An Electromyographic Analysis Study of Forward and Backward Walking

Carrie M. Voeller
University of North Dakota

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AN ELECTROMYOGRAPHIC ANALYSIS STUDY OF FORWARD AND BACKWARD WALKING

by

Carrie M. Voeller
Bachelor of Science in Physical Therapy
University of North Dakota, 2000

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May
2001
This Independent Study, submitted by Carrie M. Voeller in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Faculty Preceptor)

(Graduate School Advisor)

(Chairperson, Physical Therapy)
PERMISSION

Title An Electromyographic Analysis Study of Forward and Backward Walking
Department Physical Therapy
Degree Master of Physical Therapy

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Signature

Date 12/12/00
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ABSTRACT

Backward walking, a closed kinetic chain exercise, has become an increasingly popular intervention following lower extremity injuries secondary to suggested increases in muscle activity. Despite its use, there is limited research available relative to walking at inclines, forward or backward, above 24 and 15 percent respectively. For this study we recorded EMG activity in six muscles while walking forward and backward on a treadmill at 0, 25, and 35 percent inclinations.

In general, our results indicated a greater increase in muscle activity during BW than FW. BW at 35 percent inclination elicited the greatest EMG increase within the rectus femoris (47%), vastus lateralis (67%), vastus medialis (68%), and semitendinosus (48%). BW at 25 percent increased the activity of the biceps femoris by 38%. The gastrocnemius showed its greatest increase in activity, 55%, during FW at 25 percent inclination.

We conclude that BW at inclines can be beneficial for lower extremity rehabilitation.
CHAPTER I
INTRODUCTION

Rehabilitation facilities are always trying new approaches for rehabilitation of lower extremity injuries. One such approach is to have the patients perform forward walking (FW) and backward walking (BW) on a treadmill as part of their rehabilitation protocol.

Problem Statement: While inclined BW is currently being used by therapists and trainers, there has been a limited amount of research on BW at inclines greater than 15% and FW greater than 24%.

Purpose: The purpose of this study is to evaluate muscle activity of the lower extremity during FW and BW on a treadmill at various inclines of up to 35%.

Significance: The significance of this study is to help clarify whether or not BW is an effective intervention for rehabilitation at inclines beyond what have been previously studied.

Hypotheses:

1. There will be a change in EMG activity with increasing inclines.
2. There will be a difference in EMG activity between FW and BW.
CHAPTER II
LITERATURE REVIEW

In recent years, the predominant philosophy of physical therapists treating lower extremity injuries has focused on the use of close kinetic chain (CKC) activities. This is based on literature that suggests such exercises are more effective, safer, and more functional than previously employed open kinetic chain activities.\textsuperscript{1,2} While treadmill walking is frequently utilized as a CKC activity for rehabilitation of lower extremity injuries, it has been suggested that BW may offer benefits beyond those experienced through FW alone.\textsuperscript{2,3}

Numerous studies have examined a variety of locomotion parameters to evaluate the similarities and differences between forward and backward walking.\textsuperscript{2-12} Winter and Pluck\textsuperscript{4} suggest that BW is almost a simple reversal of FW. They conclude that, in order to produce the muscle activation patterns involved in FW, temporal cycling of the muscle contractions in BW is merely reversed. Concentric muscle activity in FW thereby becomes eccentric activity in BW, and visa versa.

Thorstensson\textsuperscript{5} agrees, concluding that the lower limb essentially follows the same trajectory in forward and backward locomotion, but in opposite directions. To accomplish this reversal, most muscles change their pattern of activity in relation to the different phases of the gait cycle. During BW, there is a switch between the flexors and extensors of the ankle, with flexor activation throughout the support phase rather than swing phase. The bursts of activity in the knee extensors are prolonged and shift to the
main part of the support phase. Lastly, the activity periods of the hip extensors retain their position relative to the leg movements, but change function due to the reversed direction of movement.

Research by Flynn and Soutas-Little\textsuperscript{3} also found significant differences in muscle firing patterns between forward and backward walking. They suggest BW requires greater sustained muscle activity of the rectus femoris (RF), vastus medialis (VM), and vastus lateralis (VL). During BW, these three quadriceps muscles act primarily as isometric stabilizers from early to midstance, followed by a concentric propulsive phase from mid to late stance. This pattern contrasts with the primary eccentric deceleration action of the quadriceps during the early stance phase of FW, followed by no activity from mid to late stance.\textsuperscript{13}

When looking at joint kinematics, Vilensky et al\textsuperscript{6} found a significant difference, reporting a faster cadence and smaller stride length in BW when compared to FW at the same speed. Table 1 compares and summarizes the joint kinematics of both forward and backward locomotion during the stance and swing phases of the gait cycle.\textsuperscript{7}

Another aspect of particular interest relates to the adaptations that occur in both forward and backward walking when an uphill grade is involved. In a study by Lange et al\textsuperscript{8}, electomyographic (EMG) activity of the lower extremity musculature was recorded at 0, 12, and 24% grade during forward treadmill walking. The average EMG activity increased significantly from 0 to 24% grade for the vastus medialis (125%), vastus lateralis (109%), and biceps femoris (53%), but remained similar for the medial hamstrings. The study also revealed that maximum knee flexion at heel strike increased significantly with inclination.
Table 1. Backward walking kinematics

<table>
<thead>
<tr>
<th>STANCE</th>
<th>Forward Gait</th>
<th>Backward Gait</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Contact:</td>
<td>-made with heel</td>
<td>-made with forefoot</td>
</tr>
<tr>
<td></td>
<td>-hip in flexion</td>
<td>-hip flexes</td>
</tr>
<tr>
<td></td>
<td>-knee is extended</td>
<td>-knee is flexed</td>
</tr>
<tr>
<td></td>
<td>-ankle is in neutral</td>
<td>-ankle is dorsiflexed</td>
</tr>
<tr>
<td>Loading Response:</td>
<td>-hip held in flexion</td>
<td>-hip flexes</td>
</tr>
<tr>
<td></td>
<td>-knee flexes</td>
<td>-knee extends</td>
</tr>
<tr>
<td></td>
<td>-ankle plantarflexes</td>
<td>-ankle dorsiflexes</td>
</tr>
<tr>
<td>Midstance:</td>
<td>-hip to neutral</td>
<td>-hip flexes</td>
</tr>
<tr>
<td></td>
<td>-knee in flexion</td>
<td>-knee extends</td>
</tr>
<tr>
<td></td>
<td>-ankle slight dorsiflexion</td>
<td>-ankle plantarflexes</td>
</tr>
<tr>
<td>Terminal Stance:</td>
<td>-hip in hyperextension</td>
<td>-hip continued flexion</td>
</tr>
<tr>
<td></td>
<td>-knee in neutral</td>
<td>-knee flexes</td>
</tr>
<tr>
<td></td>
<td>-ankle dorsiflexes</td>
<td>-ankle plantarflexes</td>
</tr>
<tr>
<td>Pre-swing:</td>
<td>-hip flexion to neutral</td>
<td>-hip continues flexion</td>
</tr>
<tr>
<td></td>
<td>-knee continues flexion</td>
<td>-knee flexion</td>
</tr>
<tr>
<td></td>
<td>-ankle plantarflexion</td>
<td>-ankle continues to plantarflex</td>
</tr>
<tr>
<td></td>
<td>-stance ends toe off</td>
<td>-stance ends heel off</td>
</tr>
<tr>
<td>SWING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Swing:</td>
<td>-hip flexes</td>
<td>-hip extends</td>
</tr>
<tr>
<td></td>
<td>-knee flexes</td>
<td>-knee flexes</td>
</tr>
<tr>
<td></td>
<td>-ankle dorsiflexes</td>
<td>-ankle dorsiflexes then plantarflexes to neutral</td>
</tr>
<tr>
<td>Mid-swing:</td>
<td>-hip flexes</td>
<td>-hip extends</td>
</tr>
<tr>
<td></td>
<td>-knee flexes</td>
<td>-knee flexes</td>
</tr>
<tr>
<td></td>
<td>-ankle held in neutral</td>
<td>-ankle held in neutral</td>
</tr>
<tr>
<td>Terminal Swing:</td>
<td>-hip flexes</td>
<td>-hip extends</td>
</tr>
<tr>
<td></td>
<td>-full knee extension</td>
<td>-knee extends</td>
</tr>
<tr>
<td></td>
<td>-ankle held in neutral</td>
<td>-ankle held in neutral</td>
</tr>
</tbody>
</table>
In comparison, Cipriani\(^2\) conducted a study to evaluate the adaptations in the gait cycle produced by BW on a treadmill at 0, 5, and 10\% grade. EMG analysis of the rectus femoris, hamstrings, gastrocnemius, and anterior tibialis revealed significant increases in average activity over the three treadmill conditions, with the greatest changes occurring in the gastrocnemius at initial contact between the 0 and 10\% conditions. The study also revealed significant increases in the joint positions of the knee and ankle at initial contact as the treadmill was raised from 0 to 10\%.

An unpublished study by Yoshimoto\(^9\) took this one step further, looking at the EMG activity of the quadriceps and hamstrings during both FW and BW at 0, 10, and 15\% inclines. While inclined FW elicited increased EMG activity, BW at 15\% grade recruited the highest EMG activity in most of the muscles studied.

Current research supports the use of controlled exercise as an adjunct to the healing of damaged or repaired tissue.\(^2\) By progressively increasing the level of treadmill inclination during BW, greater demands can be placed on the targeted tissues.\(^9-11\) These increased demands may serve to facilitate a reeducation of kinesthetic awareness following lower extremity trauma as well as to strengthen the surrounding knee joint musculature in a protected closed chain environment. The joints are also required to work through a greater range of motion (ROM) relative to the level of inclination.\(^2\) This is an important aspect in many rehabilitation programs involving the knee and ankle such as anterior cruciate ligament (ACL) reconstruction, fracture management, joint replacements, and inversion sprains.

Another concern in rehabilitation, especially for athletes wishing to return to sports, is cardiovascular conditioning. Graded treadmill exercise has been shown to elicit
significant increases in oxygen consumption and heart rate. Researchers also suggest that a greater level of energy expenditure occurs in BW when compared to FW. This is supported by Flynn et al who concludes that the cardiopulmonary demands and metabolic costs of BW are higher than FW at the same speed and even forward running at some higher speeds.

While graded treadmill walking is currently implemented by physical therapists and athletic trainers, no research has been found on inclines beyond 15% for BW and 24% for FW. There is also limited data available comparing FW and BW at the same level of inclination. As such, the purpose of this study is to analyze EMG activity of the VL, VM, RF, BF, St, and GS during forward and backward walking at 0, 25, and 35% grade. The resultant data will assist in determining the most effective direction and grade of treadmill inclination for rehabilitation of the lower extremity.
CHAPTER III

METHODS

Subjects

Ten healthy subjects (4 male, 6 female) ages 21-26 were used in this study (Table 2). All subjects reported no hip, knee, or ankle pathologies. 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) gastrocnemius (GS), (2) rectus femoris (RF), (3) vastus lateralis (VL), (4) vastus medialis (VM), (5) biceps femoris (BF) and semitendinosis (St) (Table 3). A ground electrode was applied over the superior medial tibial plateau. The hair over the placement sites was clipped if necessary, and the skin was cleansed 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.
Table 2. Subject information.

<table>
<thead>
<tr>
<th>Subject#</th>
<th>Sex</th>
<th>Age</th>
<th>Weight</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>26</td>
<td>121</td>
<td>5'3&quot;</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>27</td>
<td>165</td>
<td>5'11&quot;</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>23</td>
<td>135</td>
<td>5'5&quot;</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>23</td>
<td>135</td>
<td>5'8&quot;</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>24</td>
<td>170</td>
<td>6'1&quot;</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>23</td>
<td>130</td>
<td>5'10&quot;</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>23</td>
<td>165</td>
<td>6'</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>24</td>
<td>132</td>
<td>5'9&quot;</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>24</td>
<td>150</td>
<td>5'10&quot;</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>25</td>
<td>130</td>
<td>5'9&quot;</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
Rectus Femoris - midpoint of a line from the ASIS to superior pole of patella (minimum of 10 cm above the patella)
Vastus Medialis - along a line 1/2 of the distance from the medial knee joint line to the ASIS
Vastus Lateralis - along a line 1/4 the distance from the lateral knee joint line to the ASIS and over the belly of the vastus lateral
Gastrocnemius - over the muscle belly 1/4 the distance of the leg (fibular head to calcaneous)

Figure 1. Electrode Placement for Lower Extremity Muscles.
Table 3. Origins and insertions.

<table>
<thead>
<tr>
<th>MUSCLE</th>
<th>ORIGIN</th>
<th>INSERTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrocnemius</td>
<td>Medial &amp; lateral condyles of femur</td>
<td>Achilles tendon to calcaneal tuberosity</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>Anterior inferior iliac crest</td>
<td>Tibial tuberosity</td>
</tr>
<tr>
<td>Vastus lateralis</td>
<td>Linea aspera</td>
<td>Tibial tuberosity</td>
</tr>
<tr>
<td>Vastus medialis</td>
<td>Linea aspera</td>
<td>Tibial tuberosity</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>Long head- ischial tuberosity</td>
<td>Head of fibula</td>
</tr>
<tr>
<td></td>
<td>Short head- linea aspera</td>
<td></td>
</tr>
<tr>
<td>Semitendinosis</td>
<td>Ischial tuberosity</td>
<td>Medial proximal tibia</td>
</tr>
</tbody>
</table>
Footswitches were used to determine the phase of the gait cycle. Shoes and socks were removed from both feet in order to apply the switches, and the subjects remained barefoot throughout the study. The switches were placed over the following anatomical parts: (1) heel, (2) first metatarsal head, (3) great toe, and (4) fifth metatarsal head. In order for the footswitches to remain intact during treadmill ambulation, they were secured with tape.

A Penny & Giles M180 electrogoniometer (Penny & Giles, 2716 Ocean Park Blvd., Santa Monica, CA 90405) was placed over the lateral aspect of the right knee joint to obtain knee range of motion during ambulation. The electrogoniometer was centered over the joint axis with the proximal end aligned with the longitudinal axis of the femur and the distal end aligned with the longitudinal axis of the fibula. It was secured to the skin using Coban and double-sided adhesive tape to avoid migration during data collection. Electrogoniometric zero was obtained by having the subject stand stationary in an upright and relaxed posture.

Subjects wore a waist belt containing a pre-amplified Noraxon Telemyo8 telemetry unit (Noraxon USA, 13430 N. Scottsdale Rd., Scottsdale, AZ 85254) and PEAK Motus 5.0 (PEAK Performance Technologies, 7388 S. Revere Parkway, Englewood, CO 80112) that received information from the EMG electrodes, electrogoniometer, and footswitches. EMG signals were transmitted to a receiver and sent to a computer that presented raw and rectified EMG data, knee range of motion, and footswitch activation (Figure 2).
Figure 2. Electrode placement. A, Anterior view. B, Posterior view. C, Lateral view.
**Procedure**

Prior to the experiment, the treadmill was calibrated to 2.4 mph. Each subject’s age, height, weight, and gender 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, and the application of safety harness belts by the researcher, which were worn during backward walking. They were then instructed on proper procedure for getting on and off the treadmill.

The subjects were given a one-minute warm-up trial prior to testing at 0 and 35% 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 2.4 mph at 0, 25, and 35% 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 again asked to stand still in an upright and relaxed posture to allow for a final baseline EMG reading. The electrodes, footswitches, and electrogoniometer were removed, concluding the subject’s participation in the study (Figure 3).

**Data analysis**

Analysis of EMG data was performed using MyoResearch 2.02 software to compare forward and backward walking. The ambulation data was quantified by
Figure 3. Treadmill walking at 35 degrees incline. A, Forward. B, Backward.
selecting five consecutive phases of gait during forward and backward walking, to which the computer calculated the average electrical activity. One gait phase was defined as the period from initial contact to initial contact of the same foot. The data was then normalized to forward walking at 0% grade, allowing for comparison between trials. The percent change in EMG activity was calculated using the following formula:

\[
\text{% change} = \frac{\text{mean activity during trial} - \text{mean activity at FW 0}}{\text{mean activity at FW 0}}
\]
RESULTS

ELECTROMYOGRAPHY

Figure 4 shows the percent change in EMG activity in all muscles tested during the various trials when compared to FW at 0% grade.

Gastrocnemius

Figure 5 shows that the gastrocnemius was most active during FW at 25% grade (55%) followed by FW at 35% grade (40%). BW at 0% grade elicited the least amount of activity (-18%).

Rectus Femoris

Figure 6 shows that the rectus femoris was most active during BW at 35% grade (47%) followed by BW at 25% grade (28%). BW at 0% grade showed no change in EMG activity (0%).

Vastus Lateralis

Figure 7 shows that the vastus lateralis was most active during BW at 35% grade (67%) followed by BW at 25% grade (42%). FW at 25% grade elicited the least percent change in activity (9%).
Figure 4. EMG activity in the tested muscles during forward (FW) and backward walking (BW).
Figure 5. EMG activity in the gastrocnemius during the experimental trials.
Figure 6. EMG activity in the rectus femoris during the experimental trials.
Figure 7. EMG activity in the vastus lateralis during the experimental trials.
Vastus Medialis

Figure 8 shows that the vastus medialis was most active during BW at 35% grade (68%) followed by BW at 25% grade (54%). BW at 0% grade elicited the least percent change in activity (10%).

Biceps Femoris

Figure 9 shows that the biceps femoris was most active during BW at 25% grade (38%) followed by BW at 35% grade (25%). FW at 25% grade elicited the least percent change in activity (8%).

Semitendinosis

Figure 10 shows that the semitendinosis was most active during BW at 35% grade (48%) followed by FW at 35% grade (47%). BW at 0% grade elicited the least percent change in activity (10%).

Gait Cycle

Figures 11 and 12 show the EMG activity of various muscles over one complete gait cycle. The timing of the muscles remains relatively similar during both FW and BW gait cycles.

RANGE OF MOTION

Table 4 shows the values for knee range of motion during each of the gait cycles. The greatest amount of knee flexion occurred during BW at 35% followed by BW at 25% grade. The least amount of knee flexion occurred during BW at 0% grade. As shown in Figures 11 and 12, knee range of motion progressively increased with elevation while BW. During FW, however, the greatest amount of knee flexion occurred at 0% grade while inclined walking produced more prolonged amounts of knee flexion.
Figure 8. EMG activity in the vastus medialis during the experimental trials.
Figure 9. EMG activity in the biceps femoris during the experimental trials.
Figure 10. EMG activity in the semitendinosus during the experimental trials.
Figure 11. Ensemble average of electromyographic, range of motion and footswitch data from all subjects during forward walking on the treadmill.
Figure 12. Ensemble average of electromyographic, range of motion and footswitch data from all subjects during backward walking on the treadmill.
Table 4. Knee range of motion values during experimental trials.

<table>
<thead>
<tr>
<th></th>
<th>FW 0</th>
<th>BW 0</th>
<th>FW 25</th>
<th>BW 25</th>
<th>FW 35</th>
<th>BW 35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>17.45</td>
<td>15.95</td>
<td>22.50</td>
<td>23.22</td>
<td>23.07</td>
<td>24.10</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.09</td>
<td>0.28</td>
<td>2.69</td>
<td>2.88</td>
<td>1.67</td>
<td>1.62</td>
</tr>
<tr>
<td>Maximum</td>
<td>53.78</td>
<td>49.17</td>
<td>48.09</td>
<td>55.80</td>
<td>49.24</td>
<td>56.66</td>
</tr>
<tr>
<td>Range</td>
<td>53.68</td>
<td>48.89</td>
<td>45.40</td>
<td>52.93</td>
<td>47.57</td>
<td>55.04</td>
</tr>
</tbody>
</table>
CHAPTER V
DISCUSSION

Gastrocnemius

The GS was most active during FW at 25% grade (55%), followed by FW at 35% grade (40%). During FW, the GS is thought to be working eccentrically in stance phase to control the progression of the leg over the fixed foot.\(^\text{13}\) The EMG activity also increased during BW with increasing inclines. We agree with Cipriani et al\(^\text{2}\) who suggest that the muscle is working eccentrically to accept the body weight during initial contact, controlling ankle dorsiflexion. Our results also showed that this increased activity continued into loading response, where it peaked then gradually decreased, as it was no longer needed to control tibial motion.

According to Cipriani et al\(^\text{2}\), BW demanded greater ankle range of motion. They thought this could be useful for rehabilitation following inversion sprains. During normal forward gait, a minimum of 10 degrees ankle dorsiflexion is needed just prior to heel-off for a normal contralateral step length.\(^\text{13}\) An individual lacking sufficient ankle range of motion due to pathology or trauma may benefit from BW to facilitate an additional 3-4 degrees.\(^\text{2}\)

BW up an incline not only produced greater ankle joint range into dorsiflexion, it also produced increases in eccentric muscle activity. Because of the large
force involved, eccentric exercises should be used with caution. Therefore, it would be prudent to avoid inclined BW and FW during acute healing of the Achilles tendon.

**Quadriceps**

The quadriceps (RF, VL, VM) showed their highest EMG activity during BW, acting as isometric stabilizers from early to midstance followed by a concentric propulsive phase through the remaining stance and swing cycles. We agree with Flynn et al.\(^3\) who also found sustained quadriceps activity throughout the gait cycle. During FW, however, the quadriceps act primarily as eccentric decelerators during early stance with decreasing activity from mid to late stance.\(^3,13\)

Adding inclination to BW may further enhance the need for concentric propulsive knee extensor activity as it is working through a greater range of motion. Visual observation revealed the subjects in a “crouched” position with the knee remaining in a flexed position during most of the stance phase. The treadmill inclination demands more prolonged knee flexion, which produces a longer moment arm for knee flexion torque due to gravity, and demands greater activity of quadriceps to prevent knee buckling at initial contact.

Trainers and physical therapists often choose inclined treadmill walking as a safe closed kinetic chain exercise to rehabilitate and enhance quadriceps activity. BW on an incline is an effective exercise that increases muscular demands while reducing patellofemoral compressive forces during quadriceps contractions.\(^2,8,9,11\) Ground reaction forces are absorbed into the forefoot and calf musculature and dissipate less force toward the knee, leading to less knee joint stress.\(^11\) This is important for the rehabilitation for patellofemoral joint dysfunction where the goal is to increase
quadriceps strength without aggravating the condition. However, therapists using inclined BW as a part of a rehabilitation protocol should be aware of the marked enhancement of quadriceps muscle activity in the transition from FW to BW or level of inclination.

When comparing BW at 25 to BW at 35 % incline, the RF shows a 19% increase in activity. The VL increases 15% between the two grades, while the VM only increases 14%. This heightened level of activity is not as eminent when comparing FW at 25 to FW at 35% grade (Figure 4). The RF showed no change, while the VL and VM only increased 6% and 7% respectively.

ACL protocols often begin BW at 4-6 weeks post-surgery once normal forward gait patterns are achieved. While patients will benefit from concentric activity of the quadriceps, precaution must be taken secondary to the increased risk of an anterior drawer effect. This can be minimized by slowly progressing treadmill inclination, thereby increasing tension on the healing graft in a controlled manner. In addition, we agree with Cipriani et al who reported increased knee ROM during BW, which is also an important aspect of knee rehabilitation of the ACL. The increase in knee flexion is necessary for adequate toe clearance during swing phase in normal forward gait.

Eccentric contraction of the quadriceps muscles has been speculated to be the cause of quadriceps and patellar tendonitis. BW is therefore a safe alternative for tendonitis rehabilitation as the quadriceps are working concentrically throughout the gait cycle.
Hamstrings

The activity of the hamstrings is inconsistent during BW and FW. For both the BF and St, increasing the incline during FW somewhat produced increased activity. However, in BW, the St activity increased with increasing inclines while the BF activity decreased. Our study does not agree with other studies\textsuperscript{9-11} that found a progressive increase in muscle activity during BW at all grades. We feel these differences may be due to our using averaged EMG data whereas the other authors utilized peak EMG data. During BW, the large increase in EMG activity in both muscles occurred during the swing phase as they work concentrically to flex the knee and clear the toe.

Clinically, the greatest percent change in EMG activity was not a result of directional changes, but rather due to changes in the incline of the treadmill.

Range of motion

For protection of the ACL, literature suggests exercises should be performed with knee angles greater than 30 degrees flexion.\textsuperscript{8} It has also been suggested that patellofemoral pain can be minimized when the quadriceps are strengthened at 0-30 degrees as patellofemoral counterpressure can increase dramatically with increased knee flexion. In our study, we found knee flexion range of motion was greater than 30 degrees at all levels of forward and backward treadmill walking. Therefore, if treadmill walking is utilized during ACL rehabilitation, one must be aware of the increased risk of patellofemoral stress.

Limitations

While the study provided valuable insight to graded BW, certain limitations must be considered. The data was collected on only 10 healthy subjects, 2 of which the EMG
readings for both the VL and VM were eliminated, as well as the entire data from one subject secondary to a technical error. As a result of the limited number of subjects and an uneven gender ratio, no statistical analysis was performed. Therefore, generalization to the overall population must be done with caution. Also, motion analysis of the lower extremity joints could not be performed as a result of limited testing space. This leaves room for the possibility of error in the interpretation of eccentric versus concentric muscle activity.
CHAPTER VI
CONCLUSION

We have concluded that BW at inclines is an effective intervention for lower extremity injuries. In general, BW elicits increased EMG activity as compared to FW, with the exception of the GS. Progressive increases in inclination during BW also demonstrate an increase in muscle recruitment in all the muscles studied. In addition to increases in muscle activity and knee range of motion, BW is a CKC exercise allowing for a safe and functional method of rehabilitation.

EMG and electrogoniometric data shows that BW is applicable to lower extremity injury rehabilitation, such as post-ACL repair. Walking backwards at 35 percent incline elicited the largest increases in the RF, VL, VM, and St EMG activity. The BF showed its greatest activity during BW at 25 percent. These muscles are important to the dynamic stability at the knee joint, and BW can therefore be beneficial following ACL repair to minimize subsequent muscle atrophy.

Further research on inclined BW should be performed using a larger subject population with equal gender ratios to allow for inferential statistical analysis. In addition, subjects with lower extremity injuries such as post-ACL repair, tendonitis, or ankle inversion sprains should be considered in future research. We would have benefited from the use of motion analysis for two reasons: (1) to record the kinematics at the hip and ankle, and (2) to distinguish between concentric, eccentric, and isometric
muscle contractions within the lower extremity in relation to the direction and phase of the gait cycle.
APPENDIX
EXPEDITED REVIEW REQUESTED UNDER ITEM 3 (NUMBER[S]) OF HHS REGULATIONS

EXEMPT REVIEW REQUESTED UNDER ITEM _____ (NUMBER[S]) OF HHS REGULATIONS

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

INVESTIGATOR: Thomas Mohr, Jennifer Coauette, Carrie Voeller, Elizabeth Frye, Heidi Schwartz
TELEPHONE: 777-2831
DATE: 5/4/00

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

SCHOOL/COLLEGE: Medicine & Health Sciences DEPARTMENT: Physical Therapy

PROJECT TITLE: An Electromyographic Analysis Study of Forward and Backward Treadmill Walking

FUNDING AGENCIES (IF APPLICABLE): None

TYPE OF PROJECT (Check ALL that apply):

- NEW PROJECT
- CONTINUATION
- RENEWAL
- DISSERTATION OR
- THESIS RESEARCH
- STUDENT RESEARCH PROJECT
- CHANGE IN PROCEDURE FOR A PREVIOUSLY APPROVED PROJECT

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

PROPOSED PROJECT:

- INVOLVES NEW DRUGS (IND)
- INVOLVES NON-APPROVED USE OF DRUG
- INVOLVES A COOPERATING INSTITUTION

IF ANY OF YOUR SUBJECTS FALL IN ANY OF THE FOLLOWING CLASSIFICATIONS, PLEASE INDICATE THE CLASSIFICATION(S):

- MINORS (<18 YEARS)
- PREGNANT WOMEN
- MENTALLY DISABLED
- FETUSES
- MENTALLY RETARDED
- PRISONERS
- ABORTUSES
- UND STUDENTS (>18 YEARS)

IF YOUR PROJECT INVOLVES ANY HUMAN TISSUE, BODY FLUIDS, PATHOLOGICAL SPECIMENS, DONATED ORGANS, FETAL MATERIAL, OR PLACENTAL MATERIALS, CHECK HERE

IF YOUR PROJECT HAS BEEN/ WILL BE SUBMITTED TO ANOTHER INSTITUTIONAL REVIEW BOARD(S), PLEASE LIST NAME OF BOARD(S):

- Altru Hospital, Grand Forks, ND

Status: Submitted; Date X Approved; Date 5/2/00 Pending

1. ABSTRACT: (LIMIT TO 200 WORDS OR LESS AND INCLUDE JUSTIFICATION OR NECESSITY FOR USING HUMAN SUBJECTS.

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

The purpose of this research 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 patterns of muscle activity and joint motion, which will be used in developing training protocols for patients.

Normal, healthy, adult subjects will be used in this research project. Human subjects are needed for this research study in order to determine when the selected muscles are active while walking at various grades of incline.
PLEASE NOTE: Only information pertinent to your request to utilize human subjects in your project or activity should be included on this form. Where appropriate attach sections from your proposal (if seeking outside funding).

2. PROTOCOL: (Describe procedures to which humans will be subjected. Use additional pages if necessary.)

Subjects:
It is anticipated that we will recruit 20 subjects (both male and female) between the ages of 18 and 40. The subjects for the study will be recruited from university students and clients presently involved in training at the facility in Fargo. These subjects will participate voluntarily. These subjects will be chosen because of their age and health status. Only healthy subjects with no history of knee surgeries will be used in the study. The project will be completed at Altru Hospital in Grand Forks. Prior to walking, each subject will be asked to complete a consent form. The subjects will not be compensated.

Methods:
Prior to the walking trials, each subject's age, height, and weight will be recorded. During the trial, we will measure electromyographic (EMG) activity in selected lower extremity muscles. We will measure activity in the following muscles while the subjects are walking on the treadmill: 1) rectus femoris, 2) vastus lateralis, 3) biceps femoris, 4) gastrocnemius, 5) vastus medialis, and 6) semitendinosus. The study will be performed by Thomas Mohr, chairman of the physical therapy department and four graduate students: Jennifer Coauette, Carrie Voeller, Elizabeth Frye and Heidi Schwartz.

To record EMG activity, adhesive electrodes will be placed over each muscle. The precise electrode placement will be determined from standard electrode placement charts. Prior to placing the EMG electrodes, the skin over each placement site will be prepared by cleansing the skin with alcohol. The EMG signals will be transmitted to a receiver unit and then fed into a computer for display and recording of data. Prior to beginning the experimental trial, the researcher will apply manual resistance to the subject's lower extremity in order to elicit a maximal voluntary contraction from each muscle being monitored in this study. The muscle activity recorded during the maximal voluntary contraction will be considered as a 100% EMG activity level to which the EMG activity during exercise on the treadmill can be compared. This procedure is done to normalize the EMG data for later analysis.

The subject will walk both forwards and backwards at 3.4 mph at each of the treadmill inclines of 0%, 25%, 30% and 35%. At each incline, the athlete will walk for a total of 10 seconds in order to obtain the necessary data for analysis. A typical trial would consist of the subject walking at 0% incline for 10 seconds, followed by a two minute rest period. The order of the walking trials will be determined by random assignment.

Data analysis:
Descriptive statistics describing the subjects' anthropometric profiles will be provided. The mean activity of each monitored muscle will be calculated. The EMG data collected during the experimental trials will be expressed as a percentage of the EMG activity recorded during the maximal contraction prior to the experimental trials (i.e. normalized). The video image will be converted to a stickman-like figure, from which we can determine joint angles and limb velocity. The EMG data is synchronized with the video data to determine the level of EMG activity during the various running trials.
3. **BENEFITS:** (Describe the benefits to the individual or society.)

The data collected throughout this research study will be analyzed to determine which muscles are active when the subject is walking both forward and backward at the various inclines. The body angles will also be analyzed to examine the walking strategies at the various inclines. The data should provide information on which muscles are active during forward and backward walking, and this information will provide the basis for developing protocols specifically for postoperative patients. The benefit to the participant will be the experience of being involved in a scientific study, and knowing that they will be contributing to the body of knowledge in exercise physiology and physical therapy.

4. **RISKS:** (Describe the risks to the subject and precautions that will be taken to minimize them. The concept of risk goes beyond physical risk and includes risks to the subject's dignity and self-respect, as well as psychological, emotional or behavioral risk. If data are collected which could prove harmful or embarrassing to the subject if associated with him or her, then describe the methods to be used to insure the confidentiality of data obtained, including plans for final disposition or destruction, debriefing procedures, etc.)

The risks involved in this research project are minimal. The EMG and video analysis equipment causes no discomfort to the subject, since they are both monitoring devices. Because the video information is converted to stickman-like diagrams, the actual subject's video is not used in data reporting. Therefore, the subject is not recognizable.

The process of physical performance testing does impose a potential risk of injury to the muscle. The testing will occur in a controlled setting, and because only healthy subjects will be used, at walking speeds the risk of any injury is extremely low. The participant will be closely observed throughout the activity on the 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 of the skin following removal of the electrodes, but this will only be temporary.

In the event that this research activity (which will be conducted at Altru Hospital) results in a physical injury, medical treatment will be available, including first aid, emergency treatment and follow up care as it is to a member of the general public in similar circumstances. Payment for any such treatment must be provided by the subject's third party payor, if any.

The subjects' names will not be used in any reports of the results of this study. Any information that is obtained in connection with this study and that can be identified with the subject will remain confidential and will be disclosed only with the subject's permission. The data will be identified by a number known only by the investigator.

All of the raw data will be stored in electronic format (computer files), in the Department of Physical Therapy for a period of five (5) years. After that time, the data will be erased. Some of the processed data and the consent forms will be in stored in paper format, in the Department of Physical Therapy for a period of five (5) years. After that time they will be shredded.
5. **CONSENT FORM:** A copy of the CONSENT FORM to be signed by the subject (if applicable) and/or any statement to be read to the subject should be attached to this form. If no CONSENT FORM is to be used, document the procedures to be used to assure that infringement upon the subject's rights will not occur.

Describe where signed consent forms will be kept and for what period of time.

Consent forms will be kept in the Physical Therapy Department at the University of North Dakota for a period of five (5) years, after which time they will be shredded.

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

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

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

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

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

**SIGNATURES:**

_____________________________    ____________
Principal Investigator           Date

_____________________________    ____________
Project Director or Student Adviser Date

_____________________________    ____________
Training or Center Grant Director Date

(Revised 3/1996)
INFORMATION AND CONSENT FORM

TITLE: An Electromyographic Analysis Study of Forward and Backward Walking

You are being invited to participate in a study conducted by Jennifer Coauette, Carrie Voeller, Elizabeth Frye, Heidi Schwartz and Thomas Mohr from the physical therapy department at the University of North Dakota. The purpose of this study is to study muscle activity in your lower extremity while you are walking both forwards and backwards at different inclines on the 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 will be asked to participate in this study. If you have any previous knee surgeries you will not be eligible for this study. The benefit to you, as a participant, will be the experience of being involved in a scientific study and knowing that you will be contributing to the body of knowledge in exercise physiology and physical therapy.

You will be asked to walk on the treadmill for a total of six (6) trials consisting of the following: 1) Walking forwards and backwards on the treadmill at 3.4 mph with 0% grade, 2) Walking forwards and backwards on the treadmill at 3.4 mph with 25% grade, 3) Walking forwards and backwards on the treadmill at 3.4 mph with 35% grade. You will be given a rest period between trials.

The study will take approximately one hour of your time. You will be asked to report to the Acceleration Training Department at Altru Hospital in Grand Forks, ND, at an assigned time. You will then be asked to change into gym shorts for the experiment. We will first record your age, gender, height and weight. During the experiment, we will be recording the amount of muscle activity and the angles of your joints that is present when you walk on the treadmill at the four different inclines.

Although the process of physical performance testing always involves some degree of risk, the investigators in this study feel that the risk of injury or discomfort is minimal. In order for us to record the muscle activity, we will be placing electrodes on your trunk and lower extremity. The recording electrodes are attached to the surface of the skin with an adhesive material. These devices only record information from your muscles and joints, they do not stimulate the skin. After we get the electrodes and markers attached, we will give you a brief training session to familiarize you with the treadmill. The amount of exercise you will be asked to perform will be moderate. There may be a slight redness following removal of the electrodes, but this will only be temporary.

Your name will not be used in any reports of the results of this study. The computer files, and consent forms are kept in the physical therapy department for a period of five (5) years. After that time, the electronic media is erased and the paper files are shredded. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. The data will be identified by a number known only by the investigator. The investigator or participant may stop the experiment at any time if the participant is experiencing discomfort, pain, fatigue, or any other symptoms.
that may be detrimental to his/her health. Your decision whether or not to participate will not prejudice your future relationship with the Physical Therapy Department or the University of North Dakota. If you decide to participate, you are free to discontinue participation at any time without prejudice.

The investigator involved is available to answer any questions you have concerning this study. In addition, you are encouraged to ask any questions concerning this study that you may have in the future. Questions may be asked by calling Dr. Thomas Mohr at (701) 777-2831. A copy of this consent form is available to all participants in the study.

In the event that this research activity (which will be conducted at Altru Hospital) results in a physical injury, medical treatment will be available, including first aid, emergency treatment and follow up care as it is to a member of the general public in similar circumstances. Payment for any such treatment must be provided by you and your third party payor, if any.

ALL OF MY QUESTIONS HAVE BEEN ANSWERED AND I AM ENCOURAGED TO ASK ANY QUESTIONS THAT I MAY HAVE CONCERNING THIS STUDY IN THE FUTURE. MY SIGNATURE INDICATES THAT, HAVING READ THE ABOVE INFORMATION, I HAVE DECIDED TO PARTICIPATE IN THE RESEARCH PROJECT.

I have read all of the above and willingly agree to participate in this study explained to me by one of the investigators.

Participant's Signature  Date
REFERENCES


