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Motion Analysis and Electromyographic Analysis of Ambulation with Assistive Devices

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MOTION ANALYSIS AND ELECTROMYOGRAPHIC ANALYSIS
OF AMBULATION WITH ASSISTIVE DEVICES

by

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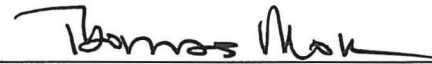This Scholarly Project, submitted by Sondra Brenk, Tracy Foltz, Danielle Jwanouskos, Steven Pederson, in partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by the Advisor and Chairperson of Physical Therapy under who the work has been done and is hereby approved.

_____
(Graduate School Advisor)

_____
(Chairperson, Physical Therapy)

PERMISSION

Title Motion Analysis and Electromyographic Analysis
of Ambulation with Assistive Devices

Department Physical Therapy

Degree Doctor of Physical Therapy

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Date _12-10-07_

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ABSTRACT

Purpose: The purpose of this study is to analyze the amount of muscle activity of the rectus abdominis and external obliques during the gait cycle with the use of forearm crutches and three different weight bearing statuses. **Subjects:** Seven female adults were recruited from the University of North Dakota Physical Therapy program. Inclusion criteria: between the ages of 19 and 40 years of age, current physical therapy students, and healthy with no current upper or lower extremity injuries. **Instrumentation:** The EMG data was collected by the Noraxon Telemyo 900 telemetry unit and analyzed using the MyoResearch XP software. Six Vicon MX40 infrared cameras were used to capture the marker motion. The Vicon Polygon 3.1 software was used to qualitatively analyze all of the motion and EMG data. **Procedure:** Prior to beginning the trials, surface electrodes were placed over the right and left rectus abdominis and right and left external oblique muscles to record the EMG activity. A MVC was performed using an isometric sit-up to establish a normalization baseline. Reflective markers were placed on bony prominences according to the Plug-in-Gait Marker Placement. Participants were fitted for forearm crutches and were allowed to practice a swing-to three point gait prior to the trials. Each participant performed two trials of each weight bearing status. **Data Analysis:** The EMG data from the crutch walking trials was compared with the EMG data from the MVC trials. The results were represented as a percent of the MVC. The EMG data was synchronized with the motion

analysis data and displayed in graph form which shows the stickman figure along with the muscle activity during each point in time during the walking trial. This was used to qualitatively describe when each muscle was active during the gait cycle. **Results:** The quantitative assessment of EMG showed that both the rectus abdominis and the external oblique muscle groups were the most active during the non-weight bearing gait pattern. Activity between the right and left muscle groups was similar in amplitude. The qualitative assessment showed that both the rectus abdominis and the external obliques were the most active during the swing phase of a gait pattern.

Conclusion: The abdominal musculature is active during crutch walking throughout the gait cycle. Physical therapists can benefit from the results of this study by evaluating the abdominal musculature strength during the examination prior to assigning an assistive device and by implementing core strengthening into the rehabilitation phase for those individuals who demonstrate weakness.

CHAPTER 1

INTRODUCTION

Assistive devices are commonly used to provide safety and security, to develop an optimal gait pattern, to reduce energy requirements, and to protect healing tissues. Physical Therapists are often the ones making the critical decision of an appropriate assistive device that allows the patient to have the most functional mobility, but provides the support needed for the patient. Optional assistive devices that provide the most stability to the least stability are the following: parallel bars, walker, axillary crutches, forearm crutches, and canes.

When choosing an assistive device, there are several factors to consider. According to Minor[1,] the patient's cognitive status and balance will help decide how much support the patient will need in order to be safe. The weight bearing status will also affect the patient's balance and ability to use certain assistive devices. There are several different gait patterns used with assistive devices. Most commonly, the three point gait and modified three point gait patterns are used with orthopedic conditions. These patterns are less stable, but require good strength in the upper extremities, trunk, and one lower extremity.[1] Higher energy expenditure can be expected when using a three point gait pattern. If the patient has poor endurance, they may need an assistive device that requires less energy expenditure (front wheeled walker vs. standard walker).

In order to determine if the patient meets the muscular demands necessary to use an assistive device, a comprehensive strength assessment should be performed. Adequate strength in the following muscles is required in order for the patient to effectively use the appropriate assistive device: arm flexors, triceps, finger and thumb flexors, wrist extensors, and shoulder depressors and scapula downward rotators.[1] The arm flexors are needed to move the assistive device forward, while the triceps allow the patient to maintain elbow extension. Wrist extensors and flexors facilitate a functional position of the hand that allows the finger and thumb flexors to grasp the hand grips. Finally, shoulder depressors and scapula downward rotators allow the patient to lift the body to decrease the amount of weight bearing on the affected limb. Although the above mentioned are commonly cited as important to crutch walking, we are hypothesizing that trunk musculature must be adequate during crutch walking, especially using non-weight bearing gait patterns.

Problem Statement:

Although we hypothesize that abdominal muscle strength must be adequate, there is a limited amount of published data that documents abdominal muscle activity during the gait cycle when using an assistive device.

Purpose:

The purpose of this study is to analyze the muscle activity of the abdominal musculature during the gait cycle with the use of forearm crutches and different weight bearing statuses.

Significance of Study: The data collected will provide information that physical therapists can utilize when assessing the abdominal muscle strength during the evaluation and incorporating core strengthening into the rehabilitation phase.

Research Question:

1. How active are the abdominal muscles during non-weight bearing, touch down weight bearing, and full weight bearing when using forearm crutches?

2. When are the abdominal muscles the most active during the gait cycle when performing non-weight bearing, touch down weight bearing, and full weight bearing statuses with the use of forearm crutches?

Hypothesis:

The abdominal musculature is the most active during the swing phase during a non-weight bearing status with forearm crutches.

CHAPTER 2

LITERATURE REVIEW

Physical therapists normally evaluate upper and lower extremity strength and range of motion along with balance to determine which assistive device is best suited for each individual patient. We commonly give patients an assistive device to improve stability. Bateni and Maki[2] conducted a systematic review looking at the advantages and disadvantages of using an assistive device. Studies included were those found to use single point canes or pick up walkers addressing benefits, physiological demands, and complications arising from using an assistive device. After completing the review they found that canes and walkers can be used to improve balance and mobility thus providing evidence for the use of assistive devices for stability.

Electromyographic (EMG) and motion analysis are commonly used for the study of muscle activity and movement. Arsenault, et al.[3] studied the number of gait cycles required to adequately analyze EMG data. In the study, they collected ten strides of data for each subject for five muscles including; soleus, rectus femoris, biceps femoris, vastus medialis, and tibialis anterior. They concluded that a minimum number of three strides per subject are reliable for data collection.

Other studies have used EMG to analyze muscle activity in normal gait patterns. Wootten, et al.[4] used EMG on ten lower extremity muscles to determine normal patterns

of movement. They found that there was no single, normal gait pattern due to the difference in age, gender, cadence, and walking speed. Many studies have looked at the gait pattern variation due to walking speeds. Anders, et al.[5] studied trunk musculature activation at different walking speeds. They used surface EMG on five trunk muscles including the rectus abdominis, internal and external obliques, multifidus, and erector spinae and had each participant walk on a treadmill at 2, 3, 4, 5, and 6 km/hr. They found that with increasing walking speed muscle activity peaked at similar times during the gait cycle. Generally, greater amplitude of muscle activity was seen at greater speeds, except for the internal obliques which were found to decrease with increasing speed. Back musculature was found to only increase in activity up to 4 km/hr, after that the musculature maintained a similar activity for increasing speeds. Contralateral muscle activity was found to be greatest during heel strike and propulsion phases.

EMG and motion analysis has been used to study gait patterns with the use of assistive devices. Noreau, et al.[6] conducted a study to determine if the deficits of motor function effect the displacement of lower limb and increase the physical strain of upper body musculature in paraplegic individuals in swing through gait using forearm crutches. They used a biomechanical model that consisted of four linked rigid bodies to analyze gait. They looked at muscle moments and mechanical power at the shoulder, elbow, and hip during a complete gait cycle. They found that paraplegic individuals had inadequate hip muscle activation that caused them to have a longer crutch stance phase than non-disabled individuals. Overall the loss of motor function with paraplegic individuals causes an increased demand of the upper extremity musculature during the overall swing through gait cycle.

Sonntag, et al.[7] conducted a study using EMG, goniometry, and force plate analysis to compare gait with total hip arthroplasty with the use and non-use of forearm crutches. They studied muscles of the lower extremity and trunk including bilateral gluteus medius, vastus medialis, and erector spinae along with unilateral vastus lateralis and biceps femoris on the affected side. With the use of forearm crutches, it was found that the cadence and stride length decreased. Muscle activity of the affected side was found to decrease except for the biceps femoris. Muscle activation on the unaffected side was only decreased for vastus medialis, while the other muscles had no significant change. The overall conclusion of this study was that forearm crutches facilitate a symmetrical gait pattern.

Peacock, et al.[8] used EMG to study upper extremity and trunk muscle activity during forearm and axillary crutch walking. They had the patient ambulate with the right foot in a non-weight bearing position with both types of crutches. They recorded muscle activation patterns for the flexor carpi radialis, extensor carpi radialis brevis, biceps, triceps, trapezius, latissimus dorsi, pectoralis major, serratus anterior, teres major, deltoid, rectus abdominis, external oblique, and erector spinae on the right side. Results of this study indicate that muscle activity increases except for the trapezius and deltoid as the upper extremity takes the load off of the weight bearing foot to allow for forward movement. The trapezius, deltoid, and biceps were found to have increased muscle activity with lifting of the crutches to clear the floor. Wrist extensor activity was found to continually increase muscle activity due to the constant holding of the crutches. The activity of trunk musculature was found to be relatively low. The rectus abdominis was

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found to have increased activity with the body being supported by the upper extremity to aid with trunk flexion for swing. While the erector spinae had increased activity with the weight bearing through the foot to aid with stabilization as the crutches are moving forward and the body is leaning forward. External obliques were found to be more active on the non-weight bearing side. Overall muscle activity showed no significant difference between the uses of axillary or forearm crutches. Biceps and triceps muscle activity was significantly increased with the use of forearm crutches.

Ajemian, et al.[9] used EMG, motion, and force plate analysis to describes the effects of unilateral cane use on bilateral joint moments, kinematics, and hip abductor muscle activity after a total hip arthroplasty. Bilateral gluteus medius, tensor fascia lata, lateral hamstring, and vastus lateralis was recorded using EMG on level surfaces with the use and non-use of a single point cane. They found that with the use of a contralateral cane, the affected hip abduction moment decreased while the unaffected hip abduction moment increased. This finding indicated that the use of a single point cane for rehabilitation purposes is useful for decreasing the load on the affected hip to allow for connective tissue healing.

Besides the use of EMG and motion analysis, oxygen consumption and energy curves can also be useful in gait analysis. Thys, et al.[10] measured the energy consumed and mechanical work performed during swing through crutch gait to assess energy expenditure needed. They had the participant walk on a treadmill with and without crutches at varying speeds. Oxygen consumption was calculated by an automated open circuit method and then used to calculate the VO_2. Force plates were used to collect data

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on the mechanical work performed. They found that energy expenditure is two to three times higher with swing through gait than with a normal gait pattern. Energy expenditure is directly related to walking speed. Mechanical work was also found to increase with swing through gait by a factor of 1.3 to 1.5. Waters, et al.[11] performed a review and concluded that both swing through and non-weight bearing crutch walking required a high rate of physical effort. They agree with Thys et al.[10] that walking speed and oxygen uptake are directly related.

EMG and motion analysis have been commonly used to analyze gait in a variety of ways. Many studies look at lower and upper extremity muscle activity, while the abdominal muscles are commonly overlooked. Of the articles that were reviewed only two mentioned the muscle activity of the rectus abdominis and external obliques. The studies found that the rectus abdominis muscle activity increases with increased walking speed, and with the use of assistive devices. Studies indicate that the external oblique muscle activity also increases with increased walking speed. External oblique muscle activity was also found to be greater on the non-weight bearing side. Due to the lack of research and the better equipment now available, further studies are needed on abdominal muscle activity during ambulation with assistive devices.

CHAPTER 3

METHODS

Subjects

Seven female adults were recruited through verbal invitation for this study. All of the volunteers were recruited from the students enrolled in the Physical Therapy program at the University of North Dakota Physical Therapy. Inclusion criteria included those between 19 and 50 years of age, current physical therapy students, and healthy with no current lower and upper extremity injuries. Exclusion criteria consisted of current upper or lower extremity injury. All participants had previous training in the proper use of forearm crutches for ambulation as part of their Physical Therapy curriculum. Before participation of the study, each participant was presented with an overview of the objectives for the project, the time commitment expected, and the activities they were to perform for the study. All participants signed a written consent form before participation. All research activities were performed in the research laboratory located in the Physical Therapy Department at the University of North Dakota. The research project was approved by the University of North Dakota's Institutional Review Board.

Table 1.
Characteristics of the Subjects (n=7 females).

Subjects	1	2	3	4	5	6	7
Age	23	23	23	23	23	23	23
Height (cm)	172.7	170.2	177.8	177.8	162.6	165.1	157.5
Weight (kg)	68.0	79.4	68.0	54.4	56.7	56.7	61.2

Table 2.
Subject's Measurement Summary.

	Average	Range	SD
Age	23	23	0
Height (cm)	169.1	157.5-177.8	7.158
Weight (kg)	63.5	54.4-79.4	8.228

Instrumentation

The focus of this study was electromyographic (EMG) muscle activity of the

bilateral abdominal musculature during ambulation with forearm crutches. The EMG

activity was collected and analyzed using a Noraxon Telemyo 900 telemetry and

receiver unit (Noraxon USA, 13430 North Scottsdale Road, Suite 140, Scottsdale, AZ

85254) that was interfaced with the Vicon Nexus (Vicon Peak, 9 Spectrum Pointe,

Lake Forest, CA 92630) motion analysis system. The information was digitized by

an analog to a digital interface module interfaced with the Vicon Nexus data

collection system. The quantitative EMG data analysis was performed using the

MyoResearch XP software.

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The motion analysis data was obtained and analyzed by the Vicon MX40 motion analysis system (Vicon Peak, 9 Spectrum Pointe, Lake Forest, CA 92630). This system consists of six Vicon MX40 cameras with 4.0 MegaPixel resolution (two of the cameras had 17-35 mm zoom lenses and four of the cameras had 12.5 mm wide angle lenses), and six infrared strobes. The cameras were set up around the laboratory. There was one camera mounted on each corner of the room and one camera on each side of the room. The cameras were connected to two MX Net boxes and a MX Link. The Vicon Nexus software was used for motion capture and collection of the EMG signals from the Telemyo system. The Vicon Polygon 3.1 software was used for qualitative analysis and the generation of the analysis report. A Dell PC with dual processor was used to run the software. During the test trials, reflective markers were placed on bony prominences that were used to calculate joint angles by the software program.

Procedure

Upon participant arrival, the individual reported their height and weight and then was measured for leg length and joint widths as described in the appendix. Measurements obtained were used for calibration of the skeletal models of the motion analysis.

EMG activity was recorded by applying surface electrodes on the skin over each of the muscles under study.[12] The muscle groups that were monitored were the 1) right and left rectus abdominis and 2) right and left external oblique.

Prior to the surface electrode placement, skin preparation was achieved by cleaning the skin with alcohol and lightly roughing the skin with sand paper to

decrease electrical impedance. The rectus abdominis surface electrodes were placed on the right and left side, 2 cm lateral to the navel with the lower electrode just below the navel level and the upper electrode just above the navel level (Figure 1). The external oblique surface electrodes were placed in an orientation parallel to the direction of the muscle fibers on the right and left side, lateral to the rectus abdominis, directly above the ASIS halfway between the ASIS and the lower rib cage. A single ground surface electrode was placed over the right iliac crest.
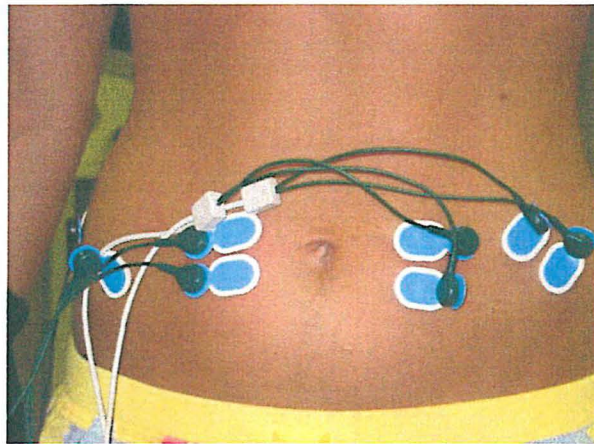
Figure 1. EMG electrode placement.

A maximum voluntary contraction (MVC) was performed to establish a normalization baseline prior to placing the reflective motion analysis markers. The participant was positioned in supine on a plinth with the knees flexed to 90° (measured with a goniometer) and feet flat on the plinth (Figure 2). The subject's hands were placed unlocked behind the head with the elbows out to the side before applying a towel and gait belt across the chest of the participant. The gait belt was

placed to restrict flexion of the upper body and provided a stable restriction to help develop the contraction force.

The participant was asked to perform a partial crunch, relax, and then a maximum contraction against the gait belt for six seconds. Verbal commands and counting were provided for each participant. EMG activity from the abdominal muscles was collected during the six second MVC trial.
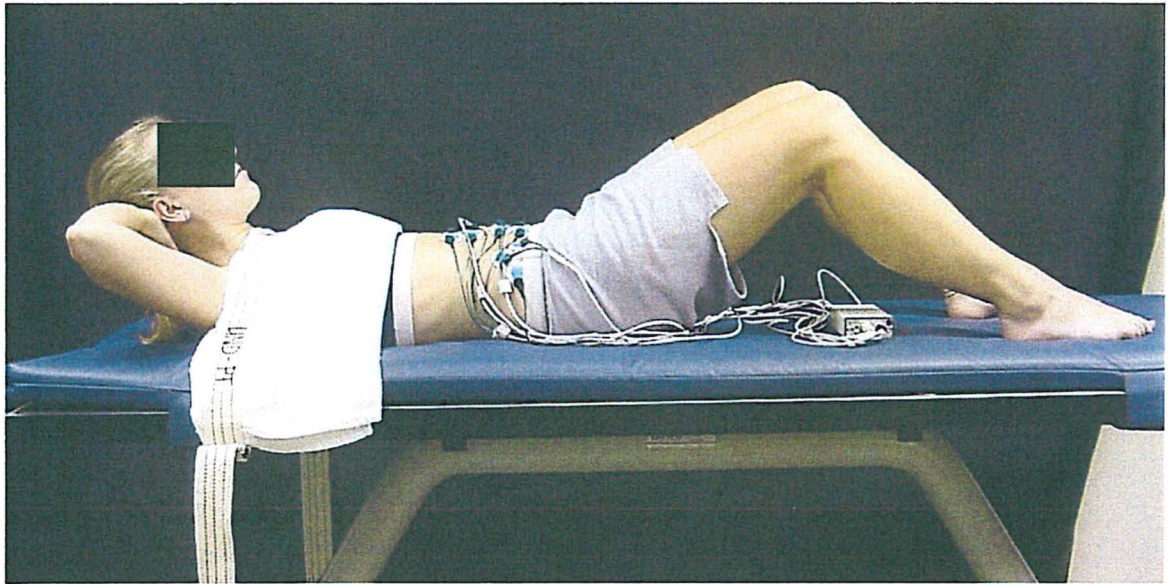
Figure 2. Maximum voluntary contraction position.

Motion analysis was used to capture the kinematic data of each participant. Self-adhesive reflective markers were placed on bony prominences on the participant's head, trunk, arms, thighs, and legs according to the Plug-in-Gait Marker Placement supplied by the equipment manufacturer (Figure 3). A complete list of the marker locations is shown in the appendix. The cameras and the capture space were calibrated per manufacturer's instruction.
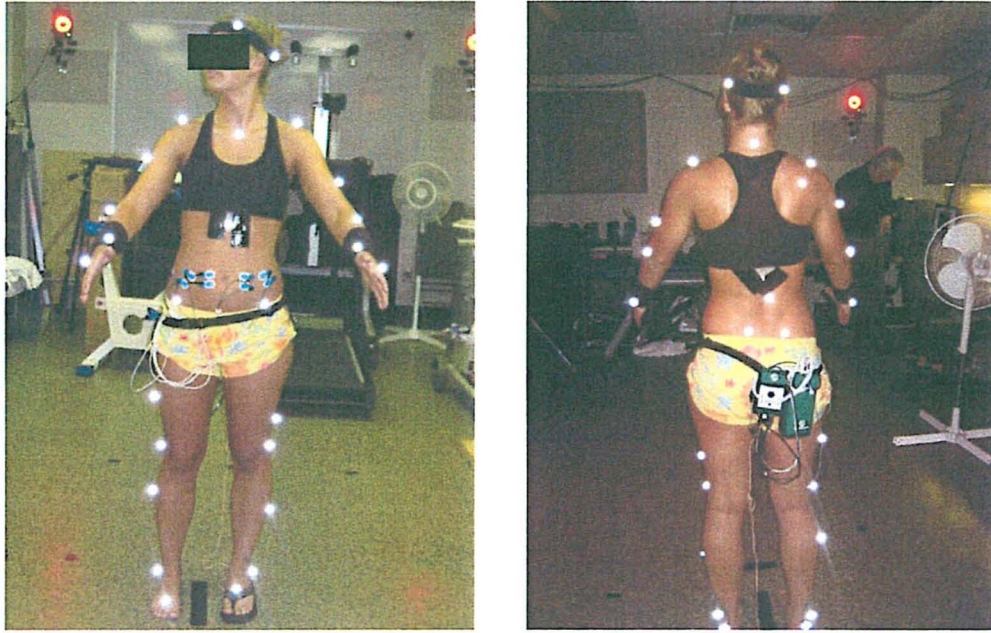
Figure 3. EMG electrode and motion analysis marker placement.

A static image in a predetermined space in the center of the room was then captured in order to label the markers to create a stick-man model.

Prior to data collection, a review of swing-to three point gait was done. Participants were specifically fitted for crutches. The crutches were adjusted so that the hand grip was level with the radial styloid process or greater trochanter of the femur. The forearm clasp was adjusted to fit comfortably below the elbow and in a position that would not interfere with the motion analysis markers. Each participant was informed of the three different weight bearing status trials (non-weight bearing, touch down weight bearing, and full weight bearing) with the right lower extremity being the involved side. The three trials of weight bearing status were randomly selected to determine the order of performance. Two trials of each weight bearing status were captured. The electrodes, reflective markers, and electronics were

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removed following the final trial. The skin where the electrodes and markers were located was cleaned with rubbing alcohol and a clean towel.

Data Analysis

The EMG signals were full wave rectified and smoothed using RMS averaging with a 50 millisecond window. The EMG data from the MVC sit-up trials was compared to the EMG data collected during the walking trials. For analysis of the EMG, the sit-up MVC data served as the baseline for normalization. Analysis was performed on the normalized EMG data that was recorded during the three walking trials. For the EMG normalization, a five second period of time was identified by event markers on the software record during the isometric sit-up. The MyoResearch software was set to identify the highest two second period of contiguous EMG activity found during the five second period. The average of that two second period of the sit-up was used as a baseline (e.g. 100 percent of MVC) to which the walking trials for that subject were compared. The results from the walking trials were represented as a percent of the MVC.

For the walking trials, event markers were placed on the software record to include at least two gait cycles. The MyoResearch software was set up identify the highest, two seconds of contiguous EMG activity that occurred during those two gait cycles.

For the analysis, the EMG activity occurring during each walking trial was compared to the activity occurring during the sit-up and was represented as a percent of MVC using the following formula:

$$Percent\ of\ MVC = \frac{EMG\ Activity\ During\ Walking\ Trial}{EMG\ Activity\ During\ Situp}$$

The resulting percent of EMG was used for all the subsequent data comparisons.

CHAPTER 4

RESULTS

Quantitative Assessment of EMG Activity

Rectus Abdominis

Both the right and left rectus abdominis muscles showed a similar level of activity during the three walking trials. The right rectus abdominis (Figure 4) showed the greatest EMG activity in a non-weight bearing gait pattern at 33% of the MVC. The touch down and full weight bearing gait patterns were 23% and 14% respectively.

The left rectus abdominis (Figure 4) also showed the greatest EMG activity in the non-weight bearing gait pattern at 28% of the MVC. The touch down and full weight bearing gait patterns were 21% and 13% respectively.

External Oblique

Both the right and left external oblique muscles showed a similar level of activity during the three walking trials. The right external oblique (Figure 4) followed a similar pattern to the right rectus abdominis. The non-weight bearing gait pattern showed the greatest EMG activity at 63% of the MVC. The touch down and full weight bearing were 45% and 36% respectively.

The left external oblique (Figure 4) showed the greatest EMG activity in non-weight bearing at 65% of the MVC. The touch down and full weight bearing having less EMG activity at 47% and 33% respectively.

Table 3 shows the average percent of the MVC of the muscles during the three trials. The non-weight bearing gait pattern showed the largest percent of MVC, followed by touch down and full weight bearing.

Qualitative Assessment of EMG Activity

For the qualitative assessment of the EMG activity, one complete gait cycle was defined by markers (foot contact to foot contact) that were placed on the record using the Nexus software package. For the analysis, an average EMG trial was created for each of the following conditions: 1) ambulation with non-weight bearing, 2) ambulation with touch down, and 3) ambulation with full weight bearing. The Polygon software provided full wave rectification of the raw EMG. The averaged, rectified EMG was plotted along with one standard deviation.

The Polygon software was setup to display one gait cycle (0 to 100%) that was an ensemble average of all seven subject's EMG activity during each of the different ambulation conditions. The ensemble average was calculated using 51 data points plotted to represent one gait cycle for each subject (i.e. 100 percent of one cycle).

Non-weight Bearing

Figure 5 shows that the period of greatest EMG activity in all of the muscles was during the time when both the left and right limbs were in the swing phase of gait

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(between initial swing and initial contact). The period of greatest activity began building up prior to initial swing and continued throughout swing phase, with the highest level occurring at about 80 percent of the gait cycle just after initial swing. EMG activity was least during stance phase of the left limb, between 20 and 50 percent of the gait cycle.

EMG activity in both the right and left rectus abdominis muscles showed a similar pattern of activity; however the right rectus abdominis showed a higher level of activity as compared to the left sided muscle. Both the right and left external oblique muscles showed a similar pattern of activity, with the right side showing more activity than the left. The right external oblique muscle also showed a burst of activity shortly after initial contact, similar in amplitude to the activity during swing phase.

Touch Down

Figure 6 shows that the greatest level of muscle activity in right external oblique occurred just after initial swing of the right lower extremity and continued throughout the swing phase of gait. The highest activity occurred during midswing phase of the right lower extremity. The greatest level of activity in the left external oblique muscle began in late stance phase of the left lower extremity and continued through early swing phase. The highest level of activity occurred just prior to the beginning of the swing phase with the left lower extremity.

The activity in the right rectus abdominis muscle followed a similar pattern of activity as the right external oblique muscle. The greatest activity occurring during swing phase of the right lower extremity and the highest level of activity occurring during late

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swing phase. The left rectus abdominis showed a pattern of activity similar to the left external oblique with the highest level of activity occurring just prior to swing phase.

Full Weight Bearing

The muscle activity in the abdominal muscles during full weight bearing (Figure 7) followed the same pattern of activity as during touch down generating less activity in all of the muscles as compared to touch down. The right external oblique and the right rectus abdominis followed a similar pattern of activity showing the most activity during swing phase of the right lower extremity. The highest level of activity in the left external oblique and left rectus abdominis occurred just prior to swing phase of the left lower extremity.

Table 3.
Average Percent MVC for the Abdominal Muscles.

Muscle	FWB	TD	NWB
Right Rectus Abdominis	13.43%	23.6%	31.32%
Left Rectus Abdominis	11.52%	21.27%	28.09%
Right External Oblique	34.93%	44.69%	59.81%
Left External Oblique	33.27%	47.05%	64.65%

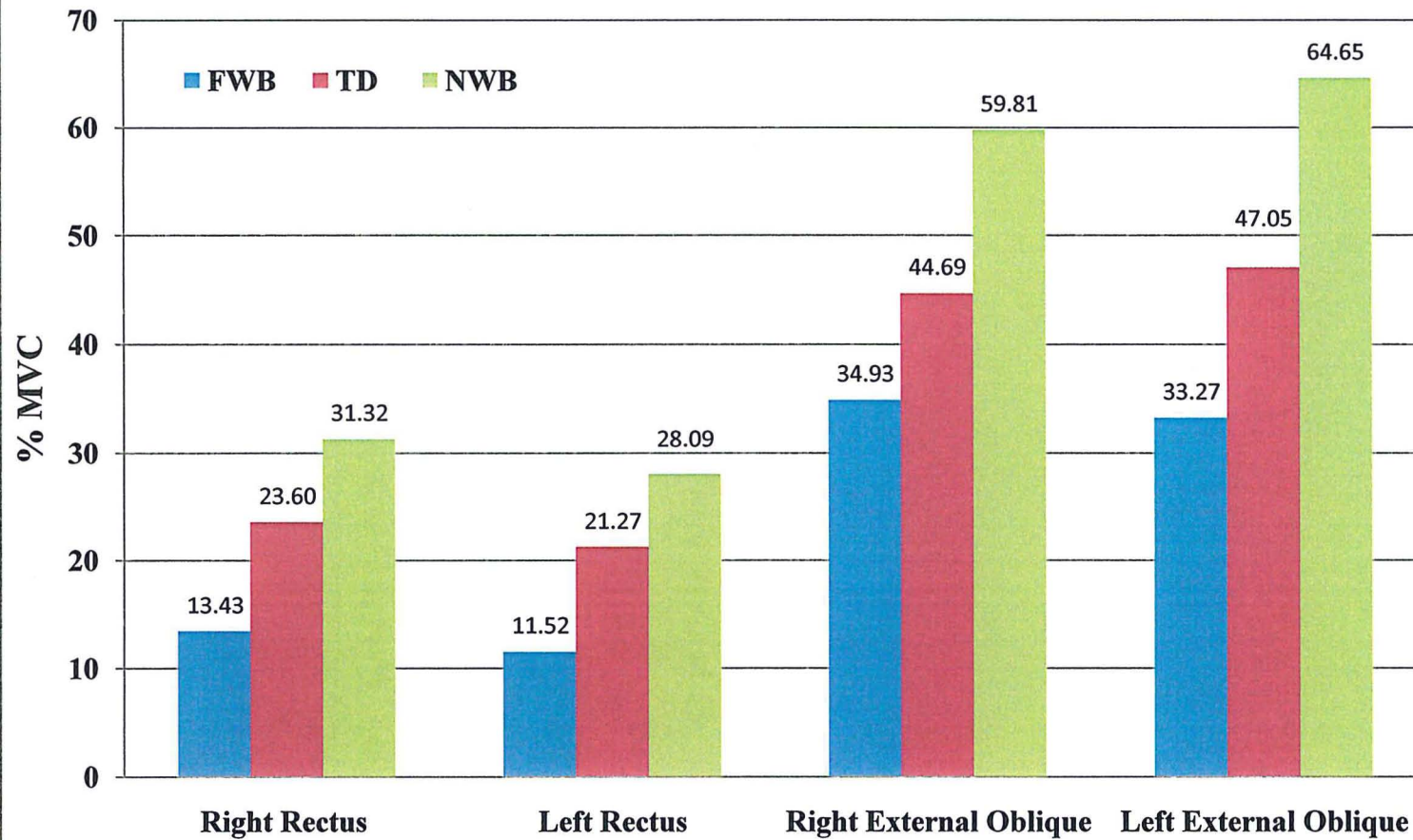**Figure 4.** Electromyographic activity during the three crutch walking trials.
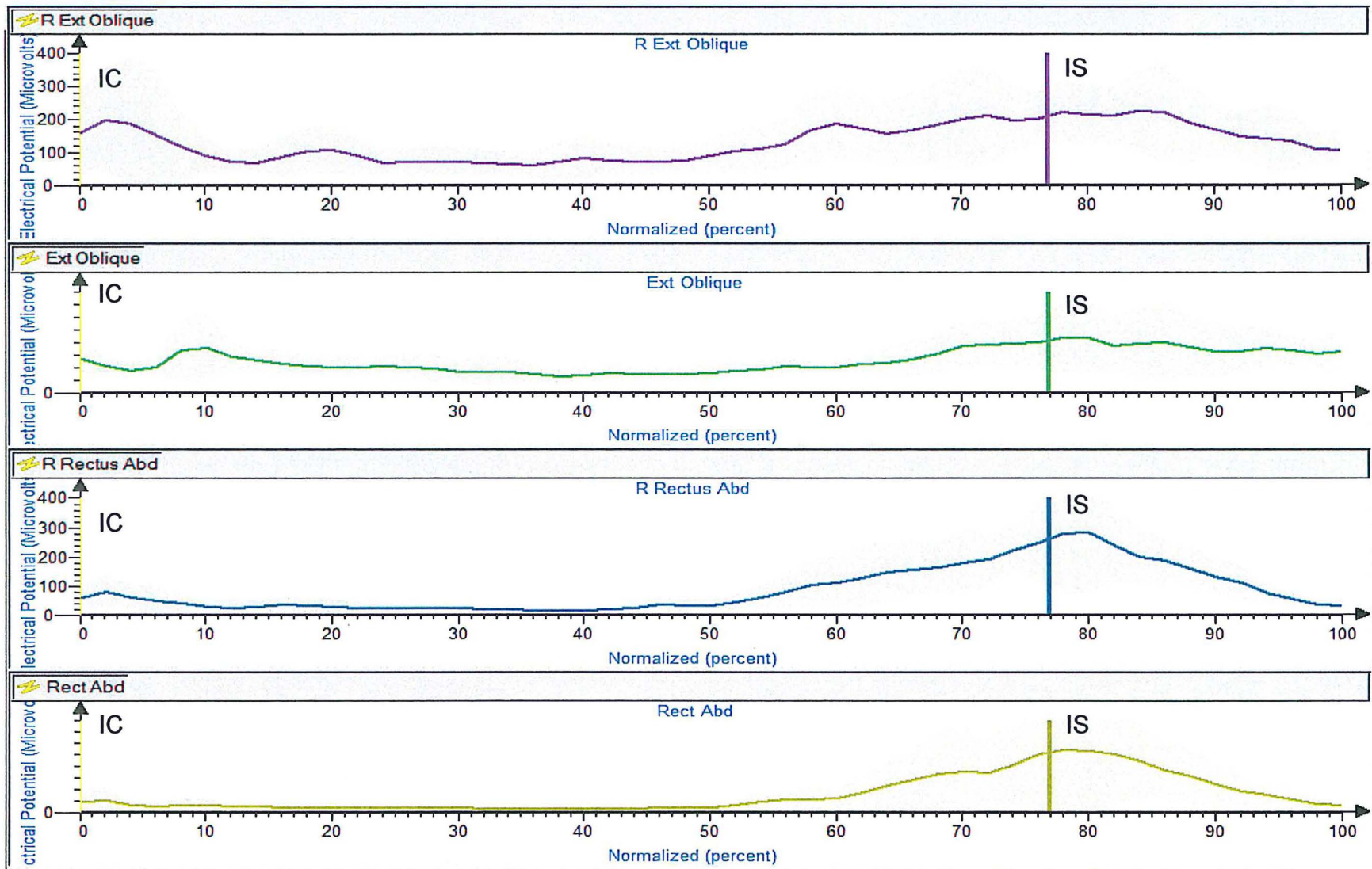
Figure 5. Average EMG activity during non-weight bearing with forearm crutches. The 0 time mark indicates initial contact (IC), and the vertical line indicates Initial Swing (IS) of the left foot.
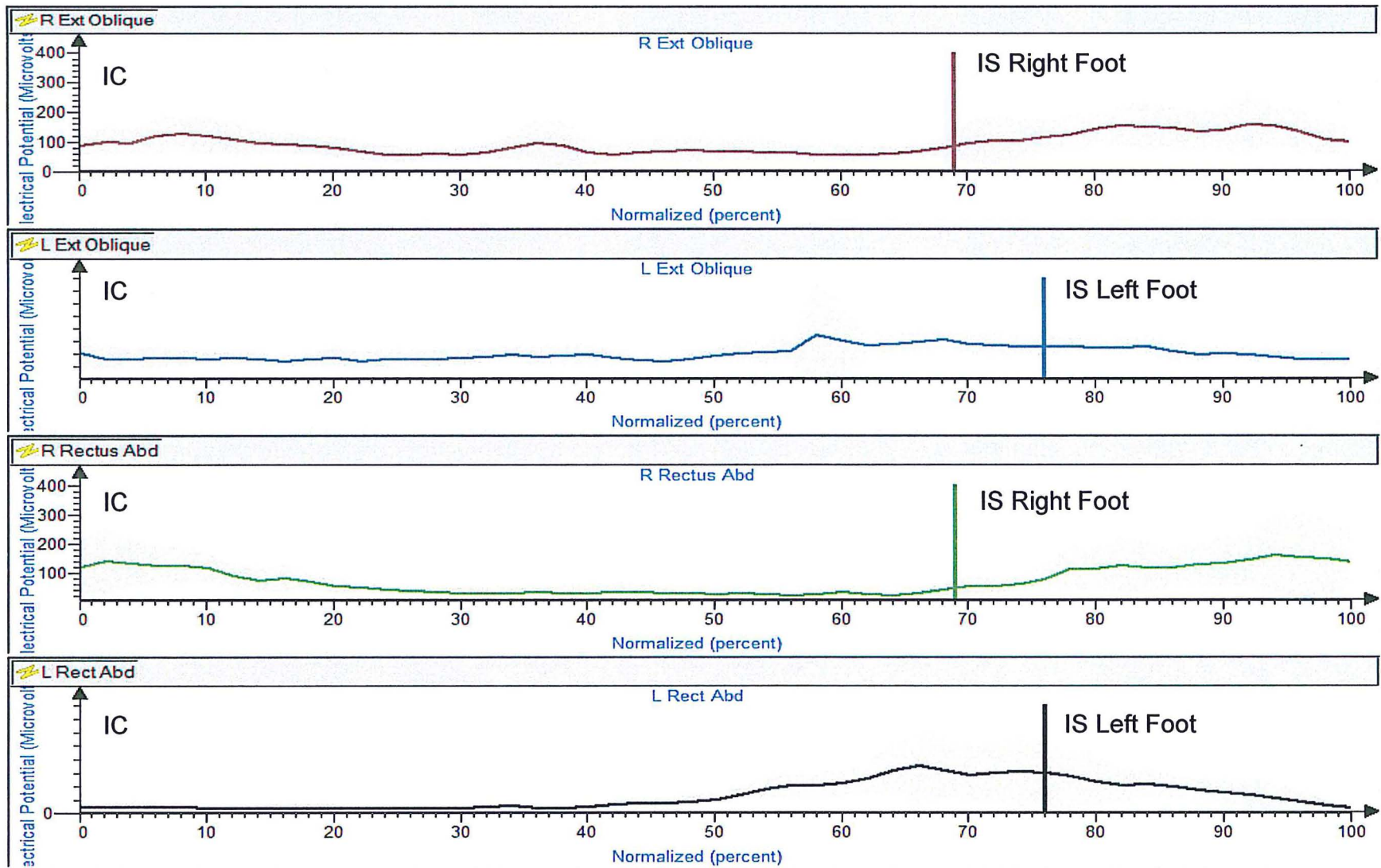
Figure 6. Average EMG activity during touch down weight bearing with forearm crutches. The 0 time mark indicates initial contact (IC), and the vertical line indicates initial swing (IS).

Figure 7. Average EMG activity during full weight bearing with forearm crutches. The 0 time mark indicates initial contact (IC), and the vertical line indicates initial swing (IS).

CHAPTER 5

DISCUSSION

Quantitative Assessment

All of the abdominal muscles studied were active during all three crutch walking
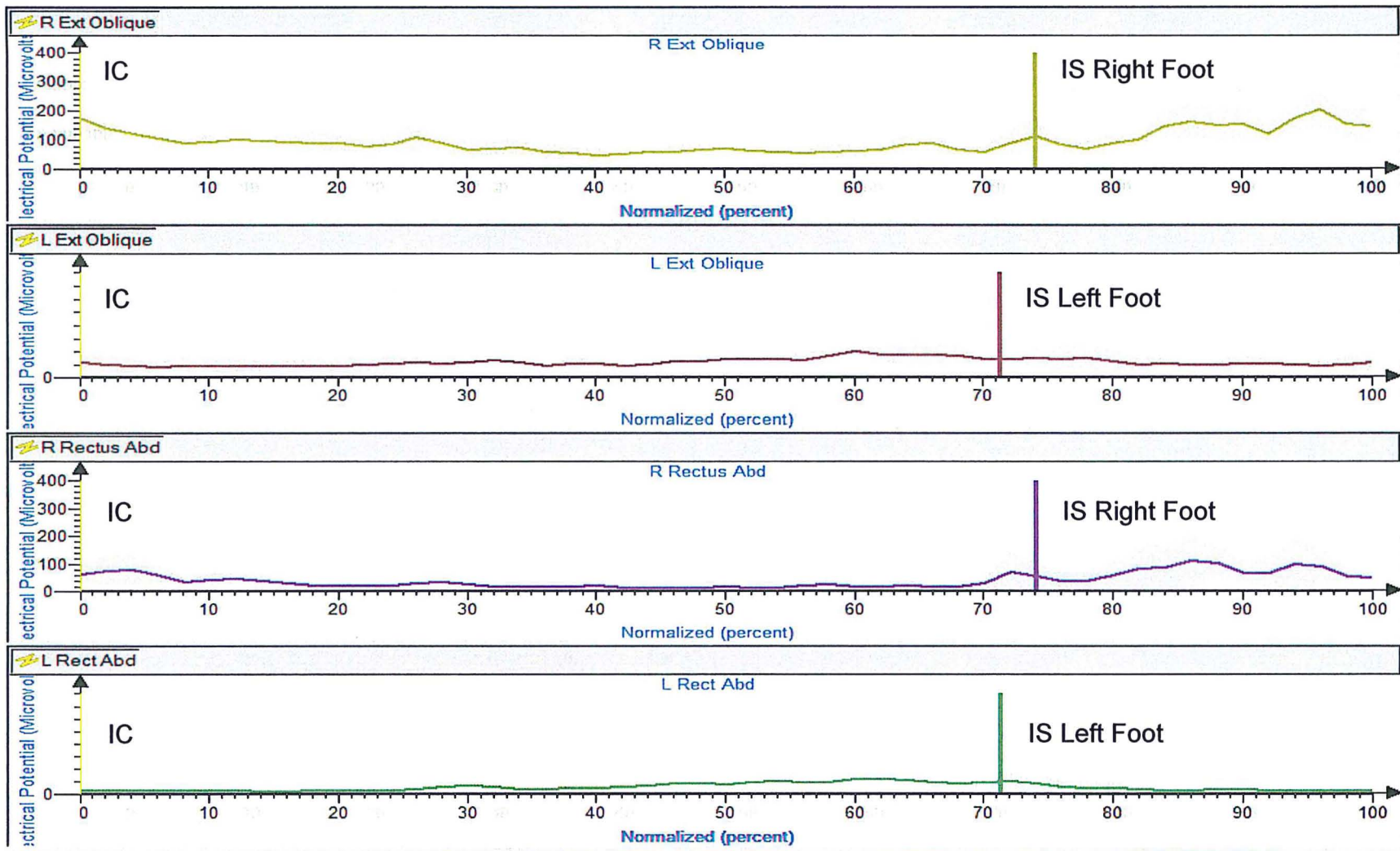
trials. The external oblique muscles displayed more activity relative to the MVC than did

the rectus abdominis muscles. Both the right and left muscle groups displayed similar

levels of activity. This is consistend with the results of La Pier et al,[13] who found no

differences in right and left rectus abdominis activity during sit up exercises. Similarly,

Ng et al[14] observed higher levels of activity during trunk rotation activities in the external

oblique muscles as compared to the rectus abdominis muscles. Although other

researchers[5,8,15] have found activity in the abdominal muscles during walking with and

without assistive devices none of those researchers reported activity in quantitative terms.

Our results are the first to report activity levels relative to a maximal voluntary

contraction.

Qualitative Assessment

All of the abdominal muscles studied showed activity throughout the gait cycle

regardless of which weight bearing mode was used. All of the muscles were most active

during the swing phase of gait as the abdominal muscles were used to bring the pelvis

forward. Our results are similar to Peacock[8] who also found the most activity during the

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swing phase of crutch walking. Waters and Morris, studying normal walking found the rectus abdominis muscles to be most active prior to and just following heel strike. They also found that the external oblique muscles were active throughout the gait cycle. Our results are consistent with Ivanenko[16] who reported activity in the rectus abdominis and external oblique muscles throughout the gait cycle, with higher levels of activity in the oblique muscles. Anders et al[5] also found activity throughout the gait cycle in both muscle groups during normal walking. Peacock[8] found the external obliques to be more active on the non-weight bearing side and the rectus abdominis to have increased activity when weight bearing through the upper extremity to aid with trunk flexion for swing. Perry[17] stated that the abdominal musculature has peak activity (10% MMT intensity) occurring during late midswing and early terminal swing during normal walking. The rectus abdominis produces low level activity throughout the normal gait cycle.

As evidenced by the pattern and quantity of activity in the present study, the abdominal muscles are particularly active during the swing phase of gait to carry the lower extremity through the swing phase. This is most apparent during crutch walking using a non-weight bearing pattern as both lower extremities have to be carried during the swing phase. The concentric activity displayed by the muscles works to keep the pelvis elevated to allow the lower extremities to clear the floor.

Based on the results of our study, following injury or any circumstance that requires the use of an assistive device, adequate muscle strength is required to allow the individual to be able to safely and efficiently ambulate. The abdominal musculature has been shown to be active throughout the gait cycle. Often times abdominal muscle

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strength is not considered a vital factor in the essential components of gait with an assistive device.

When evaluating a patient to determine the necessary strength needed for the use of assistive devices, the abdominal musculature is often overlooked. Most evaluations assess the strength of the uninvolved lower extremity and the upper extremities. However, the external obliques showed substantial activity during our trials in all weight bearing statuses. Physical therapists can benefit from the results of this study by addressing the abdominal musculature strength during the examination prior to assigning an assistive device. During the rehabilitation of the clients utilizing assistive devices, abdominal musculature should be considered for strengthening to assist the patient in the proper use of assistive devices to avoid compensation of other muscles. The external obliques require greater muscle activity than the rectus abdominis required for each weight bearing status. Examination and focusing on strengthening of this muscle may be important to target during the rehabilitation period. Ambulating with an assistive device requires adequate strength by many muscle groups. It is important to assess all muscle groups that require significant amount of activity to perform the recommended gait pattern that will be utilized by the patient.

Limitations

There were some limitations with this study. First, only seven females were recruited and participated in the study. All of these participants had extensive gait training with assistive devices during their physical therapy education. The participants in the study were young, healthy female adults as opposed to individuals that may be using the crutches following an injury or other medical condition. Another limitation

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would be the student researchers were unfamiliar and inexperienced with the high level technology used during this study. The gait speed was inconsistent as we did not use a metronome to control the speed. Anders, et al.[5] found increased muscle activity with increased walking speeds. The lack of consistent velocity may have affected the muscle activity. Due to technical difficulties, the foot switch was inconsistent and unreliable during the trials. Therefore, the foot switch information was not used during the analysis.

APPENDIX

UMBILICUS

Rectus
Abdominus

External
Oblique
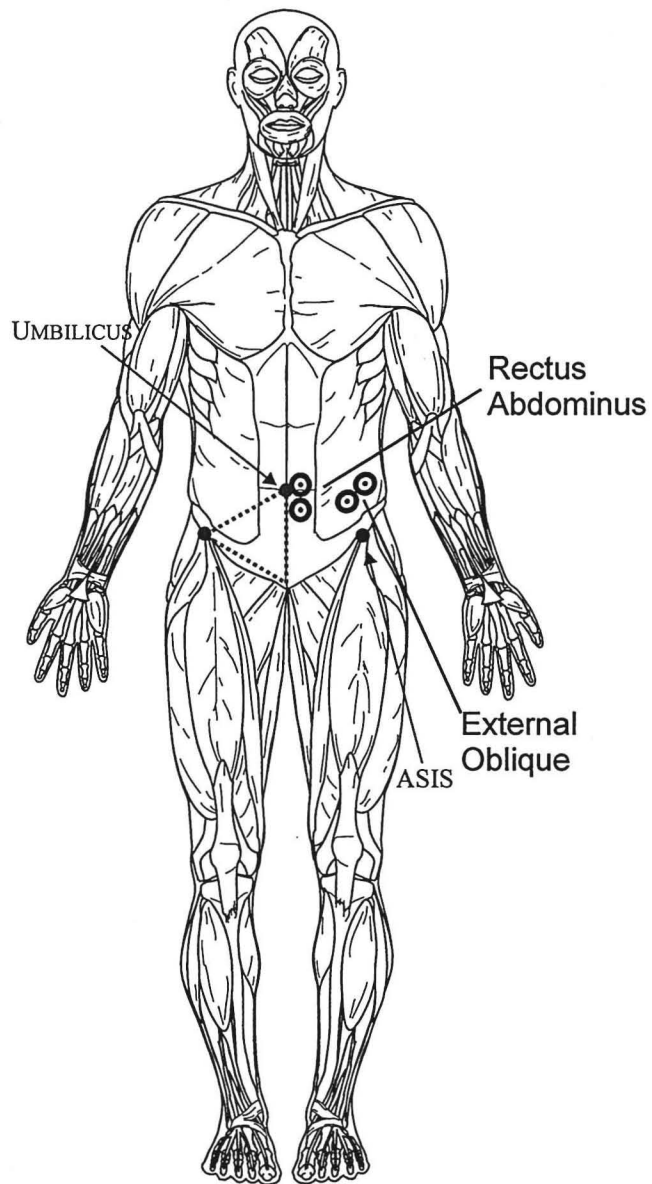
ASIS

Rectus Abdominus - 2 cm lateral to umbilicus
External Oblique - lateral to rectus abdominis, directly above the ASIS halfway between the ASIS and the lower rib cage. Placed parallel to the muscle fibers.

Electrode placements for Trunk

Plug-in-Gait Marker Placement

RFHD
LFHD
RSHO
CLAV
LSHO
STRN
LUPA
RUPA
RELB
LELB
RASI
LPSI
LASI
LFRA
RWRA
LWRA
RWRB
LFIN
RTHI
LWRB
LTHI
RKNE
LKNE
RTIB
LTIB
RANK
LANK
RTOE
LTOE

LBHD
RBHD
C7
RSHO
RBAK
RUPA
RELB
RPSI
RFRA
RWRA
RWRB
RFIN
RTHI
T10
RKNE
RTIB
RANK
LHEE
RHEE
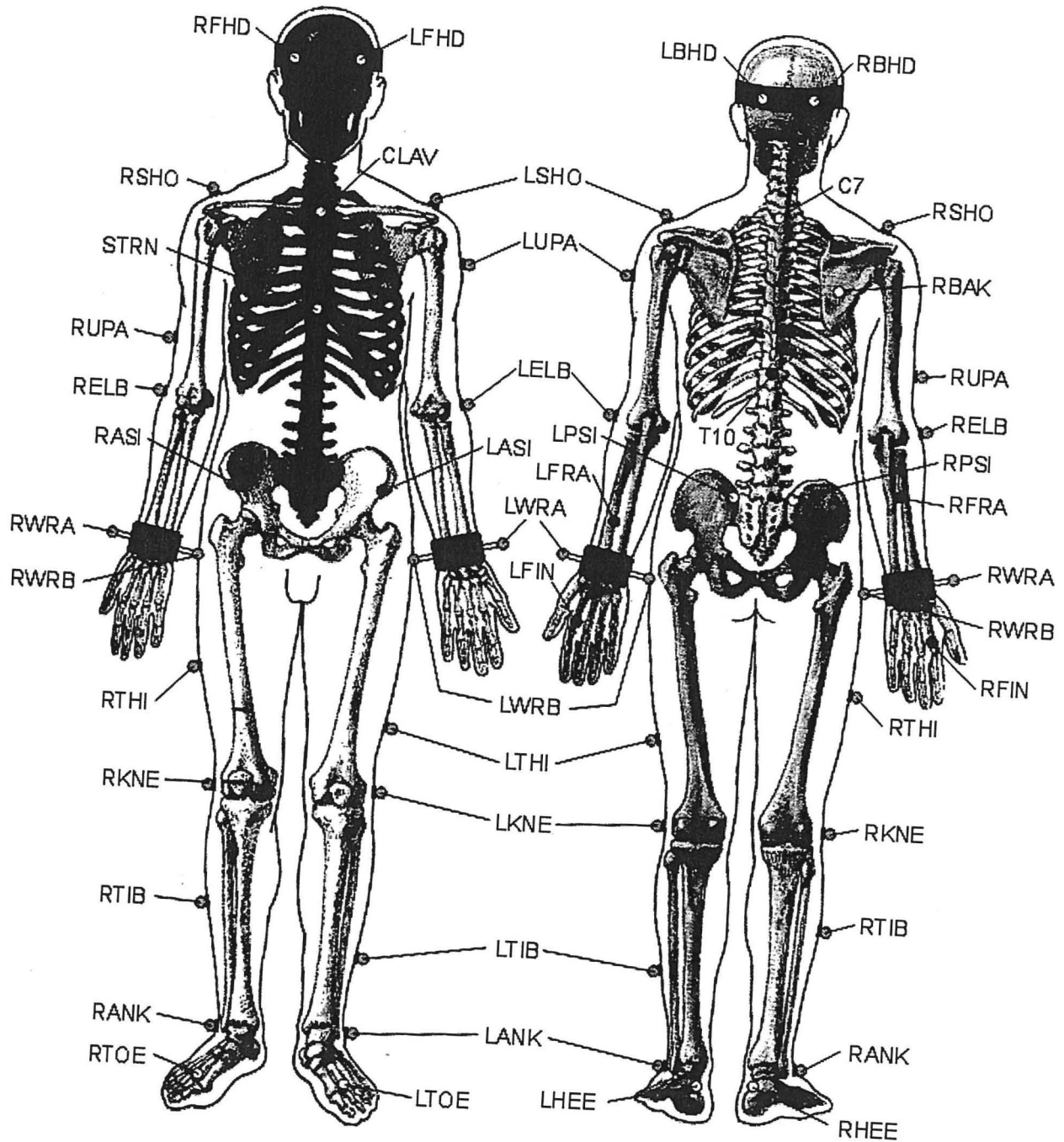
The following describes in detail where the Plug-in-Gait markers should be placed on the subject. Where left side markers only are listed, the positioning is identical for the right side.

Upper Body

Head Markers

LFHD	Left front head	Located approximately over the left temple
RFHD	Right front head	Located approximately over the right temple
LBHD	Left back head	Placed on the back of the head, roughly in a horizontal plane of the front head markers
RBHD	Right back head	Placed on the back of the head, roughly in a horizontal plane of the front head markers

The markers over the temples define the origin, and the scale of the head. The rear markers define its orientation. If they cannot be placed level with the front markers, and the head is level in the static trial, tick the "Head Level" check box under options on "Run static model" in the pipeline when processing the static trial. Many users buy a headband and permanently attach markers to it.

Torso Markers

C7	7th Cervical Vertebrae	Spinous process of the 7th cervical vertebrae
T10	10th Thoracic Vertebrae	Spinous Process of the 10th thoracic vertebrae
CLAV	Clavicle	Jugular Notch where the clavicles meet the sternum
STRN	Sternum	Xiphoid process of the Sternum
RBAK	Right Back	Placed in the middle of the right scapula. This marker has no symmetrical marker on the left side. This asymmetry helps the auto-labeling routine determine right from left on the subject.

C7, T10, CLAV, STRN define a plane hence their lateral positioning is most important.

Arm Markers

LSHO	Left shoulder marker	Placed on the Acromio-clavicular joint
LUPA	Left upper arm marker	Placed on the upper arm between the elbow and shoulder markers. Should be placed asymmetrically with RUPA
LELB	Left elbow	Placed on lateral epicondyle approximating elbow joint axis
LFRA	Left forearm marker	Placed on the lower arm between the wrist and elbow markers. Should be placed asymmetrically with RFRA
LWRA	Left wrist marker A	Left wrist bar thumb side
LWRB	Left wrist	Left wrist bar pinkie side

	marker B	

The wrist markers are placed at the ends of a bar attached symmetrically with a wristband on the posterior of the wrist, as close to the wrist joint center as possible.

LFIN	Left fingers	Actually placed on the dorsum of the hand just below the head of the second metacarpal

Lower Body

Pelvis

LASI	Left ASIS	Placed directly over the left anterior superior iliac spine
RASI	Right ASIS	Placed directly over the right anterior superior iliac spine

The above markers may need to be placed medially to the ASIS to get the marker to the correct position due to the curvature of the abdomen. In some patients, especially those who are obese, the markers either can't be placed exactly anterior to the ASIS, or are invisible in this position to cameras. In these cases, move each marker laterally by an equal amount, along the ASIS-ASIS axis. The true inter-ASIS Distance must then be recorded and entered on the subject parameters form. These markers, together with the sacral marker or LPSI and RPSI markers, define the pelvic axes.

LPSI	Left PSIS	Placed directly over the left posterior superior iliac spine
RPSI	Right PSIS	Placed directly over the right posterior superior iliac spine

LPSI and RPSI markers are placed on the slight bony prominences that can be felt immediately below the dimples (sacro-iliac joints), at the point where the spine joins the pelvis.

SACR	Sacral wand marker	Placed on the skin mid-way between the posterior superior iliac spines (PSIS). An alternative to LPSI and RPSI.

SACR may be used as an alternative to the LPSI and RPSI markers to overcome the problem of losing visibility of the sacral marker (if this occurs), the standard marker kit contains a base plate and selection of short "sticks" or "wands" to allow the marker to be extended away from the body, if necessary. In this case it must be positioned to lie in the plane formed by the ASIS and PSIS points.

Leg Markers

LKNE	Left knee	Placed on the lateral epicondyle of the left knee

To locate the "precise" point for the knee marker placement, passively flex and extend the knee a little while watching the skin surface on the lateral aspect of the knee joint. Identify where knee joint axis passes through the lateral side of the knee by finding the lateral skin surface that comes closest to remaining fixed in the thigh. This landmark should also be the point about which the

lower leg appears to rotate. Mark this point with a pen. With an adult patient standing, this pen mark should be about 1.5 cm above the joint line, mid-way between the front and back of the joint. Attach the marker at this point.

LTHI	Left thigh	Place the marker over the lower lateral 1/3 surface of the thigh, just below the swing of the hand, although the height is not critical.

The thigh markers are used to calculate the knee flexion axis location and orientation. Place the marker over the lower lateral 1/3 surface of the thigh, just below the swing of the hand, although the height is not critical. The antero-posterior placement of the marker is critical for correct alignment of the knee flexion axis. Try to keep the thigh marker off the belly of the muscle, but place the thigh marker at least two marker diameters proximal of the knee marker. Adjust the position of the marker so that it is aligned in the plane that contains the hip and knee joint centers and the knee flexion/extension axis. There is also another method that uses a mirror to align this marker, allowing the operator to better judge the positioning.

LANK	Left ankle	Placed on the lateral malleolus along an imaginary line that passes through the transmalleolar axis
LTIB	Left tibial wand marker	Similar to the thigh markers, these are placed over the lower 1/3 of the shank to determine the alignment of the ankle flexion axis

The tibial marker should lie in the plane that contains the knee and ankle joint centers and the ankle flexion/extension axis. In a normal subject the ankle joint axis, between the medial and lateral malleoli, is externally rotated by between 5 and 15 degrees with respect to the knee flexion axis. The placements of the shank markers should reflect this.

Foot Markers

LTOE	Left toe	Placed over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot
LHEE	Left heel	Placed on the calcaneous at the same height above the plantar surface of the foot as the toe marker

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