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An Electromyographic and Motion Analysis of Forward and Backward Walking

Sarah DeKrey  
*University of North Dakota*

Lori Guderian  
*University of North Dakota*

Kerry Hendricksen  
*University of North Dakota*

Glenda Scott  
*University of North Dakota*

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AN ELECTROMYOGRAPHIC AND MOTION ANALYSIS OF FORWARD AND BACKWARD WALKING

by

Sarah DeKrey
Lori Guderian
Kerry Hendricksen
Glenda Scott
Bachelor of Science in Physical Therapy
University of North Dakota, 2002

A Scholarly Project
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
2003
This Scholarly Project, submitted by Glenda Scott, Sarah DeKrey, Lori Guderian, and Kerry Hendricksen in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Graduate School Advisor)

(Chairperson, Physical Therapy)
PERMISSION

Title An Electromyographic and Motion Analysis Study of Forward and Backward Walking

Department Physical Therapy

Degree Master of Physical Therapy

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Date 12/17/02
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Finally to our families, friends, and Heavenly Father - your encouragement and love have aided us greatly throughout both school and life and we would not be who we are today without you – Thank You.
ABSTRACT

Backward walking is a common intervention in the rehabilitation of lower extremity injuries. Despite its popularity, there is limited research available on the EMG activity during backward walking at an incline when compared to forward walking. In this study, we recorded EMG activity in four muscles of the lower extremity and utilized motion analysis to evaluate the knee range of motion when walking forward and backward on a treadmill at 0 and 15 percent grade inclines.

Overall, our results indicated a greater increase in muscle activity during backward walking than forward walking. Walking backward at a 15 percent grade incline showed the largest increase in muscle activity with the vastus lateralis showing increase of 609%, vastus medialis increasing 339%, semitendinosus increasing 189%, and biceps femoris increasing 172% when compared with forward walking at a 0 percent grade.

Our results showed the degree of knee flexion to be the greatest during backward walking at a 15 percent grade (70.2 degrees of knee flexion), followed by forward walking at a 15 percent grade (68.4 degrees of knee flexion), forward walking at 0 percent grade (67.4 degrees of knee flexion) and finally backward walking at 0 percent grade (57.5 degrees of knee flexion).

We conclude that both backward and forward walking at an incline can be beneficial for lower extremity rehabilitation.
CHAPTER I
INTRODUCTION

Rehabilitation professionals, including physicians and physical therapists, are constantly trying new approaches for post-operative rehabilitation of anterior cruciate ligament (ACL) injuries of the knee. One approach is to utilize forward (FW) and backward (BW) (retrowalking) walking on a treadmill as part of their rehabilitation protocol.

Problem Statement: Currently there is a limited amount of research available to attest to the efficacy of rehabilitation techniques with FW and BW on a treadmill. Further research is needed to validate this treatment method in patients. Although some research exists regarding forward and backward walking with EMG analysis, there is a need to evaluate whether differences, if any, occur in muscle EMG activity at various inclines as well as direction.

Purpose: The purpose of this project is to describe muscle activity and range of motion (ROM) while walking both forward and backward on a treadmill at various inclines. Adults without disease, perceived to be normal and healthy, will be used as subjects in this research project.

Significance: The data from this study will be used to compare normal and abnormal patterns of muscle activity during forward and backward walking at various inclines on a treadmill. This information will promote the understanding of the biomechanics involved
at the knee and will be used in developing rehabilitation protocols for patients post-operative ACL reconstruction.

**Research Questions:**

1. Is the muscle activity significantly different in forward and backward walking?

2. Is there a difference in knee ROM during forward and backward walking at inclines?

**Hypotheses:**

1. **Null:** There is no significant difference in muscle activity between varying inclines on a treadmill during forward and backward walking.
   
   **Alternate:** There is a significant difference in muscle activity between varying inclines on a treadmill during forward and backward walking.

2. **Null:** There is no significant difference in muscle activity when comparing forward and backward walking on the treadmill.
   
   **Alternate:** There is a significant difference in muscle activity when comparing forward and backward walking on the treadmill.
CHAPTER II

REVIEW OF THE LITERATURE

One of the primary roles of a physical therapist is to get patients back to their
previous level of function in an effective and efficient manner. An increasingly popular
approach is using accelerated rehabilitation programs. Backward walking (retrowalking)
in accelerated anterior cruciate ligament (ACL) rehabilitation protocols is one such
protocol.

The concept behind the use of backward walking is using closed kinetic chain
(CKC) exercises to improve function. In CKC, the distal end of the limb is fixed, which
diffs from open kinetic chain (OKC) exercises in that open kinetic chain exercises
allow the distal end of the limb to be free to move. CKC exercise utilizes the weight of
the body as resistance in much the same way functional activities such as walking are
performed.¹

Normal gait is considered to be a CKC activity even though it includes OKC
activity during swing phase.² The swing phase of gait comprises only 36.8% of the gait
cycle while the stance phase makes up 63.3% of the gait cycle which is why gait is
considered a CKC activity.³ Steindler⁴ was one of the first researchers to describe
standing and walking as a CKC activity in which the lower extremity is attached to an
external resistance. He suggested that the muscles of the lower extremity during CKC
exercises are affected in ways that are not observed during OKC exercises. CKC
exercises have been shown to cause co-contraction of the hamstrings and quadriceps, thereby reducing the anterior movement of the tibia on the femur, resulting in less stressful forces on the ACL.\textsuperscript{5,6} CKC exercises impose significantly less patellofemoral joint stress than OKC exercise, which causes increased shear forces on the tibia and increased tibial translation.\textsuperscript{7} This is one advantage to using CKC exercises in ACL rehabilitation.

Researchers have differing views on the use and the effects of backward walking in rehab protocols. Safety is one such area of question. Thomas and Fast\textsuperscript{8} suggested that backward walking has not been proven effective in any studies and is only indicated for use in treatment when there is a task-specific need to walk backward. This is contrary to most research findings, however. Kramer\textsuperscript{3} stated that retro walking is essential to the safety and independent performance of activities of daily living, and therefore is vital to all rehab programs.

Researchers have different theories on the recruitment of muscles during retrowalking. Winter and Pluck\textsuperscript{9} proposed that forward and backward walking are merely opposite actions with the same muscle activity occurring. The two activities are the same in that the stance phase makes up 60\% of each gait cycle.\textsuperscript{10} Although the gait cycle may have similar phases, the timing of the muscle activity is not the same. During backward walking, the peak activity of the vastus lateralis and the rectus femoris occurs during foot strike and continuous throughout most of the stance phase. In backward walking, the role of the hamstrings is to initiate the swing phase, whereas in forward walking the hamstrings decelerate the leg during terminal swing. Cipriani\textsuperscript{11} found that backward walking is definitely a different action than forward walking. Kramer and
Reid\(^3\), using EMG, found that during backward walking, muscles of the lower extremity were active for longer periods of time than during forward walking. There is an increase in cadence during BW caused increased firing of the quadriceps and hamstrings, resulting in an increase in the overall muscle activity.\(^{12}\) Another reason for the difference in muscle activity between the two activities is that forward walking uses momentum of the lower extremities whereas backward walking uses less momentum and therefore relies on more muscle activity.

Van Deursen et al\(^{10}\) compared muscle activity during forward walking and backward walking included study of the soleus, vastus lateralis, tibialis anterior, lateral head of the gastrocnemius, biceps femoris, and rectus femoris. They found that only the rectus femoris had a significant increase in peak activation during backward walking. The soleus and vastus lateralis had approximately the same peak values for both forward walking and backward walking and the tibialis anterior and biceps femoris showed a decrease in peak activation when compared with forward walking.

Researchers have also studied the changes that occurred in EMG activity when backward walking at different inclines. Yoshimoto\(^{12}\) found that backward walking increases activity of the vastus medialis, vastus lateralis, semitendinosus, and biceps femoris at 0, 10, and 15 degrees of incline. The vastus medialis showed the greatest percent of increase in activity. The 15 degree incline showed the greatest amount of quadriceps and hamstring activity. In a study of EMG activity at 0, 5, and 10 percent grades, it was found that the majority of the changes in EMG occurred after a 10 percent change in incline. Few significant changes were seen with a 5 percent incline.\(^{11}\)
Subjects

Eighteen healthy male subjects ages 20-31 were used in this study (Table 1). All subjects reported no hip, knee, or ankle pathologies with the exception of Subject 1 reporting Osgood Schlatter’s at age 16, Subject 2 has a non-significant bursa, and Subject 13 had an ACL repair in September 2001 (no problems since, not using a brace, and surgery was a hamstring repair). The subjects volunteered and were informed of the purpose of this study and their rights as human subjects. 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 and the Red River Valley Sports Medicine Institute.

Instrumentation

Electrode placement over the muscles was determined by physical measurements and anatomical landmarks (Figure 1). The muscles analyzed included the (1) vastus lateralis (VL), (2) vastus medialis (VM), (3) biceps femoris (BF), and (4) semitendinosus (St) (Table 2). A ground electrode was applied over the superior medial tibial plateau. The hair over the placement sites was shaved if necessary, and the skin was cleaned with alcohol. Two pre-gelled self-adhesive electrodes were applied two centimeters apart over the muscle, parallel to the muscle fibers. The distance between the surface electrode
placements attempted to minimize volume conduction between muscle groups, increasing the accuracy in collection of specific muscular activity.

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

Four markers were placed on each subject to represent joint centers of the lower extremity. The markers were placed at the iliac crest, greater trochanter, head the fibula, and the lateral malleolus of the right lower extremity of each subject. The markers were illuminated during the walking trials and captured on tape. The marker locations were digitized for analysis of motion of the lower extremity in the sagittal plane.

Footswitches were used to determine the phase of the gait cycle. Four switches were embedded into an insole that was placed inside the subjects’ right shoe, which they wore throughout the entire study. Subjects wore a waist belt containing a Noraxon Telemyo8 telemetry unit (Noraxon USA, 13430 N. Scottsdale Rd., Scottsdale AZ 85254). EMG signals were transmitted to a receiver and sent to a computer that presented raw EMG data and footswitch activation. The motion analysis was recorded using the PEAK Motus 5.0 (PEAK Performance Technologies, 7388 S. Revere Parkway, Englewood, CO 80112). The Motus software allowed recording of both the markers and EMG activity.

**Procedure**

Prior to the experiments, each subject’s age, gender, height, and weight were recorded. The subject was subjectively screened for lower extremity surgeries, instabilities, and orthopedic problems before the consent form was read and signed. Subjects were instructed on safety precautions regarding treadmill walking including the
use of support rails, forward and backward ambulation. They were then instructed on proper procedure for getting on and off the treadmill. A spotter was used to ensure the subject’s safety.

The subjects were given a one-minute warm-up trial prior to testing at 0 and 15% grades for both forward and backward walking to become familiarized with treadmill use. The subjects were instructed to stand still, allowing the computer to establish a baseline of activity. Data was then collected in 10-second intervals while walking at 3.5 mph at 0% and 15% grades in both directions. The order of inclination and direction were randomized prior to the experiment to prevent a learning effect.

Once data collection was complete, the subjects were asked to stand still in an upright and relaxed posture to allow for a final baseline EMG reading. To conclude the subject’s participation in this study, the electrodes and footswitches were removed.

**Data Analysis**

The EMG data was normalized to forward walking at 0% grade. The normalization procedure was performed using the Noraxon Myoresearch software, which utilized the following formula:

\[
\text{% change in EMG activity} = \frac{(\text{EMG during trial}) - (\text{EMG during FW at 0\% grade})}{\text{EMG during FW at 0\% grade}}
\]

Statistical testing was performed using a Repeated Measures ANOVA with a probability level (alpha) of .05. A Scheffe Post Hoc test was run to perform multiple comparisons between muscle groups and determine if there is a significant difference between these groups.
Table 1. Subject Information

<table>
<thead>
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<th>Subject #</th>
<th>Sex</th>
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<th>Weight</th>
<th>Height</th>
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<td>21</td>
<td>190</td>
<td>6'0”</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>22</td>
<td>175</td>
<td>5'9”</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>21</td>
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</tr>
<tr>
<td>4</td>
<td>M</td>
<td>20</td>
<td>245</td>
<td>5'10”</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>22</td>
<td>202</td>
<td>5'11”</td>
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<td>6</td>
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<td>M</td>
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<td>8</td>
<td>M</td>
<td>23</td>
<td>188</td>
<td>6'2”</td>
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<td>9</td>
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<td>M</td>
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<td>5'10”</td>
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<td>31</td>
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<td>180</td>
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<td>M</td>
<td>29</td>
<td>195</td>
<td>5'10”</td>
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<td>18</td>
<td>M</td>
<td>27</td>
<td>245</td>
<td>6'1”</td>
</tr>
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Table 2. Origins, Insertions, and Actions

<table>
<thead>
<tr>
<th>MUSCLE</th>
<th>ORIGIN</th>
<th>INSERTION</th>
<th>ACTION</th>
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<tr>
<td>Vastus lateralis</td>
<td>Linea aspera</td>
<td>Tibial tuberosity</td>
<td>Knee extension</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>Linea aspera</td>
<td>Tibial tuberosity</td>
<td>Knee extension</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>Long head- ischial tuberosity</td>
<td>Head of Fibula</td>
<td>Knee flexion</td>
</tr>
<tr>
<td></td>
<td>Short head- linea aspera</td>
<td></td>
<td>Hip extension</td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>Ischial tuberosity</td>
<td>Medial proximal tibia</td>
<td>Knee flexion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hip extension</td>
</tr>
</tbody>
</table>
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
Vastus Medialis - along a line ⅓ of the distance from the medial knee joint line to the ASIS
Vastus Lateralis - along a line ⅓ the distance from the lateral knee joint line to the ASIS and over the belly of the vastus lateralis

Figure 1. Electrode Placement for the Lower Extremity
CHAPTER IV

RESULTS

Table 3 displays the descriptive statistics of the percent change in EMG activity of the muscles during the walking trials of forward 15, backward 0, and backward 15 as compared to the baseline EMG activity during forward 0. There were increases in EMG activity in all walking trials as compared to forward 0. In all muscles, the greatest increase in activity was during the backward 15 walking trial. The lowest change in activity was found during forward 15 for all muscles except the biceps femoris, which had the lowest activity during backward 0. Figures 2 and 3 depict the EMG activity during the walking trials. EMG activity for all of the muscles was increased when comparing forward 15, backward 0, and backward 15 walking trials to forward 0.

Table 3. Descriptive Statistics showing changes in EMG activity during the walking.

<table>
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<tr>
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<th>Forward 0%</th>
<th>Forward 15%</th>
<th>Backward 0%</th>
<th>Backward 15%</th>
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<tr>
<td></td>
<td>Mean %</td>
<td>N</td>
<td>Mean %</td>
<td>SD</td>
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<td>100</td>
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<td>140</td>
<td>50.0</td>
</tr>
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Vastus Medialis

The results of the repeated measures ANOVA analysis of the EMG activity for the vastus medialis during the walking trials are shown in Table 4. A significant increase in EMG activity was found between backward walking at 15 percent compared to backward walking at 0 percent and forward walking at both 0 and 15 percent. Figures 2 and 3 show the change in EMG activity during the different walking trials, with significant differences noted by an asterisk.

Table 4. Repeated measures ANOVA results for the vastus medialis.

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
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</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>429796.16</td>
<td>3</td>
<td>143265.38</td>
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<tr>
<td>Within Groups</td>
<td>315643.91</td>
<td>36</td>
<td>8767.88</td>
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<td>Total</td>
<td>2951479.00</td>
<td>53</td>
<td></td>
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</table>

Vastus Lateralis

The results of the repeated measures ANOVA analysis of the EMG activity for the vastus lateralis during the walking trials are shown in Table 5. A significant increase in EMG activity was found between backward walking at 15 percent compared to backward walking at 0 percent and forward walking at both 0 and 15 percent. Figures 2 and 3 show the change in EMG activity during the different walking trials, with significant differences noted by an asterisk.
Table 5. Repeated measures ANOVA results for the vastus lateralis.

<table>
<thead>
<tr>
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<tr>
<td>Between Groups</td>
<td>1825523.35</td>
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<td>Within Groups</td>
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<td>6768341.00</td>
<td>53</td>
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</table>

Biceps Femoris

The results of the repeated measures ANOVA analysis of the EMG activity for the biceps femoris during the walking trials are shown in Table 6. A significant increase in EMG activity was found between backward walking at 15 percent compared to forward walking at 0 percent. There was no significant difference in biceps femoris activity between backward and forward walking at a 15 percent incline or backward at 0 percent. Figures 2 and 3 show the change in EMG activity during the different walking trials, with significant differences noted by an asterisk.

Table 6. Repeated measures ANOVA results for the biceps femoris.

<table>
<thead>
<tr>
<th></th>
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<th>MS</th>
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<th>p</th>
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</thead>
<tbody>
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<td>Between Groups</td>
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<td>12194.70</td>
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<tr>
<td>Within Groups</td>
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<td>1460.44</td>
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<tr>
<td>Total</td>
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</table>
Semitendinosus

The results of the repeated measures ANOVA analysis of the EMG activity for the semitendinosus during the walking trials are shown in Table 7. A significant increase in EMG activity was found between backward walking at both 0 and 15 percent compared to forward walking at 0 percent. Figures 2 and 3 show the change in EMG activity during the different walking trials, with significant differences noted by an asterisk.

Table 7. Repeated measures ANOVA results for the semitendinosus.

<table>
<thead>
<tr>
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<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
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<td>.000</td>
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<tr>
<td>Within Groups</td>
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<td>2148.19</td>
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</table>

Knee Range of Motion

Average knee flexion angles for the subjects are displayed in Table 8 and Figures 4 and 5. When knee flexion angles were compared between walking trials (Figure 4), backward 15 required the greatest range of knee motion, followed by forward 15, forward 0, and backward 0, respectively. Figure 5 shows an ensemble average of knee range of motion for all subjects during walking trials.
Table 8. Average Knee flexion angles during walking trials from all subjects.

<table>
<thead>
<tr>
<th></th>
<th>Maximum knee flexion angle</th>
<th>Minimum knee flexion angle</th>
<th>Average knee flexion angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward 0 incline</td>
<td>67.4</td>
<td>4.8</td>
<td>30.2</td>
</tr>
<tr>
<td>Forward 15 incline</td>
<td>68.4</td>
<td>2.0</td>
<td>34.1</td>
</tr>
<tr>
<td>Backward 0 incline</td>
<td>57.5</td>
<td>26.6</td>
<td>39.5</td>
</tr>
<tr>
<td>Backward 15 incline</td>
<td>70.2</td>
<td>36.1</td>
<td>52.0</td>
</tr>
</tbody>
</table>

The EMG activity of the muscles and knee flexion angle of subject 2 during the walking trials are shown in Figures 6-9.
Figure 2. Average EMG activity during walking trials. Graph represents an average of EMG activity for all of the subjects.
Figure 3. Average EMG activity during walking trials. Graph represents an average of EMG activity for all of the subjects.
Figure 4. Average knee range of motion during trials. The range of motion is an average of all subjects.
Figure 5. Average knee range of motion during trials. The curves represent an average range of motion for all subjects.
Forward Walking at Zero Percent Incline

Figure 6. EMG, knee range of motion and stickman diagram for subject number 2.
Figure 7. EMG, knee range of motion and stickman diagram for subject number 2.
Figure 8. EMG, knee range of motion and stickman diagram for subject number 2.
Figure 9. EMG, knee range of motion and stickman diagram for subject number 2.
CHAPTER V
DISCUSSION

Walking Forward at 15% Grade

The vastus lateralis was the most active muscle during forward walking at 15% grade showing a 160% increase in EMG activity, followed by the biceps femoris, which showed a 154% increase. The vastus medialis and semitendinosus were the least active muscles during this walking trial, each showing approximately a 140% increase in EMG activity. Although increased activity was found in all muscles tested, a significant difference was found only in the vastus lateralis and vastus medialis when compared to forward walking at a 0% grade. Our findings agree with Lange et al.\textsuperscript{16}, who found that there was a significant increase in the EMG activity of the vastus lateralis and biceps femoris when walking forward at inclines.

Walking Backward at 0% Grade

The vastus lateralis was the most active muscle during backward walking at a 0% grade showing a 279% increase in EMG activity, followed by vastus medialis and semitendinosis showing a 190% and 173% increases respectively. The biceps femoris was found to be the least active muscle during this walking trial with an increase of only 135%. According to van Deursen et al.\textsuperscript{10}, the vastus lateralis has approximately the same peak values during forward and backward walking. However, our results indicated that
there was a difference in peak values, with increased activity of the vastus lateralis occurring during backward walking.

**Walking Backward at 15% Grade**

The vastus lateralis was again the most active muscle showing an increase of 609%, followed by the vastus medialis, which showed an increase of 339% in EMG activity. The semitendinosus and biceps femoris were the least active muscles during this walking trial showing an increase of 189% and 172% respectively.

Our results agree with Yoshimoto\textsuperscript{12} in that backward walking increases the activity of the vastus medialis, vastus lateralis, biceps femoris, and semitendinosus at 0% and 15% grades. We feel that the increased quadriceps activity during backward walking at a 15% grade is partially due to the crouched position the subjects demonstrated during backward walking trials at 15%. We observed the subjects to be in this crouched position with the knee remaining in some degree of flexion during both stance and swing phase. When walking backward, the quadriceps are performing concentrically during stance phase, which could account for this increase in muscle activity as compared to forward walking when the quadriceps perform more eccentrically during stance phase.

**Degree of Knee Flexion During Walking Trials**

The degree of knee flexion is greatest during backward walking at a 15% grade, followed by forward walking at a 15% grade and forward walking at a 0% grade. The least amount of knee flexion was noted during backward walking at a 0% grade.

During forward walking at 0 and 15% grades, there was little change noted between knee flexion angles with the knee being in 67.4 degrees and 68.4 degrees of flexion respectively. This disagrees with Lange et al\textsuperscript{16} who found that maximum knee
flexion increased significantly with an increase in the percent grade. The reason for disagreement may be due to the fact that they were testing subjects at a 24% grade. This is not the case, however, when comparing backward walking at 0 and 15% grades where the knee is in 57.5 degrees and 70.2 degrees of flexion respectively. This increase of knee flexion during backward walking at a 15% grade is due to the crouched position of the subjects as discussed above.

Limitations

Although this study provided us with useful information regarding muscle activity and knee flexion angles during graded forward and backward walking, there are limitations to be considered. The data was collected on 18 male subjects and data from four subjects was eliminated and not considered in our results because one subject had a previous ACL surgery and due to technical error the data from three subjects was not recorded. Some selected EMG data from four other subjects was eliminated due to technical error. The data collected from the trial of backward walking at a 15% grade and all biceps femoris data were eliminated for subject 1. All data collected during forward walking at a 15% grade was eliminated for subject 9. Biceps femoris data was eliminated for all walking trials for subject 11. All data collected during backward walking at a 15% grade was eliminated for subject 18. Therefore, due to our small sample size, the inclusion of only four muscles, and the participation of only male subjects, the results from our study cannot be accurately applied to the overall population.
CHAPTER VI

CONCLUSION

We have concluded that there is increased muscle activity in backward walking compared to forward walking. The vastus lateralis was found to be the most highly recruited muscle (relative to forward walking) during backward walking. The greatest increase in EMG activity seen with this muscle was during backward walking at a 15% grade, showing a 609.25% increase from walking forward at a 0% grade.

We found that inclined walking, both forward and backward, increases EMG activity of the vastus lateralis, vastus medialis, biceps femoris, and semitendinosus. The greatest activity for all muscles analyzed was seen during backward walking at a 15% grade. The greatest amount of knee flexion was also seen during this walking trial. From data collected, we feel that because backward walking at an incline requires the most muscle recruitment and knee flexion, it is a viable treatment option for knee rehabilitation. Graded treadmill walking offers many important aspects to knee rehabilitation programs including progressive loading, functional exercise, and appropriate range of motion. Lange et al suggest that a grade just above 12% may be the most beneficial, minimizing compressive forces on the patellofemoral joint and alleviating ACL strain. The data collected in our study may be helpful in forming guidelines for knee rehabilitation programs.

Further research should be performed using a larger sample size, including post-surgical participants and an equal gender ratio, so that the information can be generalized
to rehab programs. Future studies of forward and backward walking should analyze a larger grouping of muscles of the lower extremities that are active during the gait cycle.
APPENDIX
University of North Dakota Human Subjects Review Form

Please Note: The policies and procedures of the University of North Dakota apply to all activities involving the use of Human Subjects performed by faculty, staff and students 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 procedure governing the use of human subjects. When preparing your Human Subjects Review Form, use the attached “IRB Checklist”.

Please provide the information requested below:

Principal Investigator: Thomas Mohr, Sarah DeKrey, Lori Guderian, Kerry Hendricksen, Glenda Scott

Telephone: 777-2831 Address: PO Box 9037, Dept. of Physical Therapy, UND

E-mail address: tommohr@medicine.nodak.edu

School/College: Sciences Department: Physical Therapy

Student Adviser (if applicable): Thomas Mohr, PT, PhD

Telephone: 777-2831 Address: PO Box 9037, Dept. of Physical Therapy, UND

E-mail address: tommohr@medicine.nodak.edu

Medicine & Health School/College: Sciences Department: Physical Therapy

Project Title: An Electromyographic and Video Motion Analysis Study of Forward and Backward Treadmill Walking

Proposed Project Dates: Beginning Date: 06/02 Completion Date: 06/03

Funding agencies supporting this research: None

(A copy of the funding proposal for each agency identified above MUST be attached to the proposal when submitted.)

YES or x NO Does the Principal Investigator or any researcher associated with this project have a financial interest in the results of this project? If yes, please submit on a separate piece of paper an additional explanation of the financial interest (other than receipt of a grant)

If your project has been or will be submitted to another Institutional Review Board (s), Please list those boards below along with the status of each proposal.

Frappier Acceleration and Orthopedic Associates Date Submitted: 5/6/02 Status: x Approved ___ Pending

Type of Project: Please Check Yes or No to the following.

x YES or ___ NO New Project

YES or x NO Dissertation/Thesis

___ YES or x NO Continuation/Renewal

x YES or ___ NO Student Research Project

___ YES or x NO Protocol Change for previously approved project (resubmit “Human Subjects Review Proposal” with changes bolded or highlighted and signed)

Cooperating Institution: Frappier Acceleration, Fargo, ND

x YES or ___ NO Will any institution of agency personnel assist in the Proposed Project?

Copies of letters indicating the willingness of the institution/agency to cooperate in the study and an understanding of the study MUST be attached. Letters must include the name and title of the individual signing the letter and, if possible, should be printed on letterhead.

Subject Classification: This study will involve subjects who are in the following special populations: Check all that apply.
For information about protections for each of the special populations please refer to the protected populations section on the Office of Research and Program Development website.

This study will involve: Check all that apply.
- New Drugs (IND)
- Non-approved Use of Drug(s)
- Recombinant DNA
- Fetal Tissue
- Stem Cells
- Other (Discarded tissue, fluids, blood, etc.)
- None of the above will be involved in this study

I. Project Overview
Please provide a brief explanation (limit to 200 words or less) of the rationale and purpose of the study, introduction of any sponsor(s) of the study, and justification for use of human subjects and/or special populations (e.g., vulnerable populations such as minors, prisoners, pregnant women/fetuses).

Rehabilitation facilities are always trying new approaches to post-operative rehabilitation on anterior cruciate ligament (knee) injuries. One approach is to have patients walk forward and backward (retrowalking) on a treadmill as part of their rehabilitation protocol. Although this is a commonly used mode of exercise, there is little scientific information on retrowalking.

The purpose of this project is to describe muscle activity and joint motion while walking both forward and backward on a treadmill 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/abnormal patterns of muscle activity and joint motion, which will be used in developing training protocols for patients.

Both normal, healthy, adult subjects and patients who have had ACL reconstruction surgery will be used in this research project. Human subjects are needed for this research study in order to determine when selective muscles are active while walking at various grades of incline.

II. Protocol Description
Please provide a succinct description of the procedures to be used by addressing the instructions under each of the following categories. Individuals conducting clinical research please refer to the “Guidelines for Clinical-Research Protocols” on the Office of Research and Program Development website.

1. Subject Selection.
   a) Describe recruitment procedures (i.e., how will subjects be recruited, who will recruit them, where and when they will be recruited and for how long) and include copies of any advertisements, fliers, etc., that will be used to recruit subjects. It is anticipated that we will recruit 10 normal subjects and 10 post-op ACL reconstruction subjects between the ages of 18 and 28. The subjects for the study will be recruited from UND and Frappier Acceleration. These subjects will participate voluntarily. The project will be completed at Frappier Acceleration in Fargo, ND. Prior to performing, each subject will be asked to complete a consent form. The subjects will not be compensated.
   b) Describe your subject selection procedures and criteria, paying special attention to the rationale for including subjects from any of the categories listed in the “Subject Classification” section above. The subjects will be chosen because of their age and health status.
   c) Describe your exclusionary criteria and provide a rationale for excluding subject categories. Subjects with knee instability or knee pain will be excluded from the study. Post-operative patients will be cleared by their physician.
   d) Describe the estimated number of subjects that will participate and the rationale for using that number of subjects. It is estimated that 20 subjects will participate.
   e) Specify the potential for valid results. If you have used a power analysis to determine the number of subjects, describe your method. Twenty subjects should be sufficient for statistical analysis.

2. Description of Methodology.
   a) Describe the procedures used to obtain informed consent. Subjects will volunteer to participate and will be informed about the study and possible risks before consent is obtained.
   b) Describe where the research will be conducted. The research will be conducted at Frappier Acceleration in Fargo, ND.
c) Indicate who will carry out the research procedures.
   UND students (Sarah DeKrey, Lori Guderian, Kerry Hendrickson, Glenda Scott) and faculty (Thomas Mohr).

d) Briefly describe the procedures and techniques to be used and the time required to complete them.
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 the following lower extremity muscles: 1) Vastus Lateralis 2) Vastus Medialis 3)
Biceps Femoris 4) Semitendinosus. The study will be performed by Thomas Mohr, chairman of the Physical Therapy
Department and four physical therapy graduate students: Sarah DeKrey, Lori Guderian, Glenda Scott, and Kerry
Hendrickson.

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 shaving and 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 each 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 the study. The muscles activity recorded during the maximal voluntary contraction
will be considered as 100% EMG activity level to which the EMG activity during walking 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 the 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 period. This
will be recorded on video tape and will be transferred to a computer for analysis.

The subjects will walk both forward and backward at 3.4mph at each of the treadmill inclines of 0%, 15%, and 20%. At
each incline the subject 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 2 minute rest period. The order of the
walking trials will be determined by random assignment.

Data analysis:
Descriptive statistics describing the subject's anthropometric profiles will be provided. The main activity of each
monitored muscle will be calculated. The EMG data collected during the experimental trials will be expressed as a
percentage of 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 walking trials.

e) Describe audio/visual procedures and proper disposal of tapes.
Video files are copied from a tape to a computer (the tapes are erased and reused, however the video files are stored on
the computer hard drive for analysis) and held at UND Physical Therapy Department for 3 years before being erased.

f) Describe the qualifications of the individuals conducting all procedures used in the study.
Doctorate level UND physical therapy faculty and UND physical therapy graduate students.

g) Describe compensation procedures (payment or class credit, etc.)
None

Attachments Necessary: Copies of all instruments (such as survey/interview questions, data collection forms completed by
subjects, etc.) must be attached to this proposal.


a) Clearly describe the anticipated risks to the subject/others including any physical, emotional, and financial risks that
might result from this study.
   The risks involved in this research project are minimal. The EMG and motion 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.

b) Describe precautions you will take to minimize potential risks to the subjects (e.g., sterile conditions, informing subjects
that some individuals may have strong emotional reactions to the procedures, debriefing, etc.).
   The participant will be closely observed throughout the activity on the treadmill 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 following removal of the electrodes, but this will only be
temporary. In the event that this research activity (which will be conducted at a safe acceleration) 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 participant and
their third party payer, unless the reason for treatment is due to negligence on the part of the researchers.

c) Indicate whether there will be a way to link subject responses and/or data sheets to consent forms, and, if so, what the
justification is for having that link.
   None
4. Subject Protection

a) Describe procedures you will implement to protect confidentiality (such as coding subject data, removing identifying information, reporting data in aggregate form, etc.). The subjects’ names will not be used in any reports of the results of this study. Any information that is obtained in connection with the 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.

b) Indicate that the subject will be provided with a copy of the consent form and how this will be done. The subject will be provided with a copy of the consent form stating benefits and risks of this study.

c) Describe the protocol regarding record retention. Please indicate that research data from this study and consent forms will both be retained in separate locked locations for a minimum of three years following the completion of the study. All of the raw data will be stored in electronic format (computer files), in the Department of Physical Therapy of UND for a period of three (3) years. After that time, the data will be erased. Some of the processed data and the consent forms will be stored in paper format, in the Department of Physical Therapy for a period of three (3) years. After that time they will be shredded. Access to the data will be limited to the investigators.

d) Describe procedures to deal with adverse reactions (referrals to helping agencies, procedures for dealing with trauma etc.). See above

e) Include an explanation of medical treatment available if injury or adverse reaction occurs and responsibility for costs involved. See above

III. Benefits of the Study

Clearly describe the benefits to the subject and to society resulting from this study (such as learning experiences, services received, etc.). Please note: payment is not a benefit and should be listed in the Protocol Description section under Methodology. 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 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 specific for post-operative patients. The benefit to the patient 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.

IV. Consent Form

A copy of the Consent Form must be attached to this proposal. If no Consent Form is to be used, document the procedures to be used to protect human subjects. Refer to the ORPD website for further information regarding Consent Form Regulations.

Consent forms will be kept in the Physical Therapy Department at the University of North Dakota for a period of three (3) years, after which time they will be shredded. Please note: Regulations require that all Consent Forms, and all pages of the Consent Forms, be kept for a minimum of 3 years after the completion of the study, even if subject does not continue participation. The Consent Form must be written in language that can easily be read by the subject population and any use of jargon or technical language should be avoided. It is recommended that the Consent Form be written in the third person (please see the examples on the ORPD website). A two inch by two inch blank space must be left on the bottom of each page of the consent form for the IRB approval stamp. The consent form must include the following elements:

a) An introduction of the principal investigator

b) An explanation of the purposes of the research.

c) The expected duration of subject participation.

d) A brief summary of the project procedures.

e) A description of the benefits to the subject/others anticipated from this study

f) A paragraph describing any reasonably foreseeable risks or discomforts to the subject.

g) Disclosure of any alternative procedures/treatments that are advantageous to the subject

h) A description of how confidentiality of subjects and data will be maintained. Indicate that the data and consent forms will be stored separately for at least three years following the completion of the study. Indicate where, in general, the data and consent documents will be stored and who has access. Indicate how you will dispose of the data. Be sure to list any mandatory reporting requirements that may require breaking confidentiality.

i) An explanation of compensation/medical treatment available if injury occurs

j) The names, telephone numbers and addresses of two individuals to contact for information (generally the student and student adviser). This information should be included in the following statement: “If you have questions about the research, please call (insert Principal Investigator’s name) at (insert phone number of Principal Investigator) or (insert Adviser’s name) at (insert Adviser’s phone number). If you have any other questions or concerns, please call the Office...
of Research and Program Development at 777-4279.

k) If applicable: an explanation of who to contact in the event of a research-related injury to the subject.

l) If applicable: an explanation of financial interest must be included.

m) RE: Participation in the study:

1) An indication that participation is voluntary and that no penalties or loss of benefits will result from refusal to participate.

2) An indication that the subject may discontinue participation at any time without penalty with an explanation of how they can discontinue participation.

3) An explanation of circumstances which may result in the termination of a subject’s participation in the study.

4) A description of any anticipated costs to the subject.

5) A statement indicating whether the subject will be informed of the findings of the study.

6) A statement indicating that the subject will receive a copy of the Consent Form.

By signing below you are verifying that the information provided in the Human Subjects Review Form and attached information is accurate and that the project will be completed as indicated.

Signatures:

_________________________________________________________ Date: ______________________
(Principal Investigator)

_________________________________________________________ Date: ______________________
(Student Advisor)
INFORMATION AND CONSENT FORM

TITLE: An Electromyographic and Video Motion Analysis Study of Forward and Backward Walking

You are being invited to participate in a study conducted by Sarah DeKrey, Glenda Scott, Lori Guderian, Kerry Hendricksen, and Thomas Mohr from the Physical Therapy Department at the University of North Dakota. The purpose of this study is to study your muscle activity in your lower extremities while walking both forward and backward at different inclines on the treadmill. We will also be measuring the angles of the joints of the upper extremity, lower extremity and trunk while you are walking. We hope to describe the muscle activity and the different angles that you employ during walking. Only normal healthy subjects, or subjects who have had anterior cruciate ligament surgery and have been medically cleared by their physician for participation in the study, will be asked to participate in this study. If you have any knee instability or pain, you will not be eligible to participate in 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 treadmill for a total of six (6) trials consisting of the following: 1) Walking forward or backward on the treadmill at 3.4 mph with 0% grade, 2) Walking forward and backwards on the treadmill at 3.4 mph with 15% grade, 3) Walking forward and backward on the treadmill at 3.4 mph with 20% grade. You will be given a 2 minute rest period between trials.

The study will take approximately one hour of your time. You will be asked to report to Frappier Acceleration in Fargo, ND, at an assigned time. You will then be asked to change into gym shorts for the experiment. We will first record your age, gender, height and weight. During the experiment, we will be recording the amount of muscle activity and the angles of your joints present when you walk on the treadmill 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 of your trunk and lower extremity. The recording electrodes are attached to the surface of the skin with an adhesive material. Reflective markers will also be attached to the skin over your shoulder, hip, knee and ankle joints. These devices only record information from your muscles and joints, they do not stimulate the skin. A video camera will be used to film your walking and the reflective markers will be used as a template to construct stickman like figures from the position of the markers. 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 minimal-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, and the video files will be converted to stickman like diagrams for analysis and stored on a computer. The computer files, and consent forms are kept in the physical therapy department for a period of three (3) 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 be the investigator. The investigator or participant may stop the experiment at any time if the participant is experiencing discomfort, pain, fatigue, or any other symptoms that may be detrimental to his/her health. Your decision whether or not to participate will no 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 or John Frappier at 701-241-9018. Further information regarding subjects rights can be obtained from the University of North Dakota Office of Research and Program Development at 701-777-4279. 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 Frappier Acceleration) results in 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 payer, unless the reason for treatment is due to negligence on the part of the researchers. By signing this document, you are not giving up any legal rights you may have in case of negligence or other legal fault of anyone that is involved in the study.

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


