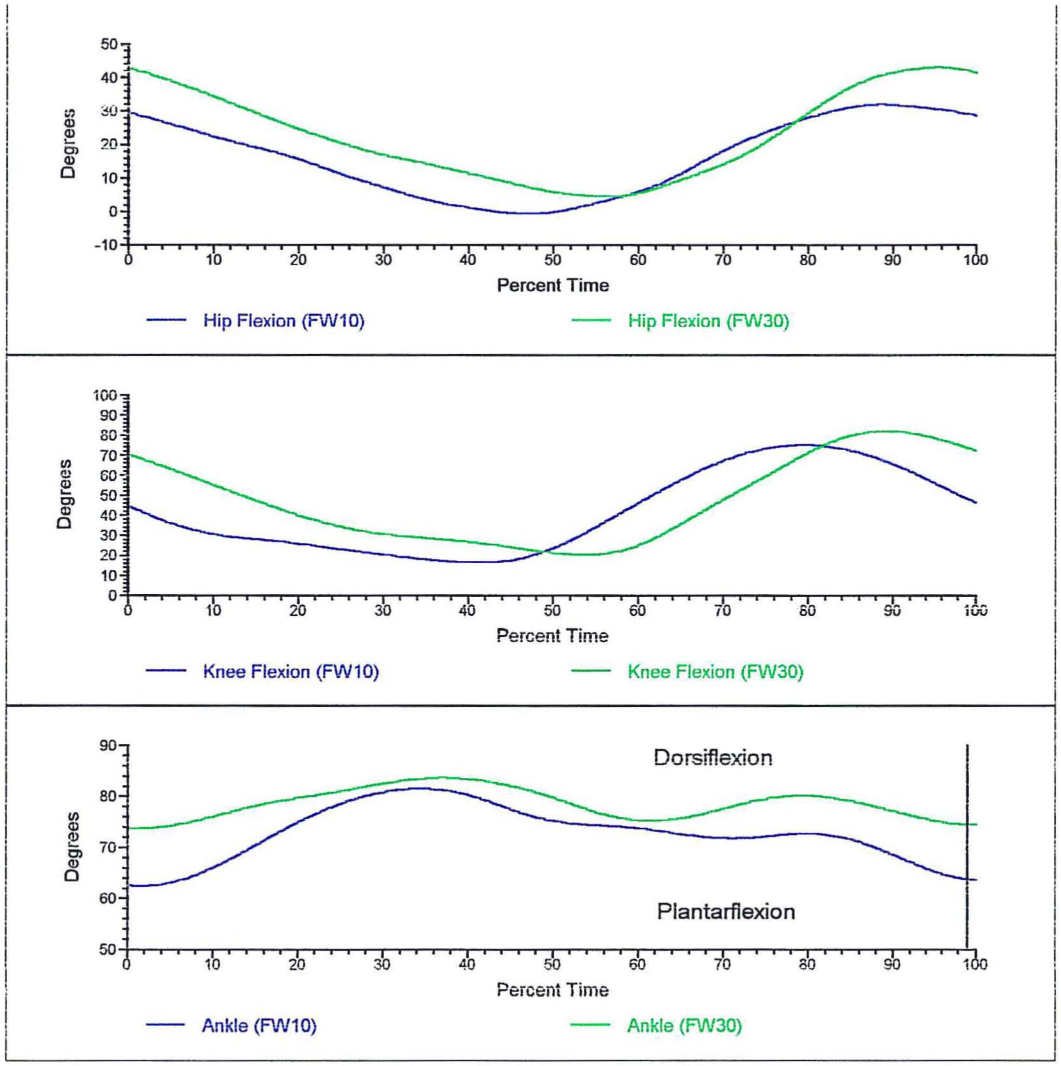


Figure 14. Range of motion during forward striding.

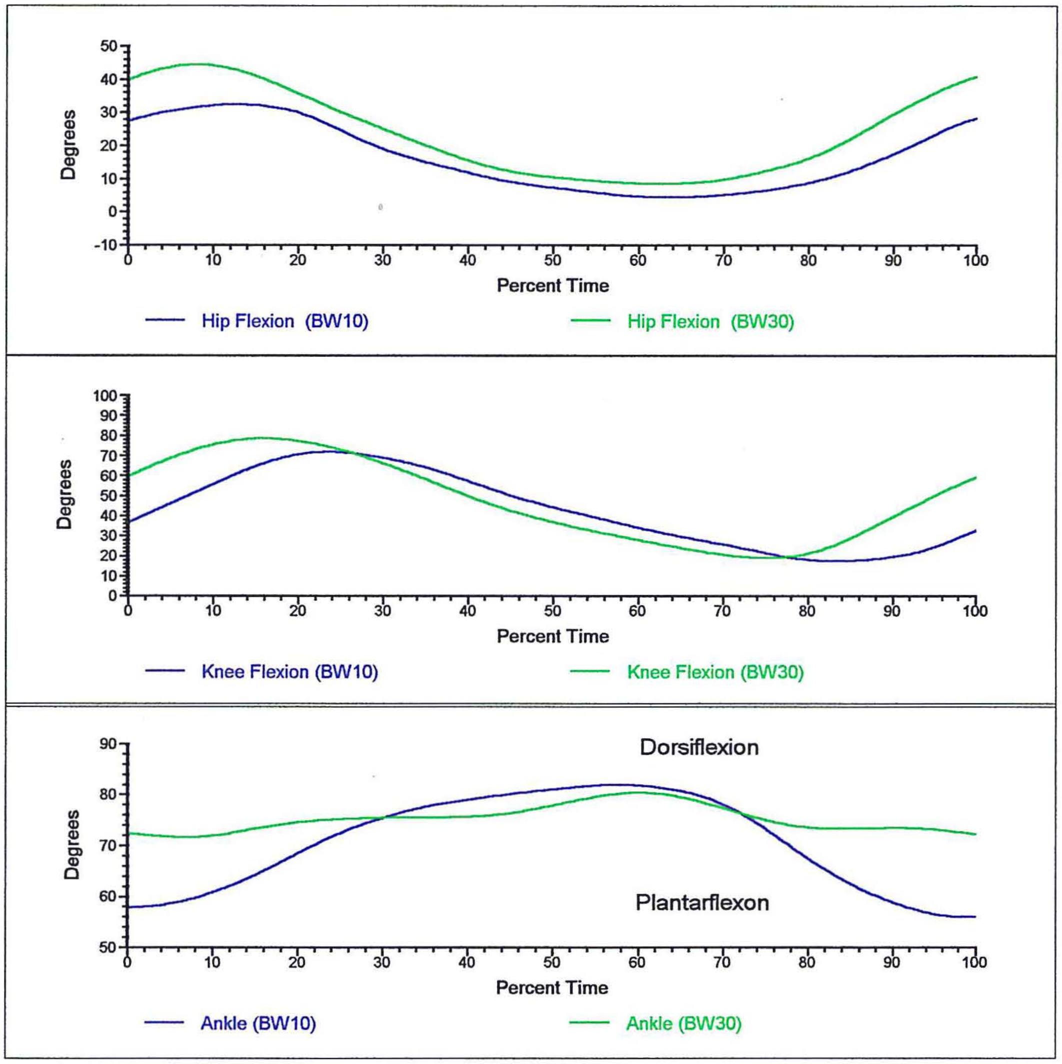


Figure 15. Range of motion during backward striding.

Table 3. Percent change in muscle activity during experimental trials. The percent changes are in comparison to forward striding at 10 degrees.

	GM	ST	BF	VL	RF	VM	AT	GS
BW 10	-21.82%	-4.84%	-11.11%	2.04%	6.25%	20.19%	-7.41%	-9.52%
FW 30	-10.91%	9.68%	14.81%	11.22%	25.00%	15.38%	-1.85%	-9.52%
BW 30	-10.91%	4.84%	-9.26%	7.14%	28.75%	15.38%	-14.81%	-14.29%

Table 4. Lower extremity joint range of motion during forward and backward striding.

Joint		10° forward	10° backward	30° forward	30° backward
Hip	**Min value**	-1 °	5 °	5 °	8°
	Max value	30 °	32 °	43 °	45 °
	Total Range	31 °	27 °	38 °	37 °
Knee	**Min value**	15 °	16 °	20 °	20 °
	Max value	75 °	72 °	82 °	80 °
	Total Range	60 °	56 °	62 °	60 °
Ankle	**Min value**	2° dorsiflexion	2° dorsiflexion	4° dorsiflexion	0°
	Max value	18 ° plantarflexion	24° plantarflexion	6° plantarflexion	10° plantarflexion
	Total Range	20°	26°	10°	10°

CHAPTER V

DISCUSSION

The Precor EFX elliptical trainer manufacturer claims that medium-high settings target the quadriceps and high ramp settings target the gluteus maximus.[3] The manufacturer's claims do not corroborate with the results of this study. The results of this study indicated that a change in muscle activity was not consistent with changing directions or inclines.

The motion of the elliptical rider is different than the motions of other exercise machines; therefore, it is impossible to compare the results of this study to another exercise machines. Backward striding on the elliptical trainer is similar to walking backward down a hill, whereas backward walking on a treadmill is comparable to walking up a hill.

Clinical Implications

If this machine is used for strengthening, the best setting for each muscle would appear to be forward stride at 10° incline for the GM, forward stride at 30° incline for the hamstrings, VM and VL are active with forward and backward stride at both inclines, backward stride at 30° incline for the RF, and forward stride for the AT and GS. Even though all muscles tested generated activity, the results show that the EMG was quite variable. Therefore, we would caution therapists using this machine for patient intervention.

Total ROM for the hip and knee increased as the incline increased. Total ankle ROM decreased when the incline increased. Use of this machine to increase hip and knee ROM may be acceptable, however buying an elliptical trainer may not be beneficial since at most facilities there are already other low impact exercise machines that increase muscle strength as well as increase ROM.

Limitations

A few limitations have been associated with the results. One limitation is that the resistance of the machine may have been set too low. Also, statistical analysis was unable to be performed due to the small sample size of the study. The electrodes on one subject didn't adhere, so the subject had to be eliminated from this study, reducing the total number of subjects to five. The muscles tested could not be compared because a baseline of each subject's muscle activity wasn't recorded. When assessing hip ROM, the pelvis was used, instead of the trunk, making the lever arm shorter and possibly not as accurate.

Future Research

Further research on the elliptical rider would help to enhance the knowledge about the machine. One idea that would be a good follow up to this study would be to study the effects of the muscles when the resistance of the machine is increased during forward and backward striding. It also may be beneficial to increase the number of subjects used, use same gender subject, or use subjects at the same training level. Additional ideas include comparing muscles and determining which muscles are most active throughout the cycle.

The subjects could also face backward on the machine. Another idea would be to compare the same subject on the elliptical rider and other exercise machines such as the stair-stepping machine, a stationary bicycle, a cross-country ski machine, and a treadmill.

Conclusion

In conclusion, we were unable to confirm any of the hypotheses. Changing the incline and direction had a variable effect on muscle activity and ROM. Until further research has been completed, it is hard to justify the use of this machine for patient intervention.

APPENDIX

_X__EXPEDITED REVIEW REQUESTED UNDER ITEM _3__ (NUMBER[S]) OF HHS REGULATIONS
___EXEMPT REVIEW REQUESTED UNDER ITEM _____ (NUMBER[S]) OF HHS REGULATIONS

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

PRINCIPAL INVESTIGATOR: Thomas Mohr, Jennifer Tveit, Kristin Sweeney, Sarah Mannel **TELEPHONE:** 777-2831
DATE: 5/4/00

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

SCHOOL/COLLEGE: Medicine & Health Sciences **DEPARTMENT:** Physical Therapy **PROPOSED PROJECT DATES:** 5/15/00 to 5/1/01 (Month/Day/Year)

PROJECT TITLE: An Electromyographic and Video Motion Analysis Study of Elliptical Trainer

FUNDING AGENCIES (IF APPLICABLE): None

TYPE OF PROJECT (Check ALL that apply):

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

___ CHANGE IN PROCEDURE FOR A PREVIOUSLY APPROVED PROJECT

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

PROPOSED PROJECT: ____ INVOLVES NEW DRUGS (IND) ____ INVOLVES NON-APPROVED USE OF DRUG ___ 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): NA

Status: __________ Submitted; Date ______ Approved; Date______ __________ Pending

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 a 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 ellipitical 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 psycho-logical, emotional or behavioral risk. If data are collected which could prove harmful or embarrassing to the subject if associated with him or her, then describe the methods to be used to insure the confidentiality of data obtained, including plans for final disposition or destruction, debriefing procedures, etc.)

The risks involved in this research project are minimal. The 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

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

1. Where to buy Elliptical Cross-Trainers. Available at: http://www.productopia.com/1c/0,1524,1-426-0,FF.html. Accessed June 5, 2000.

2. Alan R. Elliptical trainers offer a smooth ride. Available at: http://www.bewell.com/healthy/athlete/1999/elliptical/index.as. Accessed June 5, 2000.

3. The EFX™5.17- Simply The Best. Available at: http://www.precor.com/EFX/broc_efx517_2.html. Accessed June 5, 2000.

4. Ericson MO, Nisell R, Ekholm J. Quantified electromyography of the lower-limb muscles during level walking. *Scan J Rehab Med.* 1986;18:159-163.

5. The Pathokinesiology Service & The Physical Therapy Department. *Observational Gait Analysis.* Dowey, CA: Los Amigos Research and Education Institute, Inc; 1996.

6. Grasso R, Bianchi L, Lacquaniti F. Motor patterns for human gait: backward versus forward locomotion. *J Neurophysiol.* 1998;80:1868-1885.

7. Lange GW, Hintermeister RA, Schlegel T, Dillman CJ, Steadman JR. Electromyographic and kinematic analysis of graded treadmill walking and the implications for knee rehabilitation. *J Ortho Sports Phys Ther.* 1996;23:294-301.

8. Cipriani DJ, Armstrong CW, Gaul S. Backward walking at three levels of treadmill inclination: an electromyographic and kinematic analysis. *J Ortho Sports Phys Ther.* 1995;22:95-102.

9. Norkin CC, Levangie PK. *Joint Structure and Function: A Comprehensive Analysis.* 2nd ed. F. A. Davis Company: Philadelphia, PA; 1992.

10. Cook TM, Zimmerman CL, Lux KM, Neubrand CM, Nicholson TD. EMG comparison of lateral step-up and stepping machine exercise. *J Ortho Sports Phys Ther.* 1992;16:108-113.

11. Zimmerman CL, Cook TM, Bravard MS, Hansen MM, Honomichl RT, Karns ST, Lammers MA, Steele SA, Yunker LK, Zebrowski RM. Effects of stair-stepping exercise direction and cadence on EMG activity of selected lower extremity muscle groups. *J Ortho Sports Phys Ther.* 1994;19:173-180.

12. Mohr TM, Allison JD, Patterson R. Electromyographic analysis of the lower extremity during pedaling. *J Ortho Sports Phys Ther.* 1994;2:163-170.

13. Ting LH, Kautz SA, Brown DA, Zajac FE. Phase reversal of biomechanical functions and muscle activity in backward pedaling. *J Neurophysiol.* 1999;81:544-551.

14. Neptune RR, Kautz SA, Zajac FE. Muscle contributions to specific biomechanical functions do not change in forward versus backward pedaling. *J Biomechanics.* 2000;33:155-164.

15. Li, L, Caldwell GE. Muscle coordination in cycling: effect of surface incline and posture. *J Appl Physiol.* 998;85:927-34.

16. Houtz SJ, Fischer FJ. An analysis of muscle action and joint excursion during exercise on a stationary bicycle. *J Bone Joint Surg.* 1959;41-A:123-131.

17. Ericson MO, Nisell R, Argorelius UP, Ekholm J. Muscular activity during ergometer cycling. *Scan J Rehab Med.* 1985;17:53-61.