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An Electromyographic and Electrogoniometric Study of Stair Climbing with and without the Use of the Ez-Step[a] and the Quad-Step[a]

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AN ELECTROMYOGRAPHIC AND ELECTROGONIOMETRIC STUDY OF STAIR CLIMBING WITH AND WITHOUT THE USE OF THE EZ-STEP™ AND THE QUAD-STEP™

by

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This Scholarly Project, submitted by Rebecca Behrens, Catherine Gregoire, Tara Mathern, and Jennifer L. Pederson in partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by the Faculty 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 Electrogoniometric Study of Stair Climbing With and Without the Use of the EZ-Step™ and the Quad-Step™
Department	Physical Therapy
Degree	Doctor of Physical Therapy

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Signature Rebecca Behrens Date 12/09/05

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Signature Lara Mather Date 12/09/05

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ABSTRACT

Purpose: The purpose of this study is to compare lower extremity muscle activity along with hip and knee ROM in an elderly population on stair ascent and descent using the EZ-Step™ and Quad-Step™ in comparison to traditional stair climbing. **Subjects:** Twenty nine male and female adults volunteered for this study. Inclusion criteria included those 65 years of age and older, ability to climb three flights of standard stairs, and upper extremity strength to be able to manipulate the Quad-Step™.
Instrumentation: The EZ-Step™ and Quad-Step™ are devices that decrease stair step height by one-half. The EMG activity and ROM was recorded using a Noraxon TeleMyo900 telemetry unit. The goniometers that were used were Biometrics SG110 twin axis goniometers. **Procedure:** EMG activity was recorded with surface electrodes over the rectus femoris, biceps femoris, gluteus maximus, and gastrocnemius. Electrogoniometers were placed at the knee and hip to record ROM during the stair climbing activities. There were three randomly selected stair-climbing trials in the study: 1) Quad-Step™, 2) EZ-Step™, and 3) traditional stairs. **Data Analysis:** A repeated measures analysis of variance (ANOVA) was used to analyze the data collected. The significance was set at an alpha level of .05. **Results:** The study found significantly less EMG activity in all four muscles with the EZ-Step™ and Quad-Step™ devices during stair ascent and stair descent, except for the BF with the use of the Quad-Step™ during stair descent. A significant difference in hip ROM was found for stair ascent, but not

forstair descent. On both stair ascent and descent, significantly less knee ROM was required. **Conclusion and Clinical Implication:** The EZ-Step^{TM} and Quad-Step^{TM} may make stair climbing easier for older individuals who have difficulty with this task.

CHAPTER 1

INTRODUCTION

Previous research has indicated that stair climbing is more difficult for elderly individuals than ambulation on level surfaces.[1-4] The increased difficulty of stair climbing may lead to a greater number of falls on stairs, which can result in injuries such as head trauma, joint dislocation, foot fractures, or even death,[5-7] and can be one of the major causes of loss of independent living and mobility in the elderly population.[8-9] A product called the EZ-Step™ has been developed to aid people in stair climbing.[10] The system is designed to reduce the step height by one-half and comes in a home system (EZ-Step™) and a portable system (Quad-Step™). The home system is built to fit the flight of stairs in a person's home and the portable unit was created to allow for stair climbing in the community. A previous pilot study involving the elderly population used a earlier prototype version of the EZ-Step™ and found a decrease in knee range of motion (ROM) and electromyographic (EMG) activity of lower extremity muscles.[11] The current project examined both the home system and the portable unit by measuring hip and knee ROM and EMG activity of selected lower extremity muscles during stair climbing with and without the use of the EZ-Step™ and Quad-Step™. Because these products are intended for use by persons who have difficulty climbing stairs, it is necessary to evaluate these devices with the use of human subjects.

PROBLEM STATEMENT

Stair climbing becomes progressively more difficult with age and disability.[12,13] By using assistive devices that are designed to make stair climbing easier by requiring less muscle activity and ROM, it may be possible to prolong independent living.

Fethkenher and Mohr[11] analyzed lower extremity ROM and muscle activity with and without the use of the EZ-Step™. The study only examined eight subjects and did not include the Quad-Step™. Therefore, more in depth research was necessary to determine the effectiveness of the portable device and the EZ-Step™ compared to traditional stair climbing. There was also a necessity for investigating a larger sample of elderly subjects for statistical analysis.

PURPOSE OF STUDY

The purpose of this study is to compare LE muscle activity in the gluteus maximus (GM), rectus femoris (RF), biceps femoris (BF), and gastrocnemius (GS) along with hip and knee ROM in an elderly population during stair ascent and descent using the EZ-Step™ and Quad-Step™ in comparison to traditional stair climbing.

SIGNIFICANCE OF STUDY

The fastest growing age group in the United States is individuals 65 years of age and older.[14] This age group is expected to increase from approximately 35 million in 2000 to an estimated 71 million in 2030. During 2000 to 2030 the worldwide population age 65 and older is also projected to almost double.

The cost of nursing home and assisted living care is steadily rising, increasing the desire to stay independent at home. Stair climbing can be a limiting factor for individuals who want to remain in their home. Devices such as the EZ-Step™ or Quad-Step™ can aid in their goal of continued independent living at home.

RESEARCH QUESTIONS

Research Question #1: Is there a significant difference in lower extremity muscle activity with stair ascent and descent using the EZ-Step™ and the Quad-Step™ as compared to traditional stair climbing?

Research Question #2: Is there a significant difference in ROM in the hip and knee with stair ascent and descent using the EZ-Step™ and the Quad-Step™ as compared to traditional stair climbing?

HYPOTHESES

Null hypothesis: There is no significant difference in LE muscle activity and hip and knee ROM with stair ascent and descent using the EZ-Step™ and Quad-Step™ compared to traditional stair climbing.

Alternative hypothesis: There is a significant difference in LE muscle activity and hip and knee ROM with stair ascent and descent using EZ-Step™ and Quad-Step™ compared to traditional stair climbing.

CHAPTER 2

LITERATURE REVIEW

Research has shown that stair climbing can be a difficult task for many older adults.[12,15,16] Disease and decreased mobility can lead to further difficulties with this task. Mayo et al[12], reported that 75 out of 93 patients who had strokes 44 days prior could not negotiate stairs independently. Of the 75 patients, only one-third learned to climb stairs independently before discharge from the rehabilitation center. Lindmark[15] found that women who were one year post-stroke had more difficulty with stair climbing than men who were one year post-stroke.

A study using the Functional Independence Measure (FIM) to assess motor tasks found stair climbing to be one of the most difficult tasks to perform.[16] Another study used the Barthel Index to assess stair climbing ability in elderly people admitted to an acute medical ward.[17] The authors reported that more than half of the 212 patients found stair climbing difficult or impossible. At discharge, 35 percent of the patients were unable to climb stairs and 26 percent required assistance with stair climbing. The ability to climb stairs is a functional task that needs to be evaluated to determine overall outcomes for individuals. [18]

JOINT FORCES

Patellofemoral pain (PFP) is a common orthopedic knee problem that encompasses retropatellar pain.[19] The exact cause of PFP is unknown, but may be a result of excessive patellofemoral joint stress. Symptoms are aggravated through activities such as squatting and stair climbing. Salsich et al[19] compared lower extremity kinetics during stair climbing in subjects with and without PFP. Patellofemoral joint reaction force increased with quadriceps muscle force and knee flexion angle. Subjects with PFP decreased their peak knee extensor moments during stair ascent and descent by avoiding maximal quadriceps contractions.

Patients who receive a total knee arthroplasty (TKA) or total knee replacement (TKR) often experience difficulties with ascending and descending stairs. According to Saari et al,[20] "TKR patients did not have normal kinematics during stair ascending or descending. Decreased knee extension and flexion was seen. Hip extension tended to decrease and a decreased hip extension moment was noted." A study conducted by Andriacchi et al,[21] concluded that in posterior cruciate retaining TKRs, maximum anterior displacement of the femur occurred at 54 degrees of knee flexion. Minimizing the amount of anterior displacement of the femur is beneficial to promote longevity of the prosthetic components. Therefore, limiting the amount of knee flexion required during activities would be beneficial for these individuals.

Individuals with anterior cruciate ligament (ACL) deficiency show gait adaptations during stair ascent. Thambyah et al[22] reported that, "patients with ACL deficiency displayed a reduction of up to 50 percent in peak flexion moment with their involved knee. When a step height of 15.5 cm was used, peak flexion moments in all of the subjects' limbs occurred at knee flexion angles of about 40 degrees during single limb support."[22]

Hip fractures have a considerable impact on function, independence, and ability of an older person to live in the community. Marottoli et al[13] studied self-reported performance of physical function including stair climbing. Prior to the subjects' hip fractures, 63 percent had climbed stairs independently. At 6 weeks post-fracture, this number fell to just 8 percent that were independently climbing stairs. At 6 months post-fracture, still only 8 percent of these individuals climbed stairs independently.

Difficulty with stair climbing may be the result of greater joint loading forces during ascent and descent as compared to joint forces during level walking.[23] Contact forces of the tibio-femoral joint have been reported to be 5.1 times body weight during stair climbing, compared to 2.97 times body weight in walking. Loading conditions are based on individual gait and muscle activation patterns, but the average increase in knee contact forces during stair climbing was 116 percent higher than hip contact forces for the same activity. Costigan et al[2] investigated joint kinetics during stair climbing and found that during stair ascent the maximum load placed on the knee occurred at approximately 60 degrees of knee flexion, which may lead to more wear and tear at the articulating surfaces.[2]

RANGE OF MOTION

Researchers have found that stair climbing requires increased hip and knee ROM compared to level walking.[2,4] Nadeau et al[3] determined that stair climbing requires 60 degrees of hip flexion and 93 degrees of knee flexion, compared to 31 degrees and 67 degrees for hip and knee flexion, respectively, in level walking.

According to Livingston and colleagues,[24] when adjusting to different stair dimensions, individuals appear to vary the flexion/extension patterns of the knee more than those at the ankle or hip. Knee flexion angles ranging from 83 to 105 degrees are required depending on the staircase dimensions. People shorter in height have greater maximum knee flexion angles (92 degrees to 105 degrees) than those who are taller (83 degrees to 96 degrees) while ascending stairs. Maximum hip and knee flexion angles increase with increasing stair inclination[4], however hip flexion angles decrease as the slope of a staircase decreases and the tread depth increases.[24]

Other research found the maximum knee flexion required for stair climbing to be in the range of 80-100 degrees[4] and maximum hip flexion to be 70-75 degrees.[25] Lark et al[26] found increased hip flexion with an increased step height. They also noted that elderly subjects had decreased passive range of motion as compared to younger people for hip flexion and extension and knee flexion. Older adults have also been found to have greater hip joint angles as compared to younger adults and children.[27]

MUSCLE ACTIVITY

There are significant differences in the activities of muscles during stair climbing as compared to level walking.[1,28] The largest differences are in the muscles responsible for moving the body in a vertical direction. When ascending stairs, the largest differences are found in the soleus, quadriceps femoris, hamstrings, and GM muscles during the support phase. During stair descent, changes in the contractions of the soleus and quadriceps femoris muscles show the largest differences from level walking.

Brask et al[29] examined EMG activity of LE muscles during lateral step-ups of 4 and 8 inches. The shorter step produced the lowest EMG activity for all the muscles and types of contractions. Specifically EMG activity of the RF was 7.1 percent lower during concentric contraction or ascending on the 4 inch step and was 4.5 percent lower during the eccentric contraction or descending on the 4 inch step. The BF showed a 3.8 percent lower EMG activity during concentric contraction with the 4 inch step and was 2.1

percent lower during eccentric contraction on the 4 inch step. This study showed that a decrease in step height may allow for a decrease in the amount of EMG activity needed to climb the steps.

Zimmermann et al[30] conducted a study comparing lower extremity EMG activity using a stepping ergometer at different forward cadences of 35, 60 and 95 steps/min and backward cadence of 60 steps/min. Mean EMG activity during forward stepping of the GM, RF, vastus medialis (VM) and GS all showed significant differences between any two exercise cadences. The semimembranosus/semitendinosus (SM/ST) muscles showed only significant difference in mean EMG activity between 35 and 95 steps/min. Mean EMG activity of retrograde stepping revealed only a statistically significant difference for SM/ST at 60 steps/min. Maximum activation of GM, RF, VM, and GS occurred at higher cadences. Maximum activation of SM/ST occurred with retrograde stepping at 60 steps/min.

Cesari et al[27] examined a common perceptual parameter for stair climbing. They reported that older adults, when given a choice, chose to climb stairs that were significantly lower than the stairs younger adults chose, even when they were the same body size. The results also indicated that older adults were able to climb stairs that were the equivalent height of 74 percent of their total leg length compared to young adults who climbed stairs at 100 percent. The researchers determined total leg length by subtracting sitting height (hips to head) from standing height (ankles to head).

Based on previous research, it is hypothesized that individuals who have decreased ROM, decreased muscle force, joint pain or other orthopedic conditions that limit stair climbing may benefit from equipment that potentially makes stair climbing easier. Such equipment may aid in maintaining greater functional independence and may allow some individuals to remain in their current living environments with only minor architectural changes.[8,9]

A device called the EZ-Step™ was designed to make stair climbing easier by reducing the height of each step.[10] A pilot study done by Fethkenher and Mohr[11] using 8 elderly subjects, compared EMG activity and ROM of the knee during stair ascent and descent with and without the use of the EZ-Step™. EMG activity of the GM, BF, GS, and RF was recorded and the results showed an average decrease in muscle activity of 19 to 59 percent when ascending stairs using the EZ-Step™ compared to standard stairs. When descending stairs the average muscle activity decreased 11 to 31 percent when using the EZ-Step™. Average knee ROM was also shown to decrease when using the EZ-Step™ compared to standard stairs. Average knee flexion on standard stairs was 79 degrees and 83 degrees during ascension and descension, respectively. Using the EZ-Step™ average knee flexion was 69 degrees and 58 degrees for stair ascension and descension, respectively.

The purpose of the current study is to determine if there is a difference in EMG activity of LE muscles and ROM of the knee and hip in an elderly population during stair ascension and descension when using the EZ-Step™ and Quad-Step™ compared to standard stairs.

CHAPTER 3

METHODS

SUBJECTS

Twenty nine male and female adults over the age of 65 volunteered for this study. Only one of the participants had prior experience with the EZ-Step^{TM}. No participants had any experience with the Quad-Step^{TM}. Inclusion criteria included those 65 years of age and older, ability to climb three flights of standard stairs (10-12 steps) with rest breaks as needed between trials, and upper extremity strength to be able to manipulate the Quad-Step^{TM}. Exclusion criteria included recent surgical procedures within the last 6 months or injuries that affected cardiovascular or musculoskeletal systems, balance deficits, and allergies or sensitivities to adhesive materials. Prior to beginning the study, each of the participants signed a letter of informed consent. The research project was approved by the University of North Dakota's Institutional Review Board.

Table 1. Characteristics of Subjects (n=29: 8 males, 21 females)

	Mean	**Range**	**SD**
AGE (years)	73.5	65.0-88.0	7.3
HEIGHT (inches)	64.8	59.0-77.0	4.6
WEIGHT (pounds)	162.2	117.0-241.0	35.1
HEART RATE			
Before	78.1	47.0-106.0	13.4
After	84.6	50.0-130.0	17.8
O_2 SATURATION			
Before	96.9	92.0-100.0	1.9
After	96.8	94.0-99.0	1.5

INSTRUMENTATION

The EZ-Step™ (EZ-Step, Inc., P.O. Box 138, Devils Lake, ND 58301) is comprised of a series of molded steps secured together that are made to install in the client's home. They are placed adjacent to the side of the stairwell, beneath the railing of each existing step on a flight of stairs (Figure 1). Standard steps generally have a height of 7 inches and a depth of 10.25 inches. The EZ-Step™ for this study had a height of 3.5 inches and a depth of 10.25 inches, so the device did not block the entire stairwell and allowed for regular use of the stairs. Because the depth of the EZ-Step™ is adjustable, it can be built-in to nearly any type of stairwell. The Quad-Step™ has a quad-point base for adequate support, with a height-adjustable cane attached (Figure 2). The bottom surface of both devices is rubberized and the top surface is texturized to prevent slippage.

In this study, two parameters were measured during each of the stair climbing trials: 1) muscle activity of four lower extremity muscles, and 2) knee and hip joint ROM. The EMG activity and ROM was recorded using a Noraxon TeleMyo900 telemetry unit (Noraxon USA, 13430 North Scottsdale Road, Suite 140, Scottsdale, AZ 85254) and collected by a Noraxon TeloMyo900 receiver. The information was then digitized by a USB-analog to digital interface board connected to a Dell laptop computer and stored by the MyoResearch XP data collection software that accompanies the TeloMyo900 EMG system. Data analysis was performed using the MyoResearch XP software. The goniometers were Biometrics SG110 twin axis goniometers (Biometrics Ltd, PO Box 340, Ladysmith, VA 22501).

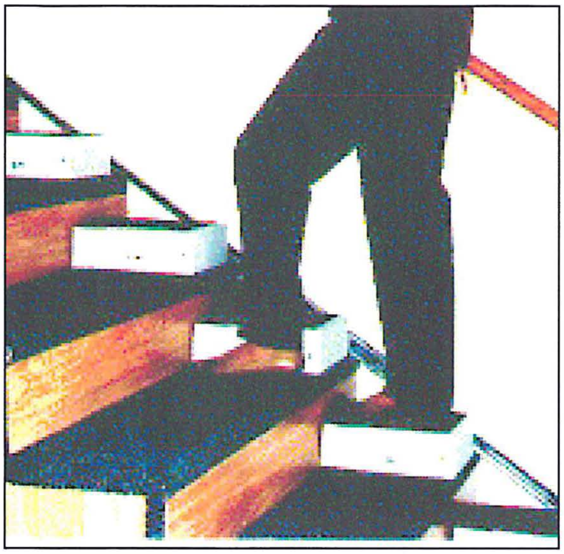


Figure 1. EZ-Step™ [10]

Figure 2. Quad-Step™ [10]

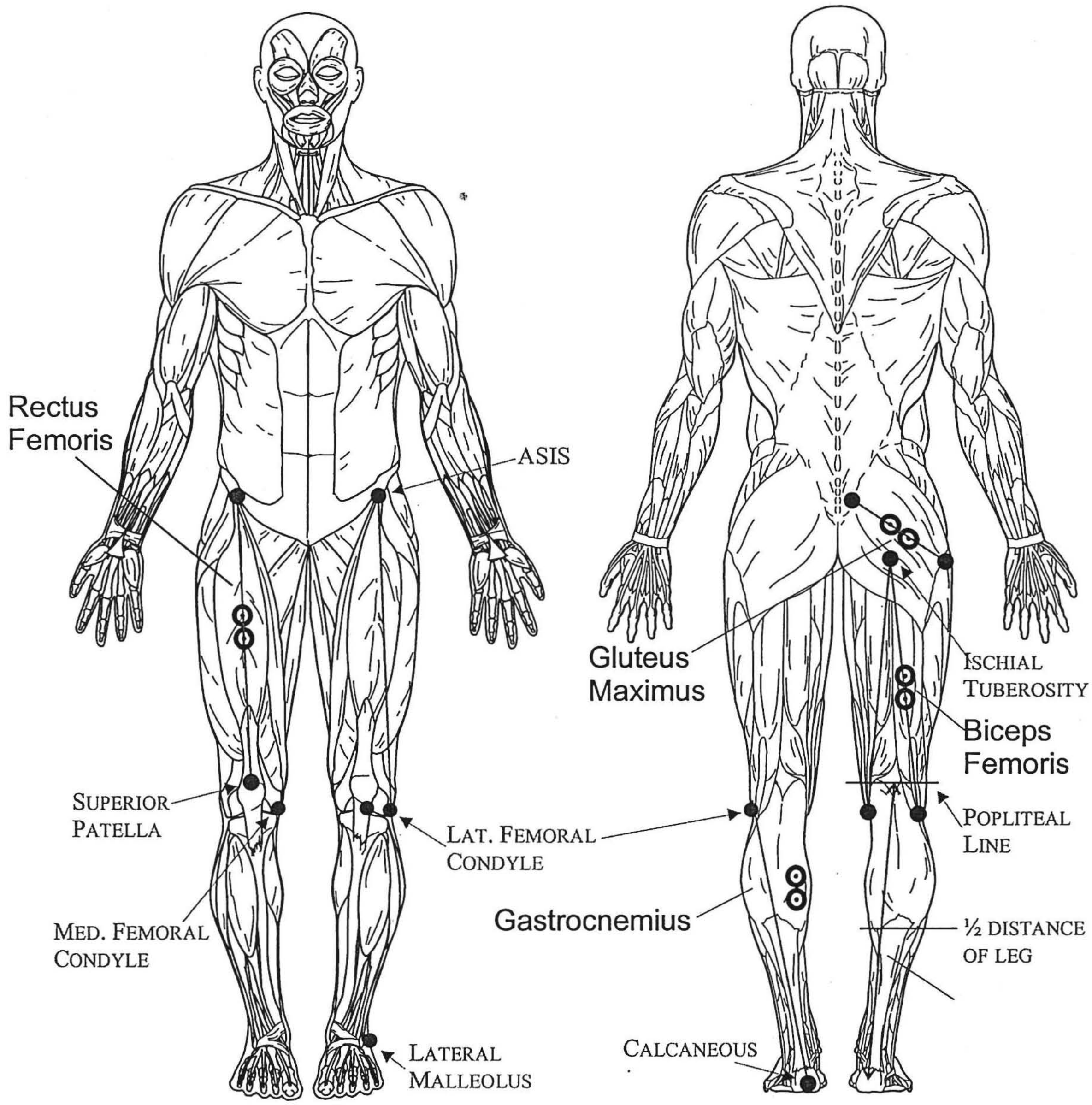
PROCEDURE

EMG activity was recorded by placing surface electrodes on the skin over each of the muscles under study. The muscles that were monitored were the: 1) GM, 2) RF, 3) BF, and 4) GS. The electrodes were placed in accordance with body measurements (Figure 3).

The skin was cleaned with alcohol in preparation for electrode placement. If needed, the skin was shaved prior to cleaning. After the measurements were taken a reference point was defined and the electrodes were placed one centimeter apart on the right side of the body and parallel to the long axis of the muscle fibers. A single common ground electrode was placed over the lateral right thigh (Figures 3 and 4).

Electrogoniometers were used to measure the ROM of the knee and hip during the stair climbing activity. The electrogoniometers were attached using double-sided adhesive tape. The knee goniometer was attached to the lateral thigh and leg above and below the knee joint. The hip goniometer was attached to the pelvis and thigh to measure the hip ROM. Both goniometers were centered on the joint on the right side of the subject's body while they were standing. The proximal end was secured first followed by the distal end with use of a straight edge (See figure 4 for hip and knee electrogoniometry placement). The electrogoniometers were connected to the NorAngle control box which was connected to the TeleMyo900 transmitter. Prior to beginning the experiment, the electrogoniometers were calibrated to assure accuracy of the measurements.

Foot switches were used to determine when the subject's foot was on or off the step. The switch was placed inside the shoe to register the foot placement on the step.



Gluteus Maximus - midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter
Biceps Femoris - midpoint of a line from the ischial tuberosity to the lateral femoral condyle
Rectus Femoris - midpoint of a line from the ASIS to superior pole of patella (minimum of 10 cm above the patella)
Gastrocnemius - over the muscle belly ¼ the distance of the leg (fibular head to calcaneous)

Figure 3. Electrode Placement for Lower Extremity Muscles

The footswitch was connected to a Multi-Mode footswitch control box which was connected to the TeleMyo900 transmitter.

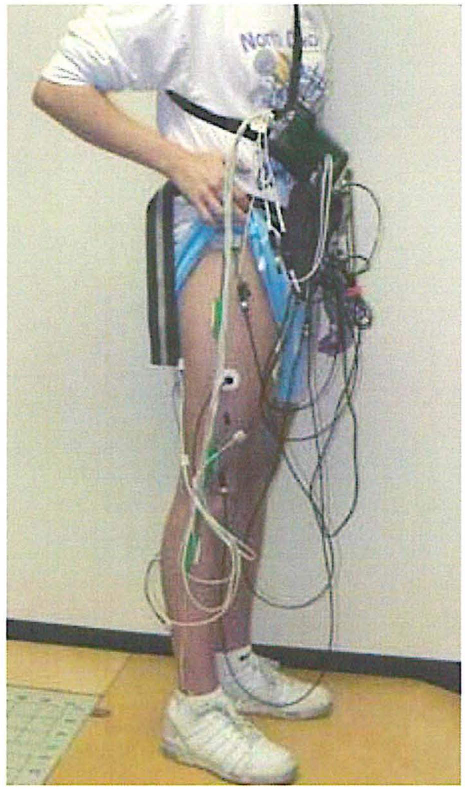


Figure 4. Electrode and lead placements

The electrical activity from the muscles, the goniometry, and footswitch data were transmitted to a receiver unit which was then fed into a laptop computer for recording and displaying the data. Prior to beginning and immediately following the last trial, participant's heart rate and oxygen consumption was measured using a pulse oximeter. Before the stair climbing trials, the height and weight of each participant was recorded. A 20 foot walk on a level surface was then performed to ensure that the equipment was working properly. The EMG data from the EZ-Step™ and Quad-Step™ trials were compared to the normal stair climbing data which served as the baseline.

There were three stair-climbing trials in the study: 1) Quad-Step™, 2) EZ-Step™, and 3) traditional stairs. The traditional stairs provided the baseline for comparison and were used to normalize the EMG data. The order of the trials was randomly selected prior to beginning the testing for each individual.

Each participant was instructed in the proper use of the devices and was allowed practice in order to become familiar with the equipment. Individuals were instructed according to the manufacturer's guidelines. The EZ-Step™ requires a reciprocal gait pattern, while the Quad-Step™ requires stepping onto the cane platform at the same stair level before advancing to the next step in a step-to gait pattern. Subjects were asked to ascend and descend the traditional stairs using their preferred method with the hand railing. Each subject was allowed to stair climb at their own chosen speed to accommodate for varying levels of functional mobility. For the experimental trials, each subject was asked to ascend and descend the stairs, during which time the EMG, goniometry and foot switch data was collected and recorded. Following each trial the subjects were allowed a seated-rest break if needed. For safety purposes, each participant donned a gait belt and one researcher stood behind as the subject ascended the stairs and in front during stair descent with one hand on the gait belt. The electrodes, electrogonimeter, and foot switches were removed during the final rest period after all trials were completed.

Figure 5. EZ-Step™ Descent

DATA ANALYSIS

Statistical analysis was performed on the normalized EMG data that was recorded during the three stair climbing trials. For the EMG normalization, four consecutive steps were marked in the software record during ascent and descent. The MyoResearch software was set to identify the highest three second period of contiguous EMG activity found during these four steps. The average of that three second period was used as a baseline (i.e. 100 percent) to which the other trials for that subject were compared. The results from the EZ-Step™ and Quad-Step™ trials were represented as a percent of the traditional stair climbing. For the ROM data, six markers were placed on the goniometer record before and after each consecutive step and the peak hip and knee ROM throughout the five steps was determined. An average of the five steps was calculated for the analysis. Repeated measures analysis of variance (ANOVA) was used to compare the EMG and goniometric data collected from the three experimental trials. The significance was set at an alpha level of .05.

CHAPTER 4

RESULTS

EMG ACTIVITY

The repeated measures ANOVA of the EMG activity showed a significant difference in muscle activity during the three step conditions when ascending stairs (Table 2). The post hoc analysis is shown in tables 3-6. The post hoc analysis was performed using a t-test for each muscle during stair ascent. The t-test results showed that all four muscles tested during stair ascent had significantly less muscle activity with the EZ-Step™ and Quad-Step™ as compared to the standard stairs. Figure 6 shows the differences in muscle activity in each of the selected muscles during each of the step conditions.

The repeated measures ANOVA of the EMG activity during stair descent showed a significant difference in muscle activity during the three step conditions (Table 7). Tables 3-6 show results of the post hoc analysis for each muscle during stair descent. The RF, GM, and GS had significantly less muscle activity in stair descent during both the EZ-Step™ and the Quad-Step™ as compared to the standard stairs. The BF muscle activity was found to be significantly lower only with the EZ-Step™ when compared to standard stairs. The BF activity during the Quad-Step™ stair descent, although less than the stairs, was not significantly different than the standard stairs. Figure 7 shows the differences in muscle activity in each of the selected muscles during each stepping condition.

Table 2.
Repeated Measures Analysis of Variance for Normalized Electromyographic Activity During Stair Ascent.

Source	df	SS	MS	F	p
Step Type	2	167658.467	83829.234	230.293	.000
Muscle	3	7120.075	2373.358	6.520	.000
Step Type x Muscle	6	4574.026	762.338	2.094	.054
Error	308	112115.668	364.012		
Total	348	1990373.580			

Table 3.
Post Hoc t-test results for Rectus Femoris EMG activity.

	Variable	Mean	SD	t	df	p
Pair 1	Stair Up	100.00	.00			
	EZ-Step™ Up	58.58	26.76	8.34	28	.000
Pair 2	Stair Up	100.00	.00			
	Quad-Step™ Up	44.00	15.25	19.77	28	.000
Pair 3	Stair Down	100.00	.00	4.73	28	.000
	EZ-Step™ Down	75.15	28.32			
Pair 4	Stair Down	100.00	.00	21.91	28	.000
	Quad-Step™ Down	39.89	14.77			

Table 4.
Post Hoc t-test results for Biceps Femoris EMG activity.

	Variable	Mean	SD	t	df	p
Pair 1	Stairs Up	100.00	.00			
	EZ-Step™ Up	66.39	16.33	11.08	28	.000
Pair 2	Stairs Up	100.00	.00			
	Quad-Step™ Up	62.41	49.58	4.08	28	.000
Pair 3	Stairs Down	100.00	.00			
	EZ-Step™ Down	77.76	23.39	5.12	28	.000
Pair 4	Stairs Down	100.00	.00			
	Quad-Step™ Down	82.76	54.94	1.69	28	.102

Table 5.
Post Hoc t-test results for Gluteus Maximus EMG activity.

	Variable	Mean	SD	t	df	p
Pair 1	Stairs Up	100.00	.00			
	EZ-Step™ Up	60.36	16.83	12.68	28	.000
Pair 2	Stairs Up	100.00	.00			
	Quad-Step™ Up	49.35	18.39	14.83	28	.000
Pair 3	Stairs Down	100.00	.00			
	EZ-Step™ Down	72.74	33.35	4.40	28	.000
Pair 4	Stairs Down	100.00	.00			
	Quad-Step™ Down	68.34	46.49	3.66	28	.001

Table 6.
Post Hoc t-test results for Gastrocnemius EMG activity.

	Variable	Mean	SD	t	df	p
Pair 1	Stairs Up	100.00	.00			
	EZ-Step™ Up	48.71	12.87	21.47	28	.000
Pair 2	Stairs Up	100.00	.00			
	Quad-Step™ Up	42.80	19.65	15.68	28	.000
Pair 3	Stairs Down	100.00	.00			
	EZ-Step™ Down	67.40	20.93	8.39	28	.000
Pair 4	Stairs Down	100.00	.00			
	Quad-Step™ Down	49.74	17.17	15.76	28	.000

Table 7.
Repeated Measures Analysis of Variance for Normalized Electromyographic Activity During Stair Descent.

Source	df	SS	MS	F	p
Step Type	2	95516.713	47758.356	79.727	.000
Muscle	3	13497.868	4499.289	7.511	.000
Step Type x Muscle	6	20033.392	3338.899	5.574	.000
Error	308	184499.842	599.025		
Total	348	2476986.810			

RANGE OF MOTION

Descriptive statistics for hip and knee ROM during stair ascent and descent in all three stepping conditions are shown in tables 8 and 9.

The repeated measures ANOVA results showed a significant decrease in hip ROM during stair ascent (Table 10). Post hoc testing, using Multiple Comparisons, revealed a significant reduction of hip ROM for both the EZ-Step™ and Quad-Step™ as compared to the standard steps (Figure 8).

During descent, the ANOVA results for the hip did not reveal a significant difference in hip ROM between any of the three step conditions (Table 11). Figure 8 shows the hip ROM differences with each of the activities.

The ANOVA results showed a significant decrease in knee ROM during stair ascent (Table 12). Post hoc testing revealed a significant reduction of knee ROM was required for both the EZ-Step™ and Quad-Step™ as compared to standard steps (Figure 9).

A significant decrease in knee ROM during descent was also found (Table 13). Post hoc testing revealed a significant reduction of knee ROM required for both EZ-Step™ and Quad-Step™ as compared to standard steps (Figure 9).

HEART RATE AND PERCENT OXYGEN SATURATION

Heart rate for each participant was found to be significantly higher following all stepping conditions. Percent oxygen saturation was not found to be significantly different before and after the trials for each participant.

Table 8.
Descriptive statistics of hip ROM during stair ascent and descent.

	Mean (Degrees)	**Standard Deviation**	**Range**
Hip ROM-ascent			
Standard Stairs	34.52	10.64	11.4-49.8
EZ-Step™	28.14	11.19	9.4-48.7
Quad-Step™	24.87	10.23	7.6-43.0
Hip ROM-descent			
Standard Stairs	23.06	8.03	5.7-35.6
EZ-Step™	22.96	11.53	8.2-65.7
Quad-Step™	21.37	8.63	5.7-37.9

Table 9.
Descriptive statistics of knee ROM during stair ascent and descent.

	Mean (Degrees)	**Standard Deviation**	**Range**
Knee ROM-ascent			
Standard Stairs	80.28	11.87	57.5-98.0
EZ-Step™	67.86	12.98	46.0-90.3
Quad-Step™	52.37	12.07	20.2-72.5
Knee ROM-descent			
Standard Stairs	73.14	15.92	30.7-96.3
EZ-Step™	55.86	11.03	36.1-77.4
Quad-Step™	47.08	16.19	11.7-100.0

Table 10.
Repeated Measures Analysis of Variance for Peak Hip Range of Motion During Stair Ascent.

Source	df	SS	MS	F	p
Step Type	2	1397.621	698.811	25.784	.000
Error	56	1517.712	27.102		
Total	87	85064.490			

Table 11.
Repeated Measures Analysis of Variance for Peak Hip Range of Motion During Stair Descent.

Source	df	SS	MS	F	p
Step Type	2	52.322	26.161	0.618	.543
Error	56	2370.645	42.333		
Total	87	51556.450			

Table 12.
Repeated Measures Analysis of Variance for Peak Knee Range of Motion During Stair Ascent.

Source	df	SS	MS	F	p
Step Type	2	10556.538	5278.269	78.274	.000
Error	52	3506.509	67.433		
Total	81	384253.3			

Table 13.
Repeated Measures Analysis of Variance for Peak Knee Range of Motion During Stair Descent.

Source	df	SS	MS	F	p
Step Type	2	9498.268	4749.134	50.329	.000
Error	52	4906.798	94.362		
Total	81	305103.86			

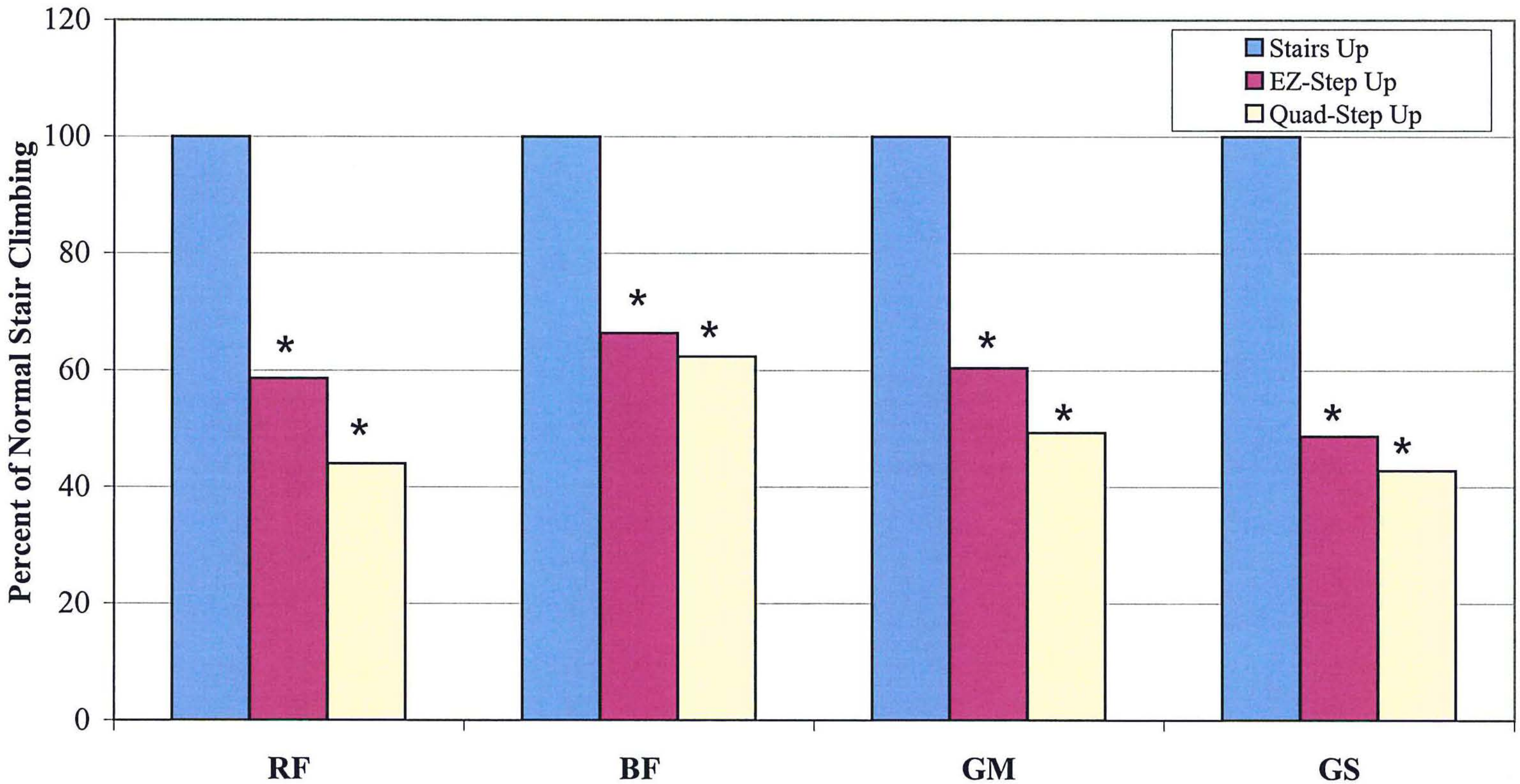


Figure 6. EMG muscle activity in each muscle in each stepping condition during stair ascent. Note that all four muscles had significantly less EMG activity (*) using the EZ-Step and Quad-Step as compared to the standard steps.

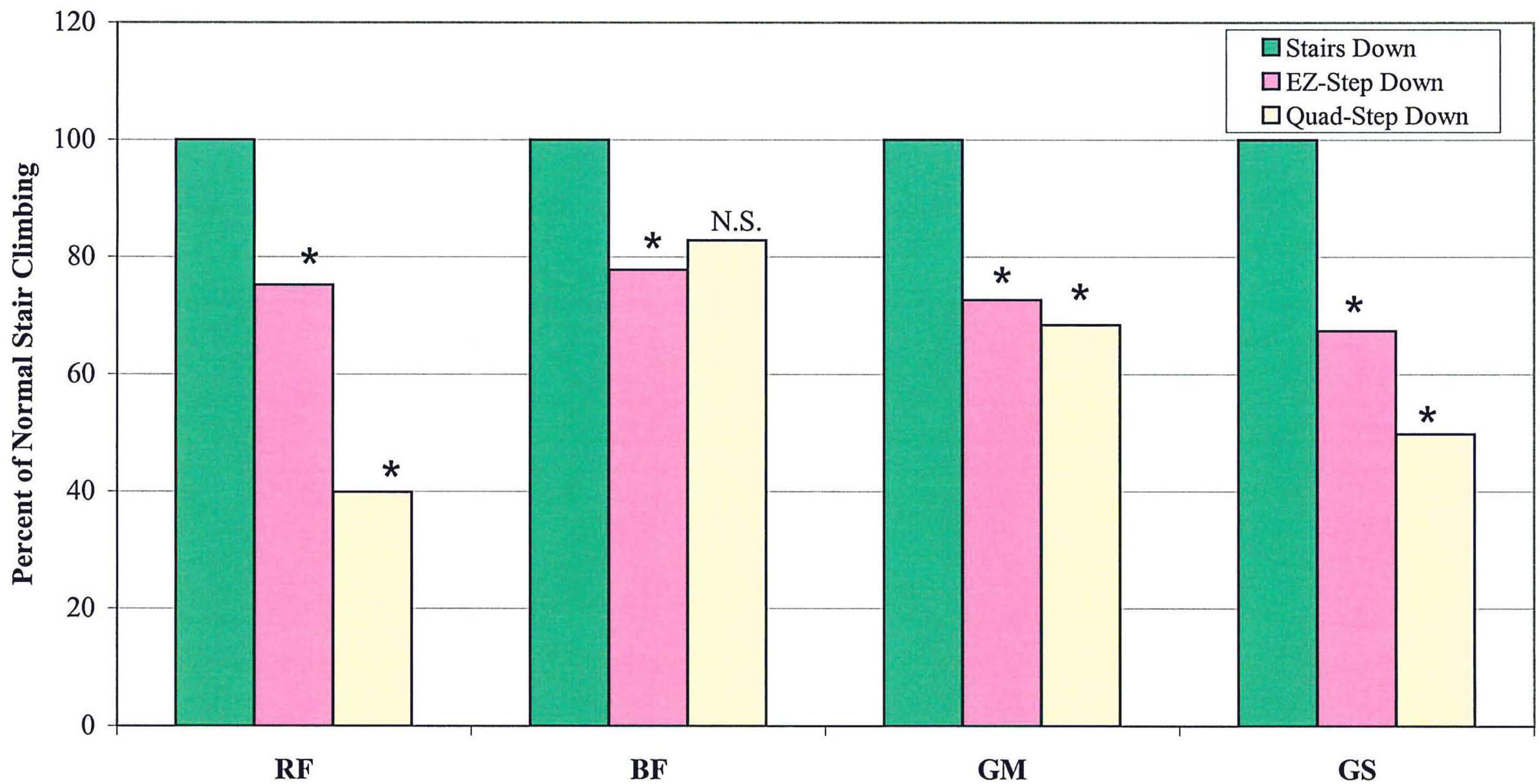


Figure 7. EMG muscle activity in each muscle in each stepping condition during stair descent. Note the muscles that had significantly less EMG activity (*) using the EZ-Step and Quad-Step as compared to the standard steps. (N.S. = not significant)

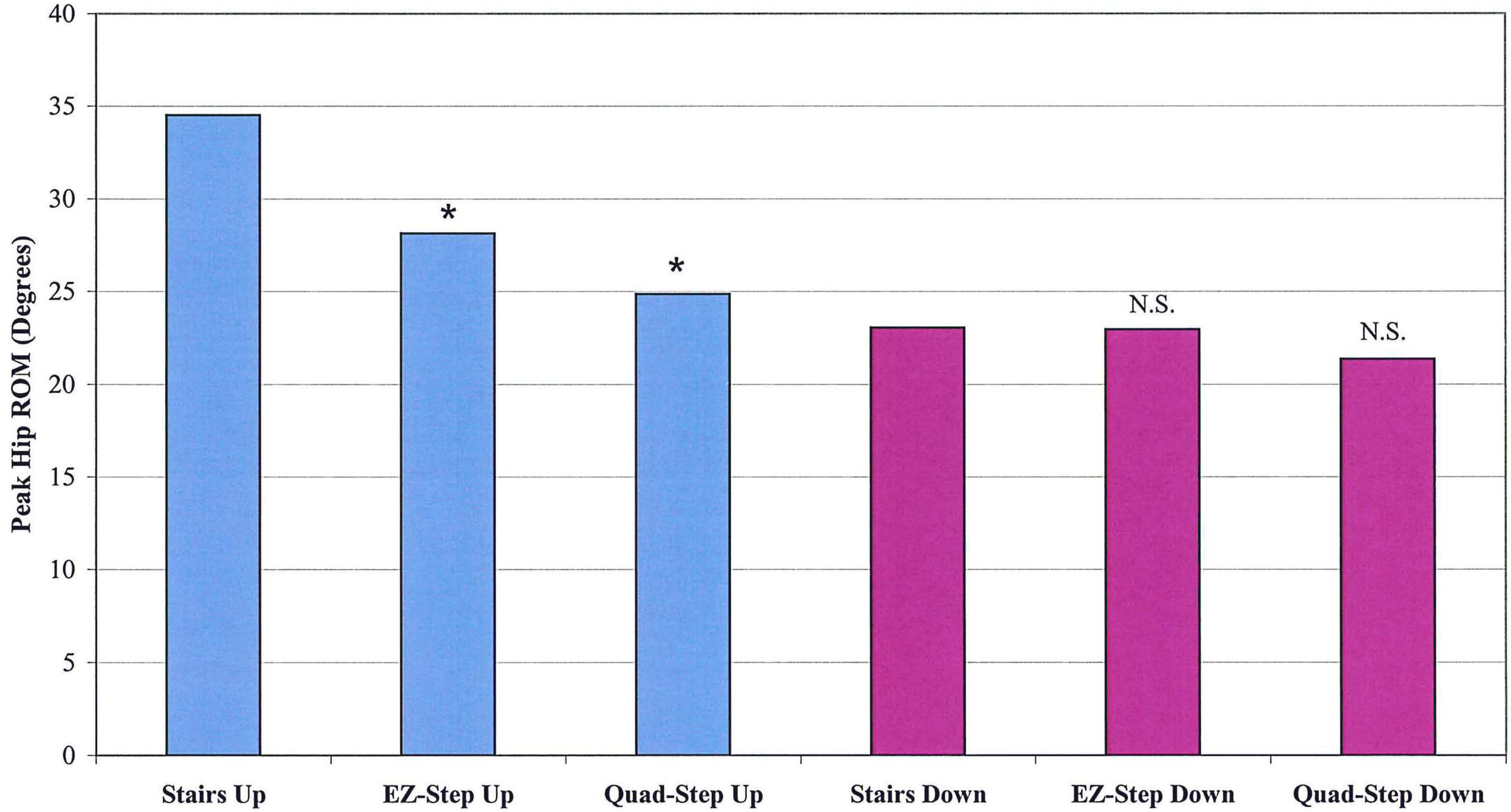


Figure 8. Hip ROM during stair ascent and descent in all stepping conditions. Both the EZ-Step and the Quad-Step required significantly less ROM (*) than the standard stairs during stair ascent. During descent, both the EZ-Step and the Quad-Step were not significant (N.S.) compared to standard steps.

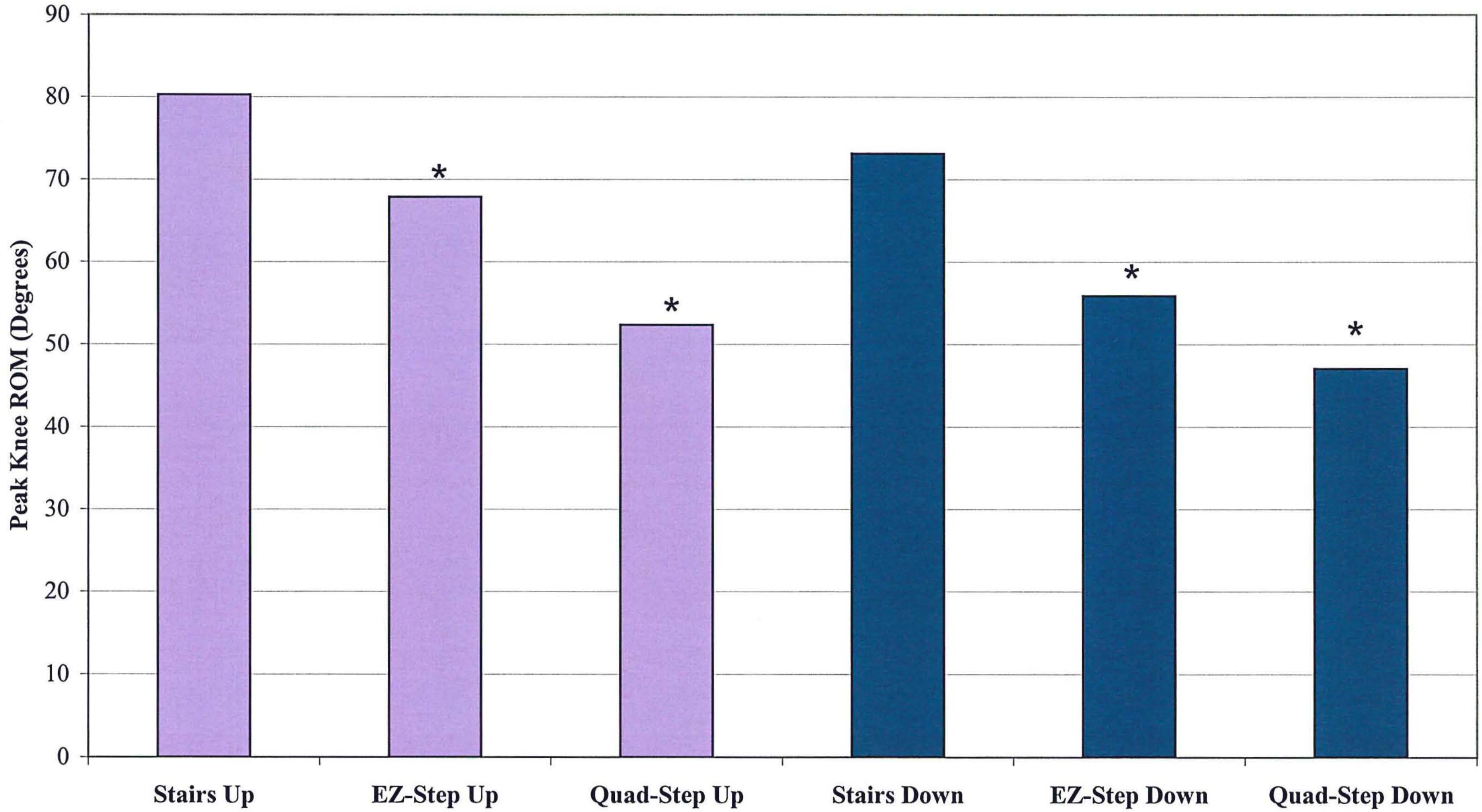


Figure 9. Knee ROM during stair ascent and descent in all stepping conditions. Knee ROM was significantly less with both the EZ-Step and Quad-Step during both ascent and descent (*).

CHAPTER 5

DISCUSSION

EMG ACTIVITY

The EMG activity results found in this study are analogous to those in a study done by Brask et al,[29] who examined EMG activity of LE muscles during lateral step-ups of 4 and 8 inches. Rectus Femoris and Biceps Femoris muscle activity was found to be lower on the 4 inch step compared to the 8 inch step during both stair ascent and descent, indicating that a decrease in step height reduced the amount of EMG activity needed to climb stairs. The present study involving the EZ-Step™ and the Quad-Step™ found significant reductions in EMG activity in all four muscles during stair ascent when compared to standard stair climbing. During stair descent using the EZ-Step™ and the Quad-Step™, all muscle activity was found to be significantly less than standard stair descent except for the BF with the use of the Quad-Step™.

The pilot study done by Fethkenher and Mohr[11] compared EMG activity and ROM of the knee during stair climbing with and without the use of the EZ-Step™. The results indicated an average decrease in muscle activity when ascending and descending stairs using the EZ-Step™ compared to standard stairs. That study compared muscle activity during stair ascent and descent using the EZ-Step™ to that of a baseline maximal voluntary contraction (MVC) of the GM, BF, GS, and RF muscles. The results for EMG activity, expressed as a percentage of the individual's MVC were as follows, for stair ascension: GM (31%), BF (19%), RF (59%), and GS (33%); for stair descension: GM (22%), BF (31%), RF (11%), and GS (20%). Those results are comparable to our study given that overall muscle activity was found to be less with the EZ-Step^{TM} compared to standard stair climbing. This study also tested only 8 subjects, so reliability may be of question. In comparison to the current study, which tested 29 subjects, standard stairs were used as the baseline to compare muscle activity when using the EZ-Step^{TM} and the Quad-Step^{TM} to increase accuracy. Using the MVC for a baseline measurement of muscle activity may be unreliable because it is difficult to determine if the subject is actually giving their maximum effort, and recruitment from surrounding musculature may contribute to this contraction.

The significant decrease in EMG activity found in the current study during stair negotiation on the shorter step height offered by the EZ-Step^{TM} and Quad-Step^{TM} may be the result of decreased work required to displace the body's center of mass. During stair climbing the body's center of mass must be displaced a certain distance in order for the person to move from one step to the next. A shorter step height would theoretically decrease the amount of displacement required for stair negotiation, therefore causing a decrease in the amount of work required by the muscles of the lower extremities. It is hypothesized that as the muscle activity decreases so does the amount of joint reaction force caused by that muscle activity. Therefore, the reduction in joint reaction force may reduce the amount of discomfort patients may have when climbing stairs especially if they had degenerative joint disorders.

RANGE OF MOTION

Peak range of motion of the LE joints during stair climbing is dependent upon the height of the stairs.[4] Nadeau et al[3] found that standard stair ascension requires 60 degrees of hip flexion and 93 degrees of knee flexion, which was considerably higher than the angles found during level walking.

Research has shown a need for increased hip flexion with an increase in step height.[26] This current study involving the EZ-Step™ and the Quad-Step™ also demonstrated a need for increased hip flexion on standard stairs compared to use of the devices.

The pilot study by Fethkenher and Mohr[11] found a 12.7 percent decrease in knee ROM during stair ascent and a 30 percent decrease during stair descent while using the EZ-Step™ compared to standard stair climbing. The current study involving the EZ-Step™ and the Quad-Step™ showed similar findings. On both stair ascent and descent, less knee ROM was required using the EZ-Step™ and the Quad-Step™ in comparison to standard stair climbing. On stair ascent, a 15 percent and 35 percent decrease was found using the EZ-Step™ and Quad-Step™, respectively, compared to standard stairs. A decrease of 23 percent using the EZ-Step™ and 31 percent using the Quad-Step™ compared to standard stairs was found on stair descent. A reduction in knee flexion would be expected to cause a resultant decrease in the joint reaction forces, especially the patellofemoral joint. This may play a significant role in reducing pain for those patients who degenerative joint disorders.

The current study did not find a significant difference in hip ROM during stair descent. Based on the results of the current study, the lack of significant difference may have been due to the fact that less overall hip ROM was needed during stair descent when compared to stair ascent.

HEART RATE AND PULSE OXIMETRY

During the current study, heart rate significantly increased during the stair climbing trials. This increase in heart rate would be an expected, normal physiological response to activity such as stair climbing. Pulse oximetry did not show a significant difference before and after the trials. All of the subjects included in this study were healthy individuals, so they were apparently able to compensate by increasing oxygen consumption and delivery during activity which caused no significant alterations in the pulse oximetry.

LIMITATIONS

The following are possible limitations that may or may not have influenced the results of the current study. It was not possible to control the cadence during stair climbing with a metronome due to the differences in age and physical ability among the subjects. If a set pace was initially established, some of the subjects may not have been able to stair climb at that set rate and safety may have been compromised. When subjects were learning to use the device, instructions to go at his or her preferred pace were given. This was done to increase individual subjects' safety and comfort level with the devices to promote accurate EMG and ROM readings.

Subject anxiety especially during stair descent, along with fatigue, may have also played a role in the overall results. The subjects were not accustomed to climbing stairs using devices and while wearing equipment. Some of the subjects may have performed more efficiently if they were allowed more practice trials prior to testing. Based on the authors observations it appeared that the subjects had more difficulty with learning how to use the equipment while descending the stairs when compared to ascending.

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