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An Electromyographic Study of Backward Walking in Normals and in Subjects following Anterior Cruciate Ligament Repair

Matthew Johnson
University of North Dakota

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AN ELECTROMYOGRAPHIC STUDY OF BACKWARD WALKING IN NORMALS AND IN SUBJECTS FOLLOWING ANTERIOR CRUCIATE LIGAMENT REPAIR

by

Matthew Johnson
Bachelor of Science in Physical Therapy
University of North Dakota, 1996

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
1998
This Independent Study, submitted by Matthew R. Johnson in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work had been done and is hereby approved.

\[\text{Signature} \]  
(Faculty Preceptor)

\[\text{Signature} \]  
(Graduate School Advisor)

\[\text{Signature} \]  
(Chairperson, Physical Therapy)
PERMISSION

Title
An Electromyographic Study of Forward and Backward Walking in Normals and in Subjects Following Anterior Cruciate Ligament Repair.

Department
Physical Therapy

Degree
Master of Physical Therapy

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Signature  Matt Johnson

Date  Dec. 18, 1987
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ABSTRACT

Physical therapy strives to incorporate innovative and efficient protocols for rehabilitation of anterior cruciate ligament (ACL) surgeries. Research supports the benefits of closed kinetic chain exercises (distal segment of extremity is fixed) over the traditional open kinetic chain exercises (distal segment not fixed). It is theorized that backward walking on inclined surfaces will recruit the knee musculature to a greater extent than forward walking, but there is little research to support this theory. The purpose of this study was to utilize electromyography during treadmill walking to analyze the muscle activity in the lower extremity of individuals were normal and who have had an ACL repair. Seventeen subjects (11 males, 6 females) at the mean age of 25 participated in the study.

The results for all subjects were that the muscle activity of the vastus medialis, vastus lateralis, semitendinosus and biceps femoris increased during backward walking in comparison to forward walking. The semitendinosus muscle activity remained relatively equal for forward and backward walking. Increasing the angle of treadmill incline during forward and backward walking generally increased muscle activity. The subjects were classified into two groups, the normal group (N=5) and ACL group (N=12). The results from the two groups varied, however, with small subject number in each group being a large reason for the differences. Future research will need to use a larger number of subjects from both types of repair populations.
CHAPTER I
INTRODUCTION

Because the ACL is protected in a closed kinetic chain, backward walking is a valuable rehabilitation tool utilized in ACL rehabilitation protocols.¹

Problem Statement: Little published data exists that clearly documents the electromyographic activity of specified muscles during backward walking in comparison to forward walking in patients following ACL reconstruction.

The Purpose of this Study: To analyze and compare EMG activity during backward and forward walking in subjects who were both post ACL reconstruction surgery and normal.

Significance of Study: The results of this study will help confirm the efficacy of using backward walking in a clinical setting for the ACL population, in order to strengthen the affected lower extremity musculature.

Research Questions: 1) Will a change in walking direction affect the level of muscular activity in the lower extremity? 2) Will an alteration in treadmill incline affect the level of muscular activity in the lower activity?

Hypothesis: (Null Hypothesis) It is the researcher’s belief that backward walking, as well as increasing the angle of the treadmill, will produce increases in activity within all the muscles tested.
CHAPTER II
LITERATURE REVIEW

With managed care becoming a major influence on what types of treatment will be reimbursed and how long a therapist can see a patient, it is becoming more important for therapists to find faster and more effective ways to treat patients. There is also an increased emphasis placed on a therapist’s responsibility to provide evidence that the treatments their patients receive are accomplishing the goals that are established.

Steindler\textsuperscript{2} was one of the first to describe closed kinetic chain exercises. He described it as a motion in which the terminal joint meets with a considerable external resistance that prohibits free motion, such as in standing knee bends.\textsuperscript{2} With closed chain activities, motion at the knee is also accompanied by motion at the hip and ankle. The main difference between open and closed kinetic activities is that in open kinetic activities there is only motion around one joint, for example knee extension.\textsuperscript{3} This occurs because the foot is mobile and allowed to move freely in space.

Over the last several years therapists have been turning towards using closed kinetic chain activities in the rehabilitation setting. Closed kinetic chain activities have been found to have a variety of benefits over open kinetic chain activities. One of the most important advantages is that closed chain activities provide stresses that are similar to those produced during normal weight-bearing activities.\textsuperscript{4} This activity produces stresses on the joints and muscles that will be similar to those produced in everyday life.
Through the stresses produced during closed chain activities, there is also the benefit of preventing both bone and muscle atrophy. With weight-bearing activities the patient will also receive proprioception training that is necessary for normal activities.4

Another benefit of using closed kinetic activities is the decrease in anterior/posterior shear force of the tibia on the femur.5, 6 This reduction is accomplished in two ways. First, there is a co-contraction of the hamstrings with the quadriceps. The contraction of the hamstring helps to inhibit the forward translation of the tibia on the femur. In one study, the researchers found that with simultaneous contraction of the quadriceps and hamstring, the shear force was always directed posteriorly. The only time this was not the case was when the knee was near terminal extension; in which case the shear force was near zero.4, 5 The second way anterior/posterior shear force is reduced is by increasing the joint compressive force. This occurs because of the body weight that the knee is supporting in closed kinetic chain activities.7

One type of closed kinetic chain activity that has increased in use in the rehabilitation setting is backward walking. Backward walking/running adds some additional benefits that are not found with the traditional types of closed chain activities such as forward walking/running. Researchers have found that with backward running there is a significant decrease in the patellofemoral joint compressive forces.4, 7, 8, 9 This occurs because with closed kinetic chain activities there is an increase in contact between the patella and femur. With the increase in surface contact, the force in the patellofemoral joint is spread over a greater surface area decreasing the amount of force in any one location.7, 9 Not only is there a decrease in compressive force, but the force also developed is significantly slower and occurs at a later time in the stance phase. This can
be of some clinical significance because articular cartilage has visoelastic properties that make it more susceptible to injury during rapid loading. With backward running, there is a decrease in the rate of patellofemoral joint compressive forces, which decreases the chance of injuring the cartilage in the knee.\(^8\)

Backward running has also been found to be an effective tool that can be utilized in many different problems that are found in the knee. Backward running can be very effective in the rehabilitation of patients who have undergone anterior cruciate ligament reconstruction. The main reason that this can be such a useful type of treatment is that it allows a therapist to strengthen the musculature around the knee while decreasing the amount of anterior shear force produced in the knee.\(^3\)\(^-\)\(^6\),\(^8\),\(^10\) There have been several studies that have shown that backward running with ACL repaired patients results in less elongation of the anterior cruciate ligament graft.\(^4\),\(^6\)

Not only is backwards walking an effective way to increase the strength and power around the knee, it also places higher demands on the cardiovascular system than does forward running.\(^8\) This cardiovascular effect is very important when a patient is trying to regain their endurance following surgery. One study found that backward walking can also be an effective way to help increase the range of motion at the knee.\(^10\) This can be useful in efforts to prevent the formation of knee flexion contractures. Backwards running has also been effective in treating one of the most common complications following anterior cruciate ligament reconstruction, which is patellofemoral pain syndrome. This syndrome is best treated through the strengthening of the quadriceps muscle between zero and thirty degrees of motion. The reason backwards running is commonly used to treat this problem is because this is the range of
motion that creates the largest amount of stress on the anterior cruciate ligament with open kinetic chain activities.⁶

A third condition that occurs around the knee that can be successfully treated with backwards running is patellar tendonitis. During forward running the quadriceps muscle contracts eccentrically from initial contact to midstance. Research has demonstrated that early eccentric contraction of the extensor tendon is a common cause of patellar tendonitis. The reason backward running can be effective in treating patellar tendonitis is because during the early phase of gait the quadriceps contracts both isometrical and concentrical.¹¹

Significant differences can be noted between backward and forward walking. There is an increase in cadence and decrease in stride length in backward walking when compared to forward walking. It has also been found that the joint kinematics for backward walking are significantly different from those in forward walking.¹⁰ Studies have also found that backward walking is more effective in increasing the strength of the knee extensors.⁸,¹⁰,¹¹,¹²
Backward walking has been shown to be an effective way of treating several different knee pathologies, such as patellar pain syndrome and patella tendonitis. Many of the accelerated ACL rehabilitation protocols begin with early closed kinetic chain activities.⁹ With physician approval, one activity that can be very effective in the rehabilitation of anterior cruciate ligament repair is backward walking. Backward walking has been found to help decrease the anterior shear force at the knee in several studies.⁹,¹⁰
CHAPTER III
METHODS

Subjects

Seventeen subjects (12 who had undergone an anterior cruciate ligament surgery, and 5 who had were classified as normal), ages 17-42, volunteered for this study. The normal group was composed of 2 females and 3 males. The subjects, who were nine to sixteen weeks post-operative anterior cruciate ligament reconstruction, included 4 females and 9 males (Table 1 and 2). All subjects were informed of the purpose of this study and their rights as a human subject. The subjects' approval of participation was obtained by completion of a consent form approved by the Institutional Review Board at the University of North Dakota, Medical Park, and Orthopedic Associates (Appendix).

Instrumentation

Electrodes were placed according to the motor point location on the vastus medialis (VM), vastus lateralis (VL), semitendinosus (ST), and biceps femoris (BF) of the involved lower extremity. These points were defined as one-fifth the distance from the medial knee joint line and the ASIS for the VM, one-fourth the distance between the lateral femoral condyle and the ASIS for the VL, one-half the distance between the lateral femoral condyle and the ischial tuberosity for the BF, and one-half the distance between the medial femoral condyle and the ischial tuberosity for the ST, respectively. The hair over the motor points was clipped if necessary, and the skin cleansed with alcohol. Once the skin was prepared, two pre-gelled, self-adhesive electrodes (Multi Bio-Sensory, El
Table 1. ACL subject character table.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Gender</th>
<th>Height</th>
<th>Weight</th>
<th>Extremity</th>
<th>Type of Surgery</th>
<th>Wks post surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>MALE</td>
<td>6'3&quot;</td>
<td>185 lbs.</td>
<td>RIGHT</td>
<td>PATELLAR</td>
<td>15 weeks</td>
</tr>
<tr>
<td>2</td>
<td>31</td>
<td>FEMALE</td>
<td>5'3&quot;</td>
<td>120 lbs.</td>
<td>LEFT</td>
<td>PATELLAR</td>
<td>12 weeks</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>MALE</td>
<td>5'9&quot;</td>
<td>165 lbs.</td>
<td>LEFT</td>
<td>PATELLAR</td>
<td>12 weeks</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>MALE</td>
<td>6'1&quot;</td>
<td>224 lbs.</td>
<td>LEFT</td>
<td>PATELLAR</td>
<td>9 weeks</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>FEMALE</td>
<td>5'8&quot;</td>
<td>135 lbs.</td>
<td>LEFT</td>
<td>PATELLAR</td>
<td>9 weeks</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>MALE</td>
<td>6'1&quot;</td>
<td>182 lbs.</td>
<td>RIGHT</td>
<td>PATELLAR</td>
<td>9 weeks</td>
</tr>
<tr>
<td>7</td>
<td>22</td>
<td>MALE</td>
<td>6'0&quot;</td>
<td>171 lbs.</td>
<td>RIGHT</td>
<td>HAMSTRING</td>
<td>16 weeks</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>FEMALE</td>
<td>5'6&quot;</td>
<td>130 lbs.</td>
<td>RIGHT</td>
<td>HAMSTRING</td>
<td>11 weeks</td>
</tr>
<tr>
<td>9</td>
<td>42</td>
<td>MALE</td>
<td>5'10&quot;</td>
<td>195 lbs.</td>
<td>RIGHT</td>
<td>HAMSTRING</td>
<td>10 weeks</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>MALE</td>
<td>6'2&quot;</td>
<td>160 lbs.</td>
<td>RIGHT</td>
<td>HAMSTRING</td>
<td>12 weeks</td>
</tr>
<tr>
<td>11</td>
<td>17</td>
<td>FEMALE</td>
<td>5'6&quot;</td>
<td>170 lbs.</td>
<td>LEFT</td>
<td>PATELLAR</td>
<td>11 weeks</td>
</tr>
<tr>
<td>12</td>
<td>27</td>
<td>MALE</td>
<td>5'10&quot;</td>
<td>206 lbs.</td>
<td>RIGHT</td>
<td>PATELLAR</td>
<td>14 weeks</td>
</tr>
</tbody>
</table>
Table 2. Normal subject character table.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Gender</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>FEMALE</td>
<td>5'5&quot;</td>
<td>117 lbs.</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>MALE</td>
<td>5'10&quot;</td>
<td>195 lbs.</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>MALE</td>
<td>5'7&quot;</td>
<td>155 lbs.</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>MALE</td>
<td>5'7&quot;</td>
<td>155 lbs.</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>FEMALE</td>
<td>5'5&quot;</td>
<td>115 lbs.</td>
</tr>
</tbody>
</table>
Paso, TX, 79913), were applied to the skin, two centimeters apart over the motor points, parallel to the muscle fibers. The distance between surface electrode placement attempted to minimize volume conduction between muscle groups, increasing the accuracy of specific muscular activity at each motor point.¹⁵

Foot switches (Noraxon USA, 13430 North Scottsdale Rd., Scottsdale, AZ, 85254) were used to determine the phases of the gait cycle. The switches were placed over the following anatomical points: 1) heel, 2) first metatarsal head, 3) fifth metatarsal head, and 4) great toe. The electrodes were secured to the skin with tape to prevent migration during treadmill activities. The subjects remained barefoot for the entire treadmill walking portion of the study.

A Penny & Giles M180 electrogoniometer (Penny & Giles Inc., 2716 Ocean Park Blvd., Santa Monica, CA, 90405) was applied over the lateral aspect of the involved knee joint in order to obtain knee range of motion during ambulation. The electrogoniometer was centered over the joint axis with the proximal end of the electrogoniometer aligned with the longitudinal axis of the femur, and the distal end aligned with the longitudinal axis of the fibula. The electrogoniometer was secured to the skin with double-sided adhesive tape to avoid migration during data collection. The electrogoniometric zero was obtained by having the subject stand stationary with their lower extremities in full extension.

The subjects wore a waist belt containing a pre-amplified Noraxon Telemo8 telemetry unit (Noraxon USA, 1340 North Scottsdale Rd., Scottsdale, AZ, 85254), which received information from the EMG electrodes, the electrodes, the electrogoniometer, and the foot switches. The EMG signals were transmitted to a Noraxon Telemyo8
receiver and then digitized by a DT2801-Analog to a digital interface board installed in a NET 486DX computer. The digitized EMG signals were analyzed using the Myosoft data collection software that accompanies the Telemyo8 EMG system. The Myosoft software allows for several forms of data analysis once the EMG signals are collected.

**Procedure**

The treadmill was calibrated using a Veeder-Root 6611 Calibrater to 3.0 m.p.h. The subjects were tested for their maximal voluntary contraction (MVC) of the VM, VL, ST, and BF on the involved lower extremity to obtain a base line of activity. The data was used to normalize EMG data collected during forward and backward walking.

The MVCs of the vastus medialis and vastus lateralis were obtained with the subjects sitting with legs over the edge of a plinth. The subjects were allowed to lean backward and grasp onto the edge of a plinth. The subjects were allowed to lean backward and grasp onto the edge of surface for support. The knee was positioned in slight flexion, and stabilization was provided proximally to the knee joint without applying pressure over the quadriceps. The force of resistance was given proximal to the anterior ankle and for a duration of five seconds. The MVC for the semitendinosus and biceps femoris was obtained in the same position as the vastus medialis and vastus lateralis, using the same stabilization method and duration. The force of resistance was applied proximally to the posterior ankle.

Prior to experimentation, each subject's age, height, weight, gender, physician, date of surgery, type of surgery (specifically patellar or hamstring graft), and resting peripheral pulse rate. The subjects were then instructed on safety precautions while walking on the treadmill, on the use of the support rails for forward and backward
walking, and on the application of the safety harness belt worn during backward walking. They were instructed on the proper procedure for getting on and off the treadmill for both forward and backward walking. The subjects were given warm up trial prior to the test, to become familiar with forward and backward barefoot walking on the treadmill. Data was collected from ten second trials of forward and backward walking at 3.0 miles per hour, and at 0,10,15 degrees of incline. Subjects were allowed a one-minute rest period between trials.

Once data collection was completed, the electrodes, foot switches, and electrogoniometer were removed and the skin cleansed with alcohol. Each subject was questioned via a brief interview to determine if the subject experienced any pain during any portion of the study. The subjects’ pulse rate was again taken after the treadmill portion of the study. This concluded the subject’s participation in the study.

Data Analysis

A descriptive analysis of the EMG data was performed using the Mysoft and Norquest software to make comparisons between forward and backward walking. The data collected from the normal subjects was analyzed separately and was compared to the results of the post-reconstructed anterior cruciate ligament patients. The normal subjects were obtained from a previous unpublished study conducted by Yoshimoto\textsuperscript{16} and were reanalyzed. Ten of the twelve ACL subjects analyzed were obtained from an unpublished study by Litt\textsuperscript{17}

Normalization of EMG data is necessary to allow comparison between subjects (Noe\textsuperscript{23}). The EMG data for the trials was normalized using the muscle activity that occurred during forward walking at 0\% grade.
The ambulation data was quantified by selecting three consecutive phases of gait during forward and backward walking. The Myosoft and Norquest software was used to calculate the average activity using the fifty highest peaks during the three cycles. One gait phase was defined as the amount of activity between initial contact to initial contact of the same foot.

To obtain the normalized value, the average EMG activity obtained for each muscle during the three trials was divided by the average EMG activity obtained during forward walking at a zero degree incline and expressed as a percentage.

\[
\text{% Activity} = \frac{\text{Average EMG Activity During Exercise}}{\text{Average EMG Activity During Forward Ambulation}} \times 100
\]
CHAPTER IV

RESULTS

Muscle Recruitment for all Subjects:

Data was collected at a ten degree incline for all subjects. However, due to the similarities of the electromyographic activity at ten and fifteen degrees, this data was not analyzed. All quantitative data can be observed in table 3 on page 16. When observing FW15, BW0, and BW15, all muscles displayed an increase in activity as compared to forward walking at a zero percent grade (Figure 1). The activity level observed during backward walking was greater than that found during forward walking at fifteen degrees, regardless of treadmill inclination. Backward walking at fifteen degrees elicited the greatest increase in muscle activity for all muscles tested. The VM and VL muscle activity levels surpassed the activity in the ST and BF during backward walking at both zero and fifteen degrees.

Muscle Recruitment within the ACL Sample:

During FW15, the VL, ST, and BF achieved a higher level of activity than FW0, however, the VM demonstrated a slight decrease. All muscles display an increase in activity when walking backward, with the exception of the BF during BW0. Backward walking at zero degrees produced increases in muscle activity within the VM and VL, which surpassed the activity level in those same muscles during forward walking at fifteen degrees. In addition, the quadriceps tested displayed a greater increase in EMG
activity than did the hamstrings when walking backward at zero and fifteen degrees (Figure 2).

**Muscle Recruitment within the Normal Sample:**

Compared to forward walking at zero degrees, an increase in muscle activity was noted during FW15, BW0, and BW15 in all the tested muscles. The greatest amount of activity was consistently observed within the vastus medialis during all activities. Backward walking at zero degrees elicited a greater amount of muscle activity than FW15 in all of the tested muscles. The activity within the quadriceps was greater than that observed within the hamstrings when walking backward (Figure 3).
Table 3. Electromyographic activity of lower extremity muscles during forward and backward walking. The values are given as a percent of forward walking at 0 degrees.

**Normal Subjects**

<table>
<thead>
<tr>
<th></th>
<th>Vastus Medialis</th>
<th>Vastus Lateralis</th>
<th>Semitendinosus</th>
<th>Biceps Femoris</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW 15 degrees</td>
<td>173.0%</td>
<td>104.5%</td>
<td>85.5%</td>
<td>134.6%</td>
</tr>
<tr>
<td>BW 0 degrees</td>
<td>245.1%</td>
<td>180.6%</td>
<td>94.0%</td>
<td>170.2%</td>
</tr>
<tr>
<td>BW 15 degrees</td>
<td>528.0%</td>
<td>482.6%</td>
<td>130.0%</td>
<td>238.4%</td>
</tr>
</tbody>
</table>

**ACL Reconstructed Subjects**

<table>
<thead>
<tr>
<th></th>
<th>Vastus Medialis</th>
<th>Vastus Lateralis</th>
<th>Semitendinosus</th>
<th>Biceps Femoris</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW 15 degrees</td>
<td>-13.9%</td>
<td>7.4%</td>
<td>14.5%</td>
<td>6.2%</td>
</tr>
<tr>
<td>BW 0 degrees</td>
<td>111.3%</td>
<td>25.8%</td>
<td>9.2%</td>
<td>-6.2%</td>
</tr>
<tr>
<td>BW 15 degrees</td>
<td>153%</td>
<td>84%</td>
<td>28.3%</td>
<td>20%</td>
</tr>
</tbody>
</table>

**All Subjects**

<table>
<thead>
<tr>
<th></th>
<th>Vastus Medialis</th>
<th>Vastus Lateralis</th>
<th>Semitendinosus</th>
<th>Biceps Femoris</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW 15 degrees</td>
<td>79.6%</td>
<td>56.0%</td>
<td>50.0%</td>
<td>70.5%</td>
</tr>
<tr>
<td>BW 0 degrees</td>
<td>178.2%</td>
<td>103.2%</td>
<td>51.6%</td>
<td>82.0%</td>
</tr>
<tr>
<td>BW 15 degrees</td>
<td>340.5%</td>
<td>283.3%</td>
<td>79.2%</td>
<td>129.2%</td>
</tr>
</tbody>
</table>
Figure 1. Electromyographic activity of the quadriceps and hamstrings during forward and backward walking in all subjects.
Figure 2. Electromyographic activity of the quadriceps and hamstrings during forward and backward walking in patients following ACL reconstructive surgery.
Figure 3: Electromyographic activity of the quadriceps and the hamstrings during forward and backward in normal patients.
All Subjects:

There is no question that backward walking is a different activity than forward walking.\textsuperscript{12, 13, 16} When all subjects were analyzed as a group, there was an increase in muscle activity in all of the muscle groups tested with backward walking at both zero and fifteen degrees. The muscle activity was also higher during BW0 and BW15 than FW15. The increase in the VM, VL, and BF was consistent with other studies on muscle activity during backward walking.\textsuperscript{11, 16, 18, 19} One possible explanation for the increase in the muscle activity during backward walking is that the subject has to pull the leg back instead of having momentum that would carry the leg backward.\textsuperscript{20} This results in the muscles being more active in a pulling and stabilizing function during backward walking than forward walking.

This study also found that, when all the subjects were analyzed as a group, the quadriceps muscles were consistently activated to a greater degree than the hamstrings at all levels of incline for backward and forward walking. Other studies have found similar results.\textsuperscript{10, 11, 16, 21} The EMG activity in the semitendinosis remained relatively consistent with BW and FW, regardless of the change in the incline. The largest increase was during backward walking at fifteen degrees. However, Cipriani\textsuperscript{10} found a decrease in the amount of activity in the semitendinosus with an increased incline of the treadmill. This
activity was noted at initial contact, midstance, and midswing phases of the gait cycle.

One possible explanation for this difference is that we had a mixture of anterior cruciate ligament subjects and normal patients. Whereas in the Cipriani et al\textsuperscript{10} study they only analyzed normal subjects.

**Normal Group**

The results of the normal group strongly resembled the results of the combined group of ACL and normal subjects. In both cases, there was an increase in the muscle activity of all tested muscles when the activity was changed from forward to backward walking. There was also an increase in all muscle activity when comparing FW15 with BW0. With all the muscle groups there was an increase in muscle activity when comparing backward walking at zero with backward walking at fifteen degrees.

In a study by Yoshimoto\textsuperscript{16}, he found that regardless of the activity there was an increase in all muscle activity, except for the semitendinosus, as the treadmill incline was increased. The semitendinosus produced a slight decrease in muscle activity when the treadmill was increased from ten to fifteen degrees. This occurred during both in forward and backward walking.

**Anterior Cruciate Ligament Repair Group**

An increase in muscular activity was noted in all the tested muscles, during BW15. During BW0, there was an increase in activity level for the ST, VM, and VL. The BF demonstrated a slight decrease in EMG activity when walking backward at zero grade. All muscles, with the exception of the VM, showed an increase in activity during FW15.
In an unpublished study by Litt\textsuperscript{17}, there were several differences and similarity between our study and hers. In both studies there was an increase in muscle activity of the VM when comparing backward walking at zero and fifteen degrees to forward walking at zero and fifteen. Both studies also showed an increase in VM activity when comparing BW at zero to BW at fifteen degrees. In forward walking, Litt\textsuperscript{17} found that there was a increase in muscle activity for the VM as the treadmill incline was increased. She also found that the activity of the VL decreased as the incline of the treadmill was increased for forward walking. However, the activity level of the VL increased when performing backward walking at zero degrees and fifteen degrees incline. This was similar to the results of our study. In both studies, the activity for the VL was higher in backward walking than forward walking.

There were very few similarities between the activity level for the hamstrings in Litt's\textsuperscript{17} study as compared to ours. The activity of the semitendinosus was similar to ours in that in both studies the muscle activity was higher in backward walking at zero than forward walking at zero. Litt\textsuperscript{17} found that the activity of the ST decreased as the level of the treadmill was increased during backward walking. She also found that the muscle activity in the ST decreased when comparing FW0 to FW15. The only similarity for the biceps femoris was that BW15 elicited a higher level of EMG activity than forward walking at zero and fifteen degrees. Litt\textsuperscript{17} also found that the activity in forward walking decreased as the treadmill incline was increased for the biceps femoris. She also found a slight decrease in EMG activity when comparing BW0 to BW15.

One of the possible explanations for the differences in these two studies is that the data was analyzed differently for the two research projects. In our study we used the
electromyographic activity during forward walking at zero, as our base line for muscle activity. Litt\textsuperscript{17} used the patient’s maximum voluntary contraction as her base line for EMG activity for each tested muscle.

**Limitations**

There were several limitations in this study. First, and probably the most important was the small sample size. With a small sample group the results are easily skewed by one or two people that fall outside of the standard. Also, with a small sample size it is difficult to generalize these results. A second problem was the unequal number of subjects in each group. There was twelve subjects in the anterior cruciate ligament group and only five in the normal group. This makes it difficult to make assumptions about the similarities and differences between the normal and ACL group. Another limitation of this study was the identification of the motor points. Even though we had a second person double check the measurements it is still possible that the electrodes were not placed in the exact same location between patients. A fourth limitation of this study was that we assumed that the stride length between subjects would be the same for our data analysis. It is conceivable that the stride length was different depending on the subject height and gait substitutions between patients. The lack of accurate gait analysis was another limiting factor. It would be beneficial to use cinematography or motion analysis to optimize accurate analysis of lower extremity musculature during gait.

**Clinical Implications**

This study has shown that when performing backward walking there is an increase in overall muscular activity around the knee. This finding was consistent with both post ACL reconstruction subjects and normals. The use of backward walking should continue
to be utilized in anterior cruciate ligament protocols because the surrounding musculature can be strengthened while the tension on the graft is minimized
APPENDIX
REPORT OF ACTION: EXEMPT/EXPEDITED REVIEW
University of North Dakota Institutional Review Board

DATE: October 8, 1997
NAME: Matt Johnson
PROJECT NUMBER: IRB-9710-067
DEPARTMENT/COLLEGE: Physical Therapy
PROJECT TITLE: An Electromyographic Study of Forward and Backward Walking in Normal Subjects

The above referenced project was reviewed by a designated member for the University’s Institutional Review Board on October 14, 1997 and the following action was taken:

☐ Project approved. EXPEDITED REVIEW NO. ____________.
☐ Next scheduled review is on October 1998.
☐ Project approved. EXEMPT CATEGORY NO. ____________.
☐ No periodic review scheduled unless so stated in the Remarks Section.
☐ Project approved PENDING receipt of corrections/additions. These corrections/additions should be submitted to ORPD for review and approval. This study may NOT be started until final IRB approval has been received. (See Remarks Section for further information.)
☐ Project approval deferred. This study may not be started until final IRB approval has been received. (See Remarks Section for further information.)
☐ Project denied. (See Remarks Section for further information.)

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

cc: T. Mohr, Adviser
Dean, Medical School

[Signature of Designated IRB Member]
UND’s Institutional Review Board

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

(3/96)
October 6, 1997

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

Dear Mr. Mohr,

I have had the opportunity to review the research proposal “An Electromyographic Study of Forward and Backward Walking in Normal Subjects.” As the Medical Director of the Red River Valley Sports Medicine Institute, I approve and fully support this research endeavor. We look forward to working together with you.

Sincerely,

Mark A. Lundeen, MD
Medical Director RRVSMI
It has become commonplace in many physical therapy clinics to employ both forward and backward treadmill walking in the rehabilitation programs of patients with post-anterior cruciate repairs. Although this technique is used, there is little evidence available as to the muscle activity required in backward walking as compared to forward walking. Some clinicians speculate that backward walking recruits lower extremity muscles in a different pattern than forward walking, and they claim that backward walking causes greater use of the hamstring muscles than does forward walking. There is little evidence to support any of the clinical claims, because there is no published research on this particular form of exercise. In an effort to provide clinicians with information as to the muscle activity in both forward and backward treadmill walking, we are proposing to study four knee muscles during treadmill walking; with both a level treadmill and at several different inclines. Information gained from this study will help provide clinicians with information that will be useful to them in setting up exercise protocols for the patient populations. Since this technique is presently used clinically, it is necessary that we utilize human subjects for this study.
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 normal, healthy, male and female volunteers, ages 19 to 40 years. The subjects used for this study will be physical therapy students enrolled in the professional physical therapy program at UND.

METHODS:
We will measure the electromyographic (EMG) activity in these four lower extremity muscles: 1) vastus medialis, 2) vastus lateralis, 3) biceps femoris, and 4) semitendinosus. Knee range of motion, and foot-ground contact during treadmill walking will also be analyzed.

To record the EMG activity, surface electrodes will be placed over the muscle under study. The EMG signals will be transmitted to the receiver unit and then relayed into a computer for display and for recording data. Prior to beginning the experimental trials, each subject will be asked to perform a maximal voluntary contraction (MVC) of each monitored muscle. The activity recorded during the MVC will be considered as 100% EMG activity level, which the EMG activity during treadmill walking can be compared. This procedure is done to normalize the EMG data for later analysis.

An electrogoniometer will be used to measure knee range of motion during treadmill walking. The electrogoniometer will be attached to the thigh and leg above and below the knee joint, respectively using double sided adhesive tape. This will allow measurement of knee flexion during treadmill walking. The electrogoniometer will be calibrated prior to beginning the experimental trial to assure accuracy of measurement.

A footswitch device will be secured with tape to the foot at the following points: 1) heel, 2) 1st metatarsal head, 3) 5th metatarsal head, and 4) great toe. The switch will trigger a small signal that will be recorded during the various phases of the gait cycle.

Prior to the trials, each subject's age, height, and weight will be recorded. During the experimental trials, the involved lower extremity will be used for data collection. Before beginning the experiment, each of the subjects will be given a short training session on proper treadmill ambulation.

The actual experiment involves applying the electrogoniometer device and the footswitch apparatus to each subject. The skin of the lower extremity will be cleansed with alcohol before attachment of the self-adhesive pre-gelled EMG electrodes over the muscles. The subject will be asked to elicit a MVC of each monitored muscle which will be recorded on the computer as a reference voltage level. The actual experiment will consist of the following trials: 1) forward and backward walking at 0 degrees of incline, 2) forward and backward walking at 10 degrees of incline, and 3) forward and backward walking at 15 degrees of incline. Treadmill speed will be set at 3.0 m.p.h for all the trials.

Subjects will be asked to walk on treadmill for a trial period of 15 seconds during which time the EMG, electrogoniometer, and footswitch data will be collected and recorded. Subjects will be allowed one minute rest periods between the experimental trials to avoid a fatigue factor. Finally, the subjects will be given a rest period while the electrodes, electrogoniometer, and footswitch devices are removed.

DATA ANALYSIS:
Descriptive statistics characterizing the subject's anthropometric profiles will be provided. Statistical analysis (t-test & ANOVA) will be performed on the following dependent variables: 1) integrated EMG activity, and 2) electrogoniometric measurements.
3. **BENEFITS:** (Describe the benefits to the individual or society.)

The results of this study will help to determine if backward walking shows a different muscle recruitment pattern than forward walking. At the present time, there is no available research data on backward vs forward walking, and therefore its use in the clinic is unsupported. If backward walking is determined to increase muscle activity, it could validate its use in an ACL rehabilitation protocol. It is expected that the use of backward walking increases recovery rate and the return to full activities of daily living, thus decreasing the cost of lengthy rehabilitation. If this exercise proves beneficial, it may become a well accepted and integral activity in the rehabilitation of ACL repair.

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 risk to the subjects in this experiment will be minimal. Treadmill walking is a safe form of exercise and the amount of time on the treadmill is minimal. During the course of the experiment, subjects will be accompanied on the treadmill by an assistant, and treadmill hand rails will be close by for added safety. The EMG, electrogoniometer, and footswitch equipment will cause no discomfort to the subjects, since they are only monitoring devices. The subjects will be asked to wear gym shorts during the experiment, and every effort will be taken to preserve subject dignity during the course of the experiment.
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.

The consent forms will be kept by Thomas Mohr at the University of North Dakota, Department of Physical Therapy, Room 1521, Medical Science Building for a period of three (3) years. A copy of the consent form is attached.

Copies of the original data will be archived on computer disk in the office of Dr. Thomas Mohr, Department of Physical Therapy, Room 1521, Medical Science North Building for a period of at least three (3) years.

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

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

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

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

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

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**SIGNATURES:**

**Principal Investigator**

**Project Director or Student Adviser**

**Training or Center Grant Director**

(Revised 3/1996)
INFORMATION AND CONSENT FORM

TITLE: An Electromyographic Study of Forward and Backward Walking In Normal Subjects.

You are being invited to participate in a study conducted by Dr. Thomas Mohr, a Professor at the University of North Dakota. The purpose of this study is to compare muscle activity in your lower extremity while you are walking on the treadmill. We hope to learn that backward walking will recruit the knee musculature to a greater extent than forward walking. Only normal, healthy subjects will be asked to participate in this study.

You will be asked to walk on a treadmill under the following conditions: 1) forward and backward walking at 0 degrees of incline, 2) forward and backward walking at 10 degrees of incline, and 3) forward and backward walking at 15 degrees of incline. The treadmill speed will be set at 3.0 m.p.h. Each experimental trial duration will be 15 seconds, and you will be allowed a one minute rest period between trials.

The study will take approximately one hour of your time. You will be asked to report to Red River Valley Sports Medicine in Fargo, ND at an assigned time. You will then be asked to change into gym shorts for the experiment. We will first record your age, gender, height, and weight. During the experiment, we will be recording the amount of muscle activity you have when you walk on the treadmill, measure the amount of movement that occurs in your knee joint, and record data from foot contact with the ground.

Although the process of physical performance testing always involves some degree of risk, the investigator in this study feels that the risk of injury or discomfort is minimal. In order for us to record the muscle activity, we will be placing nine electrodes on your lower extremity. The recording electrodes are attached to the surface of the skin with an adhesive material. We will also attach a measuring device to your knee with adhesive material. We will place foot switches on the sole of foot. None of these electrodes or devices penetrate the skin, and they should cause no discomfort. These devices only record information from your muscles and joints, they do not stimulate the skin. After we get the electrodes attached, we will give you a brief training session to teach you how to walk on treadmill. The amount of walking you will be asked to perform will be minimal compared to what you might expect of walking on a daily basis.

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

The investigator involved is available to answer any questions you have concerning this study. In addition, you are encouraged to ask any questions concerning this study that you may have in the future. Questions may be asked by calling Dr. Thomas Mohr at (701) 777-2831. A copy of this consent form is available to all participants in the study.
In the event that this research activity (which will be conducted at Red Rive Valley Sports Medicine) results in a physical injury, medical treatment will be available, including first aid, emergency treatment, and follow-up care as it is to members 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 Dr. Thomas Mohr.

Participant’s Signature Date

Witness (not the scientist) Date
REFERENCES


