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Electromyographic and Motion Analysis of the Trunk and Pelvis during the Golf Swing

Christopher Lugibihl
University of North Dakota

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ELECTROMYOGRAPHIC AND MOTION ANALYSIS OF THE
TRUNK AND PELVIS DURING THE GOLF SWING

by

Christopher Lugibihl
Bachelor of Science in Physical Therapy
University of North Dakota, 1998

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
1999
This Independent Study, submitted by Christopher Lugibihl 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 Electromyographic and Motion Analysis of the Trunk and Pelvis During the Golf Swing: A Comparison Between Men and Women

Department Physical Therapy

Degree Master of Physical Therapy

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Signature

Date 12-11-98
# TABLE OF CONTENTS

LIST OF FIGURES .................................................. vi

LIST OF TABLES ................................................... vii

ACKNOWLEDGMENTS ................................................ viii

ABSTRACT ............................................................ ix

CHAPTER

I  INTRODUCTION .................................................. 1

  Problem Statement ............................................. 1
  Significance .................................................... 2
  Research Questions ........................................... 2
  Hypotheses ...................................................... 3

II LITERATURE REVIEW .......................................... 4

III METHODOLOGY .................................................. 12

  Subjects ........................................................ 12
  Instrumentation ............................................... 12
  Procedure ...................................................... 13
  Data Analysis ................................................ 17

IV RESULTS ......................................................... 20

  Takeaway Phase ................................................ 21
  Forward Swing ................................................. 21
  Acceleration ................................................... 22
  Early Follow Through ....................................... 23
  Late Follow Through ......................................... 23
  Peak Activity .................................................. 24
  X-Factor ........................................................ 24
  Duration of Swing ............................................ 24
DISCUSSION .............................................. 26

EMG ....................................................... 26
X-Factor ............................................... 30
Time of Swing ...................................... 31
Injury Findings .................................... 32
Limitations of Study ......................... 32
Clinical Implications ................. 33
Conclusion ........................................ 35

APPENDIX A ............................................ 37

APPENDIX B ........................................... 45

APPENDIX C .............................................. 48

REFERENCES ............................................. 59
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>The phases of the golf swing</td>
<td>8</td>
</tr>
<tr>
<td>2.</td>
<td>Camera set-up</td>
<td>14</td>
</tr>
<tr>
<td>3.</td>
<td>EMG electrode placement for external obliques, erector spinae and gluteus maximus(^9)</td>
<td>16</td>
</tr>
<tr>
<td>4.</td>
<td>Set-up and reflective marker placements</td>
<td>18</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Summary of EMG Activity During the Five Phases of the Golf Swing</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Peak Muscle Activity by Stage and Study</td>
<td>25</td>
</tr>
</tbody>
</table>
ACKNOWLEDGMENTS

There are a lot of people I would like to thank for making this study possible, but before I do, all thanks and praise are raised to my God and Lord Jesus Christ. I am nothing without them.

I would then like to give a special thanks to my wife, Ruth, for supporting me through this entire year long process. I quickly found out that an independent study on golf was not going to be easy, and it was not. She was always there for me with a helpful suggestion and an ear to hear, and I thank hr from the bottom of my heart.

The team members in this study are to be applauded for their effort. Without all of us working toward a common goal, this study would never have been finished. I would like to specifically thank my classmates Torin Berge, James Simmons, and James Vranna. Thanks to Tom Mohr and John Frappiere for their efforts and for use of the facilities in Fargo and Grand Forks. A final thanks goes to the man, Dave Relling, who put in many, many hours of hard work to keep this project running smoothly. There were some bumps along the way, but Dave was truly the calm water amidst a sometimes torrential storm.
ABSTRACT

The purpose of this study was to analyze and compare the trunk muscle activity and range of motion in male and female golfers. With the use of surface electrode electromyography and motion analysis, three male and three female Division II collegiate golfers were evaluated. The EMG activity of the erector spinae, gluteus maximus, and external oblique muscles was measured bilaterally during the golf swing. The main emphasis in analyzing the trunk range of motion was comparing relative pelvis to shoulder rotation (X-factor) throughout the swing. The researchers found definitive differences in the patterns of muscle activity and range of motion between male and female golfers. The male golfers' muscle activity occurred slightly earlier in the swing than the female golfers. The males also had a greater X-factor by about 10° and a faster swing by approximately .20 seconds than the females. These findings demonstrate the importance of the trunk and pelvic muscles in stabilizing and initiating motion in the spine during the golf swing. This study, along with previous studies, provides the framework for developing rehabilitation and training programs for the golfer stressing stability, strength, and mobility of the trunk.
CHAPTER I

INTRODUCTION

According to a recent survey, 26.5 million golfers played at least one round of golf in 1997, which is a 7% increase from 1996. As the popularity of golf continues to increase in the United States, so does the rate of golf-related injuries. A review of over 1400 letters concerning golf injuries, sent to the editor of Golf Digest, revealed that the majority (52%) of recreational golfers complained of back problems. In amateur and professional golfers over the age of 50, there was an injury rate of 64%, and with those under 50, the rate was 58%. Many of these people suffer from low back injuries. In fact, low back injuries are the most common problem in male amateur and professional golfers, and the second most common in female amateur and professional golfers. According to the National Medical Expenditure Survey conducted in 1987, the medical spending on various injuries within the United States was 64.7 billion dollars. Thirteen major categories of injury were analyzed, and back injuries incurred the highest payment per case. With that in mind, a need exists for a way to prevent and treat low back injuries among golfers.

Problem Statement

In recent years, there has been an increased level of participation in golf and accordingly an increase in golf-related injuries. The physical therapy
profession needs a better working knowledge of how to treat the golfer with a low back injury. The purpose of this study is to compare trunk and pelvis muscle activity and range of motion (ROM) in Division II men and women golfers. This study will help physical therapists target specific muscles within a certain ROM that correlates with the golf swing to help best treat low back injuries relating to golf.

Significance

This study is important to physical therapists who work with golfers because it will provide information to help target both training and rehabilitation for low back injuries secondary to participation in golf. It will also benefit golfers around the world who suffer from low back injuries. The results from this study will allow physical therapists to return these golfers to their normal activity level more quickly and to prevent reoccurrence of this injury. A golf-specific training program will be able to be formulated using the results from this study to prevent these low back injuries from occurring. Insurance companies can also save money with an improved golf-specific treatment plan which saves time in rehabilitation and also helps decrease the number of golf-related back injuries. If this study were not done, low back injuries in golf will persist and possibly recur due to a lack of knowledge and specificity in rehabilitation of the golfer.

Research Questions

#1. Is there a difference in electromyographic (EMG) activity of the trunk and hip musculature between men and women during the different phases of the golf swing?
#2. Is there a difference in trunk ROM between men and women during the golf swing?

#3. Does ROM and EMG activity have an effect on club-head speed generated by men as compared to women?

Hypotheses

#1. There is no significant difference in EMG activity of the trunk and hip muscles between males and females during the phases of the golf swing.

#2. There is no significant difference in trunk ROM between men and women during the golf swing.

#3. There is no significant difference comparing men to women in the effect EMG activity and ROM have on club-head speed generated.
CHAPTER II
LITERATURE REVIEW

Golf may be thought of as a leisure sport with little to no risk of injury, but in reality, low back injuries are common among golfers at the amateur and professional levels. Studies have shown that low back injuries are prominent among both men and women golfers.\textsuperscript{2,3} However, there was a notable difference between male and female golfers relating to the site of the injury. Men sustained more frequent injury to the spine than to the upper extremities, whereas females more often injured the upper limbs compared to the spine.\textsuperscript{2,3} Research has not yet explained the reason for these differences seen between genders, but theories have been suggested to help clear this confusion. Theriault and Lachance\textsuperscript{5} felt that gender differences involving injury to the spine could be explained by the greater swing velocity and the greater use of muscle strength during trunk rotation by men. Another theory was that women tend to generally have better trunk flexibility than men, which might decrease their risk of injury to the spine.\textsuperscript{5}

The high occurrence of low back injuries among golfers has been related to overuse, improper swing mechanics, and poor physical conditioning.\textsuperscript{2,3,5-9} It has also been found that previous back injuries were a strong indicator for back pain while participating in golf.\textsuperscript{9} A study looking at the incidence of back pain
among golfers found that 45% of those people who had previous back problems had recurrent episodes of back pain over a 12-month follow-up.9 These are factors that should be considered when evaluating the risk of injury to both male and female golfers.

Today's trend in golf is to be like Tiger Woods, and to emulate him best, the golfer attempts to hit the long drive (300+ yards). A study by Robinson10 correlating swing characteristics with club head velocity found that professionals' club-head speed was significantly greater than that of the amateur. Professionals averaged a club-head velocity of 48.3 m/s, and that of the amateurs was only 41.8 m/s. They noted that angular velocity of the hips during the down swing and of the shoulders at the time of impact had a positive correlation with club-head velocity.10 Another study noted that PGA tour professionals had a significantly faster swing time as compared to amateurs.11 On average, the amateur took 1.28 seconds of time to impact as compared to 1.09 in professionals. They concluded that the Tour players' faster trunk rotation during the swing contributed to a greater club-head speed. It was also theorized that a more efficient motion between the trunk and arms could be a reason for faster swing time.11 This could mean that amateurs and/or recreational golfers who try to hit the ball farther than their capabilities may overuse or overstress the muscles of the trunk to compensate for a lack of proper swing technique. Both of the studies previously mentioned analyzed male golfers only, so a lack of knowledge does exist when comparing men versus women in this area.
Studies have looked at the motion of the spine and the forces exerted there during the golf swing. McTeigue et al\textsuperscript{11} claimed that a tremendous amount of motion was performed by the lumbar spine during the golf swing. Hosea et al\textsuperscript{7,8} concluded that the golf swing produced rapid, complex, and intense loads on the lumbar spine. There are four forces (loads) on the low back during the golf swing; three are axial (lateral bending, shear, and compression) and the fourth is rotational (torsion).\textsuperscript{7,8} These studies found that the golf swing of amateurs and professionals produced compression loads on the lumbar spine upwards of 6000 N of force (4000 N is associated with vigorous activities).\textsuperscript{7,8} They also noted that amateur golfers developed greater peak lateral bending and shear loads on the spine than the professionals.\textsuperscript{7,8} These loads on the lumbar spine may put the golfer at risk for muscle strains, spondylolysis, herniated discs, and other disorders of the low back.\textsuperscript{7,8} Low back muscle strains and muscle spasms were noted to be the most common cause of low back pain in golfers.\textsuperscript{8}

Over the last few years, research has been looking at the muscle activity and trunk motion occurring during the golf swing to help find solutions for injuries incurred while playing golf. Presently, there have been EMG studies done on the shoulder,\textsuperscript{12} trunk,\textsuperscript{13,14} and hip and knee,\textsuperscript{15} while a golf swing is performed to calculate the level of muscle activity present. Video motion analysis of the spine and hip\textsuperscript{11} during a golf swing has also been done to look at trunk motion. These studies will be discussed further to describe the current knowledge relating to trunk activity and motion during the golf swing.
The EMG studies of the trunk were done by Watkins et al\textsuperscript{14} and Pink, Perry, and Jobe.\textsuperscript{13} Both studies examined the trunk muscle activity of male subjects during the golf swing. Watkins\textsuperscript{14} recorded the activity of the abdominal oblique, gluteus maximus, and erector spinae bilaterally, as well as the upper and lower rectus abdominus during a golfer's swing. Pink\textsuperscript{13} focused only on the abdominal oblique and erector spinae muscles bilaterally. Both studies used surface EMG electrodes for collection of their data. They also used high-speed cinematography to correlate the data with the five phases of the golf swing: take away, forward swing, acceleration, early follow-through, and late follow-through (see Figure 1).\textsuperscript{13,14} Breaking the golf swing down into these five phases seems to be the prominent choice of many researchers.\textsuperscript{12-15}

The results of both EMG trunk studies revealed a high level of trunk muscle activity during the golf swing (see Table 1).\textsuperscript{13,14} This information showed the importance of these muscles when a golfer swings his club and the value of strengthening specific trunk musculature to prevent and rehabilitate low back injuries. These studies did not, however, correlate trunk ROM to the muscle activity in the trunk. By providing data which correlates trunk ROM with the level of muscle activity in the trunk for both men and women, a void will be filled within the research of this topic.

The electromyographic study of the hip and knee by Bechler\textsuperscript{15} and Watkins's\textsuperscript{14} EMG study of the trunk both singled out the gluteus maximus (especially on the right) as the most active hip muscle during forward swing (see Table 1). The action of this muscle is to push the trail hip forward and initiate
Figure 1. The phases of the golf swing.
Table 1.—Summary of EMG Activity During the Five Phases of the Golf Swing.

<table>
<thead>
<tr>
<th></th>
<th>TAKE-AWAY</th>
<th>FWD SWING</th>
<th>ACCELERATION</th>
<th>EARLY FOLLOW THROUGH</th>
<th>LATE FOLLOW THROUGH</th>
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<td><strong>RIGHT</strong></td>
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<tr>
<td>GLUTEUS MAXIMUS</td>
<td>15%\textsuperscript{14} 18%\textsuperscript{15a}</td>
<td>84%\textsuperscript{a} 99%\textsuperscript{a}</td>
<td>21%\textsuperscript{a} 27.5%\textsuperscript{a}</td>
<td>14%\textsuperscript{a} 12.5%\textsuperscript{a}</td>
<td>8%\textsuperscript{a} 9%\textsuperscript{a}</td>
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<tr>
<td><strong>LEFT</strong></td>
<td>11%\textsuperscript{14} 8%\textsuperscript{15a}</td>
<td>35%\textsuperscript{a} 50%\textsuperscript{a}</td>
<td>53%\textsuperscript{a} 58%\textsuperscript{a}</td>
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<td><strong>RIGHT</strong></td>
<td>16%\textsuperscript{14} 20%\textsuperscript{13}</td>
<td>55%\textsuperscript{a} 75%\textsuperscript{a}</td>
<td>38%\textsuperscript{a} 58%\textsuperscript{a}</td>
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\textsuperscript{a} Represents average of upper and lower gluteus maximus EMG. Both portions of this muscle exhibited similar firing patterns throughout the golf swing.\textsuperscript{15}

rotation of the pelvis during the golf swing. The hip and knee muscles are most active in forward swing confirming the idea that the hip leads the shoulders through the golf swing.\textsuperscript{15} Since the hip rotates prior to the movement of the
upper body, rotation must occur in the torso. According to McTeigue et al.,\textsuperscript{11} this trunk motion has often been summarized as 45° for the hips and 90° for the shoulders.

In a recent study of spine and hip motion during the golf swing,\textsuperscript{11} a more specific means of measuring the degrees of trunk motion was used. This method compared the relative rotation in the upper body and the hip during the golf swing and is known in research as the "X-Factor."\textsuperscript{11} The results from this study showed the amount of rotation occurring in the trunk from the top of the backswing to ball impact. It was found that amateurs averaged 34° of trunk rotation at the top of backswing and 8° of rotation at impact, and professionals averaged 32° rotation at top of backswing and 6° at impact using this method.\textsuperscript{11} McTeigue et al.\textsuperscript{11} was, therefore, able to provide a method for researchers to follow in the specific analysis of trunk rotation. Trunk rotation measurements comparing men and women during the five phases of the golf swing have not yet been analyzed using the "X-factor."

The EMG study of the shoulder by Jobe et al.\textsuperscript{12} compared both male and female golfers to determine whether differences in muscle firing patterns existed during the golf swing. They found that women tended to have more shoulder muscle activity in the takeaway and forward swing phases, whereas men had more activity during the acceleration and follow-through phases of the golf swing. However, through the use of an independent two-tailed t-test, this study was unable to find statistically significant differences in shoulder EMG activity between male and female golfers. They concluded by saying that, although men
and women had similar firing patterns in the shoulders, this did not remove the possibility of gender differences in body biomechanics or EMG activity in other parts of the body. This study will try to determine if gender differences exist at the trunk during the golf swing.
CHAPTER III

METHODOLOGY

Prior to initiation of this study, the project was reviewed and approved by the University of North Dakota Institutional Review Board (see Appendix A). The methods used in this study are detailed below.

Subjects

Six volunteer subjects (three male and three female) participated in this study. All subjects met specific limitations set by the researchers which included no previous or current back injuries, 18 years of age or older, currently a member of a NCAA Division II golf program, and not pregnant. The purpose and procedures of the study were explained to each subject prior to his/her signing a statement of informed consent. EMG and motion analysis data were collected from each subject.

Instrumentation

Surface electrodes were placed on the subjects to record EMG activity. The EMG activity was transmitted by a Noraxon Telemyo8 telemetry unit (Noraxon USA, 13430 North Scottsdale Rd., Scottsdale, Ariz. 85254) and collected by the Noraxon Telemyo8 receiver. The Peak Motus5 system (Peak Performance, Englewood, Colo.) was used to store and analyze the EMG data. Three high-speed video cameras (Peak Performance High-Speed Video System,
Englewood, Colo., and Pulnix TM-640 Sequential Scanning Camera, Sunnyvale, Calif.) operating at 60 frames per second were set up to tape the golfers' swings. Three hi-fi videocassette recorders (JVC BR-S3784 Hi-Fi VCR) recorded the swings onto super VHS tape. The Peak Calibration Frame (Peak Performance, Englewood, Colo.) was used to calibrate the cameras before the subjects were run for the study. According to research, the Peak Motus system has been found to be both reliable and valid; the Noraxon EMG measurement system has been found to be “reasonably” reliable in determining parameters of neuromuscular performance.

Procedure

Subjects were tested at the University of North Dakota Physical Therapy Department in Grand Forks, ND. Cameras were set up at approximate 45° angles from the right shoulder anteriorly and from the right and left shoulder posteriorly, at a height of approximately 8 feet. Lights were attached to each of the cameras to illuminate the golfer (Figure 2). The 25-point Peak Calibration Frame was then used to calibrate the three-dimensional area in which the golfer would be swinging the golf club for motion analysis. EMG equipment was tested by the researchers for appropriate signal transmission and reception prior to placement on the subjects.

The procedure and the purpose of the study were first explained to the subjects, after which they were asked to sign a statement of informed consent. Female subjects were asked to wear athletic shorts and sports bras; males were asked only to wear athletic shorts. Subjects were shaved as needed and the
Figure 2. Camera set-up.
skin was cleaned with rubbing alcohol prior to electrode placement in order to maximize signal conduction. Pre-gelled, silver-silver chloride, self-adhesive surface electrodes (Multi Bio-Senors, El Paso, Tex. 79913) were used. The electrodes were placed bilaterally according to the following landmarks: five centimeters superior to the ASIS for the abdominal oblique muscles, horizontally aligned with the L₃₄ interspace and four centimeters lateral to midline for the erector spinae muscles, and at the midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter for the gluteus maximus muscle (Figure 3). A ground electrode was placed on the ASIS. Leads from the electrodes were connected to a transmitter, which was attached to each subject's leg in a manner that would not impede the golf swing.

Subjects were asked to perform maximal manual muscle tests (MMT) bilaterally. The muscle test for the abdominal oblique was performed supine with legs flexed approximately 5° to 10° at the hips with resistance provided on the distal lower extremity for 5 seconds. To test the erector spinae, subjects were positioned in prone and were instructed to raise their trunk off the plinth, holding an isometric contraction against resistance for 5 seconds. The gluteus maximus test was also performed in prone; subjects were asked to contract their gluteal muscles for 5 seconds. Each subject's EMG activity for each muscle tested was recorded as the subject's 100% MMT.

Reflective markers were attached to the subjects using double-sided tape to the following landmarks bilaterally: lateral malleolus, lateral femoral
Figure 3. EMG electrode placement for external obliques, erector spinae, and gluteus maximus.
epicondyle, top of the iliac crest, acromion process, lateral humeral epicondyle, and radial styloid process. Additional markers were attached to spinous processes at the T_{12} and S_{1} level. Reflective tape was also attached to the subject's club and to the tee for a total of 16 points (Figure 4).

Subjects were allowed to warm up as desired to stretch their muscles and to get accustomed to swinging with the EMG equipment and reflective markers in place. Subjects stood on an astro-turf mat with bare feet and were asked to hit a rubber tee when swinging (no ball was used). A microphone was placed near the tee in order to trigger an event marker when the club struck the tee; this was done for the purpose of determining club head impact. Each subject used his or her own driver and performed three or four "normal" swings. The EMG activity was recorded simultaneously as the swings were videotaped.

Data Analysis

Swings from the three female and three male subjects were trial averaged using the PEAK Motus system trial averaging software at a sampling rate of 0.5%. This was done to produce an "ensemble average" incorporating all of the subjects. These data were separated into male and female groups. The trial averaged EMG activity of the six total muscles and trial averaged shoulder to hip angle (X-factor) was used for qualitative analysis.

The EMG activity was divided into the five phases of the golf swing described earlier using set event markers. Qualitative analysis of the "ensemble average" muscle activity was operationally defined as one of three levels:
Figure 4. Set-up and reflective marker placements.
1. No or minimal EMG activity: muscle activity less than 33% of the maximal EMG activity within that muscle during the golf swing.

2. Moderate activity: muscle activity between 33% and 66.5% of the maximal EMG activity for that muscle during the golf swing.

3. Maximal activity: muscle activity greater than or equal to 66.6% of the maximal EMG activity within that muscle during the golf swing.

Each muscle had to be active for 3% of the swing to be classified with a minimal, moderate, or maximal activity level. In order for the classification to be changed to a higher or lower level, a 3% duration at that activity level was required.

This method of using the ensemble average to analyze EMG data has been shown to have several advantages. According to Yang and Winter,\textsuperscript{20} the normalization method of using a peak or mean ensemble average for EMG activity significantly reduces intersubject variability in normal subjects and thus improves the sensitivity of surface EMG. In previous research, Yang and Winter also stated that the method of normalizing EMG data using 100% of a maximal voluntary contraction is not a very reliable method.\textsuperscript{21} This research, in addition to the number of subjects run led this author to conclude that qualitative analysis using an ensemble averaged EMG activity and ROM was the most desirable way to analyze these data.
CHAPTER IV

RESULTS

During data analysis, the EMG activity of the trunk muscles for the men and the women were divided into the five phases of the swing as per specific event markers. For the women, the takeaway phase lasted the first 52.5% of the swing, the forward swing phase lasted from 52.5% to 66.5% of the swing, the acceleration phase lasted from 66.5% to 69% of the swing, early follow through lasted from 69% to 72% of the swing, and the late follow through phase lasted from 72% to 100% of the swing. The men had a longer takeaway phase and a shorter late follow through phase, but all other phases remained comparable. The takeaway phase lasted the first 67% of the swing, the forward swing phase lasted from 67% to 80% of the swing, the acceleration phase lasted from 80% to 83% of the swing, the early follow through lasted from 83% to 85.5% of the swing, and late follow through lasted from 85.5% until the end of the swing (see Figures 5 & 6, Appendix B).

The EMG data were classified as minimal activity, moderate activity, or maximal activity and described in terms of percentages of total swing. The data were then converted to percentages within each phase of the golf swing so that men and women could be more accurately compared.
Takeaway Phase

The men's right external oblique was minimally active during the first 39.2%, moderately active through 60%, minimally active through 73.9%, and moderately active for the remainder of this phase. The left external oblique was active at a minimal level during the first 23.1%, moderate through 87.3%, and maximally active through the remainder. The right erector spinae produced a minimal level of activity for the first 79.1%, moderate through 97%, and maximal for the remainder. The left erector spinae was minimally active through 82.8%, moderate through 90.3%, maximal through 98.5%, and minimal for the remainder. The right gluteus maximus showed minimal activity through 70.1%, moderate through 84.3%, minimal through 97.8%, and moderate through the end of the phase. The left gluteus maximus had minimal activity through 37.3%, moderate through 76.1%, minimal through 82.8%, maximal through 97%, and moderate for the rest of the phase (see Figure 7, Appendix C).

The women's right external oblique showed minimal activity through 57.6% and moderate for the remainder. The left external oblique and right and left erector spinae all produced minimal activity throughout this phase. The right gluteus maximus showed minimal activity through 92.8% and moderate for the remainder. The left gluteus maximus was minimally active through 71.9% and moderate for the remainder (see Figure 8, Appendix C).

Forward Swing

The men's right and left external obliques showed moderate levels throughout this phase. The right erector spinae continued maximal levels of
activity for the first 7.7%, dropped to moderate through 65.4%, and was minimal for the remainder. The left erector spinae was minimally active throughout. The right gluteus maximus was moderate for the first 26.9% and minimal for the remainder. The left gluteus maximus showed moderate activity through 42.3% and minimal for the remainder (see Figure 9, Appendix C).

The women's right external oblique produced moderate activity throughout. The left external oblique was minimal for the first 12.5% and moderate for the remainder. The right erector spinae showed minimal activity through 16.1%, moderate through 39.3%, maximal through 85.7%, and moderate for the remainder. The left erector spinae produced minimal activity for the first 16.1%, moderate through 71.5%, and maximal for the remainder. The right gluteus maximus was moderately active through 23.2%, maximally through 87.5%, and moderately for the remainder. The left gluteus maximus was moderate throughout (see Figure 10, Appendix C).

Acceleration
The men's right and left external obliques showed moderate activity throughout. Bilateral erector spinae and gluteus maximus muscles were minimally active throughout (see Figure 11, Appendix C).

The women's right and left external obliques were moderately active throughout. The bilateral erector spinae muscles were minimally active throughout this phase. The right gluteus maximus was moderate through 70% and minimal for the remainder. The left gluteus maximus was moderately active throughout (see Figure 12, Appendix C).
Early Follow Through

The men's right and left external obliques were moderately active throughout. The bilateral erector spinae and gluteus muscles showed minimal activity for the duration of this phase (see Figure 13, Appendix C).

The women's right external oblique was maximally active throughout. The left external oblique showed moderate activity throughout. The bilateral erector spinae muscles were minimally active during this phase. The right gluteus maximus was minimally active throughout. The left gluteus maximus was moderately active throughout (see Figure 14, Appendix C).

Late Follow Through

The men's right external oblique was moderately active through 46.6% and minimally active for the remainder. The left external oblique produced moderate activity throughout. The bilateral erector spinae and gluteus maximus muscles were minimally active throughout this phase (see Figure 15, Appendix C).

The women's right external oblique remained maximally active through 32.1% and moderately active for the remainder. The left external oblique was moderately active throughout. The bilateral erector spinae and right gluteus maximus were minimally active throughout. The left gluteus maximus remained moderately active through 2.7% and was minimally active for the remainder (see Figure 16, Appendix C).
Peak Activity

Peak activity of the men's right external oblique occurred at 7.7% of forward swing, left external oblique at 97.8% of takeaway, right erector spinae at 3.8% of forward swing, left erector spinae at 98.5% of takeaway, right gluteus maximus at 91% of takeaway, and left gluteus maximus at 89.6% of takeaway (see Figure 5, Appendix B).

Peak activity of the women's right external oblique occurred at 71.5% of early follow through, left external oblique at 78.6% of forward swing, right erector spinae at 64.3% of forward swing, left erector spinae at 78.6% of forward swing, right gluteus maximus at 32.1% of forward swing, and left gluteus maximus at 20% of acceleration (Table 2) (see Figure 6, B).

X-Factor

At address, the men showed an X-factor of approximately 18° with shoulders closed relative to the hips. This angle increased to a maximal excursion of approximately 48° as they neared the top of backswing. By impact, the shoulders had moved past the hips to an angle of 14°.

Women showed an X-factor of approximately 19° at address with the shoulders open relative to the hips. Toward the end of backswing, the X-factor was 37.8° with the shoulders in a position closed relative to the hips. At impact, the shoulders were closed relative to the hips approximately 2°.

Duration of Swing

The duration of the men's swings averaged .94 seconds. The women's swings averaged 1.13 seconds.
**Table 2.**—Peak Muscle Activity by Stage and Study

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Take Away</th>
<th>Forward Swing</th>
<th>Acceleration</th>
<th>Early Follow Through</th>
<th>Late Follow Through</th>
</tr>
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<tbody>
<tr>
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<td>1</td>
<td>4,5</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L External Oblique</td>
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<td></td>
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<tr>
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</tr>
<tr>
<td>L Erector Spinae</td>
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<td>2,4,5</td>
<td>2</td>
<td></td>
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</tr>
<tr>
<td>R Gluteus Maximus</td>
<td>1</td>
<td>2,3,5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>L Gluteus Maximus</td>
<td>1</td>
<td>2,3,5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Male subjects in this study
2. Female subjects in this study
3. Subjects from Bechler et al
4. Subjects from Pink et al
5. Subjects from Watkins et al
CHAPTER V

DISCUSSION

EMG

This study has found that during the golf swing EMG activity in the gluteus maximus, erector spinae, and external obliques differs between men and women. The graphs of EMG activity may look similar between the male and female golfers, but the time during the swing when that activity occurs varies somewhat. Comparisons will be made of the men and women from this study, the male golfers versus those from other studies, the women golfers versus the men from other studies, and finally overall EMG activity of all the subjects as one group versus the subjects of other studies.

In the takeaway phase, men displayed peak muscle activity in the L external oblique, L erector spinae, and in both the L and R gluteus maximus. This activity occurred just prior to the forward swing phase. This burst of activity correlated with the peak rotational movement in the trunk and could be one reason why men had larger "X-factors" than women. The women in this study had very minimal activity in this phase.

During the forward swing phase, the male subjects primarily had moderate muscle activity, although the R erector spinae did peak during the initiation of this phase. The female subjects had their greatest output of muscle activity during
this phase. Maximal muscle activity occurred in the L erector spinae, R erector spinae, and R gluteus maximus. Moderate activity occurred in the three remaining muscles. This high level of activity shows that the women were creating the force behind their swing during this phase of the golf swing.

The EMG activity during the acceleration phase was very similar between the men and women golfers. The only substantial difference was the greater gluteus maximus muscle activity in females. Both the L and R gluteus maximus muscles had moderate activity as compared to the minimal activity occurring in males. This may mean that the women generated more relative torque (force production) through their hips during this phase of the golf swing than the men did.

Both the early and late follow-through phases will be discussed together due to the fairly consistent results during these phases. Minimal EMG activity occurs except in the abdominal oblique muscles. Both men and women have at least moderate activity in both the left and right abdominal external obliques throughout the majority of the follow through, thus underlying the importance of the abdominals in controlling/stabilizing the trunk during this portion of the golf swing. Some differences noted between the men and women include peak maximal activity of the R external oblique in women as compared to moderate activity in men. Women also had greater L gluteus maximus activity than men. This could be a result of women attempting to control their trunk and pelvis during the follow-through more than men.
In studies of the hip\textsuperscript{15} and trunk,\textsuperscript{13,14} EMG activity in male golfers was analyzed using $\%$MMT (see Table 1). A comparison of these studies with the results of this study will be discussed. To make this comparison clearer, a definition of $\%$MMT will be given as it relates to the results of this study. According to Pink et al.,\textsuperscript{13} less than 30\% of MMT is minimal activity and greater than this is considered relatively high muscle activity.

The male subjects in our study had moderate to maximal EMG activity occurring during the latter half of the takeaway phase. In contrast, previous studies show only minimal muscle activity during this phase. This inconsistency may be due to the differences in how the EMG data were quantified. The past studies may have averaged the level of muscle activity during each phase, whereas this study reported changes in activity throughout each phase. Thus, a short period of high muscle activity would be hidden by the overall average in past studies. Differences may also be due to the operational definition of EMG activity. Previous studies calculated the amount of EMG activity during a golf swing based on a MMT of the subjects, whereas this study used a percent of the maximal EMG activity recorded during the swing. Past research instead noted greatest EMG activity occurring during the forward swing and acceleration phases. During the follow through phases, the external abdominal obliques were moderately active in both our study and in those previously conducted.

A number of similarities were seen when the women in this study were compared to the male subjects of former EMG trunk studies. The women had the majority of their muscle activity during the forward swing and acceleration
phases as did the men from past studies. The major difference noted between
the two groups was the maximal activity occurring in the R external oblique of
females during the follow through phases rather than the acceleration phase.
This overall comparison of men and women EMG trunk activity concurs with a
previous EMG study of the shoulder by Jobe et al.\textsuperscript{12} He stated that no significant
differences were found between men and women regarding the relative level of
muscle activity occurring during the golf swing.\textsuperscript{12}

The overall group (males and females) from this study do not appear to
differ from previous trunk and hip studies. The majority of muscle activity occurs
in the forward swing and acceleration phases. Abdominal activity in the follow
through phases is moderate. This information coincides with the thought that
force production occurs primarily during the downward swing of the club and that
stabilization and control of the trunk occurs as the golfer follows through.

However, this study does note that peak muscle activity in males occurred
just prior to the forward swing phase. This might best be explained by Pink et
al\textsuperscript{13} who postulated that at the top of backswing the trunk muscles are stretched
to facilitate their action during forward swing. The action just described was
similar to the principle of plyometrics (a quick, powerful movement that pre-
stretches the muscle to increase force production concentrically). This concept
could explain why the trunk muscles fired so strongly prior to forward swing; the
male golfers wanted to create a quick stretch of the muscles in order to produce
a more powerful golf swing. This maneuver may have also been present during
the females' swing, but it was not of the magnitude seen in men. This is most likely due to the low level of EMG activity observed prior to forward swing.

**X-Factor**

When comparing the trunk rotation occurring in men and women during the golf swing, this study found that men had approximately 10° more X-factor than the women. This may mean that men had more overall trunk flexibility than the women or that the men rotated their trunk to its limits, whereas women avoided the extremes of trunk motion. Prior theory has stated that women tend to have better flexibility than men, so the second proposal is more likely to be true. This might explain why men are more prone to back injury than women; men go to more extremes of trunk ROM, which increases the forces placed on supporting structures (i.e., ligaments, muscles) of the spine. The high level of muscle activity these men produced just prior to forward swing may account for this push into extreme trunk ROM.

The X-factor results from this study are greater than those produced in the McTeigue et al\textsuperscript{11} study. They noted trunk rotation averages of 32° in male professionals and 34° in male amateurs,\textsuperscript{11} whereas the male college level golfers averaged just over 48°. This large difference could be due to a number of factors. The analysis of the X-factor in our study compared the shoulders to the hips. In the previous study, the mid-thoracic spine was compared to the hips.\textsuperscript{11} This difference in X-factor calculation may cause these results to be relatively higher (since rotation does occur in the upper thoracic spine) than those found in the past. The college-age subjects might also be more flexible than older
players seen at the professional and amateur levels. Pink et al\textsuperscript{13} noted that older
golfers can have up to 50\% less trunk rotation than a younger player.

The X-factor seen in the female subjects were comparable to those of
men in the McTeigue et al\textsuperscript{11} study. However, this does not mean that men and
women have similar trunk rotation during a golf swing. In the present study,
males had a greater X-factor than the females. This difference was found under
similar testing conditions and among subjects who were of similar age,
experience, and skill level. The men from the previous study\textsuperscript{11} were older, more
experienced golfers, who were analyzed under different testing conditions.

Time of Swing

The swing times recorded in this study are less than those seen in a
previous study by McTeigue et al.\textsuperscript{11} The low swing times seen in our male
subjects are consistent with the idea that greater X-factors produce greater club-
head velocity (smaller swing time). Whether the swings they attempted were
consistent with those in an actual shot-making situation is difficult to say because
accuracy was not measured.

The women in this study can only be compared to other men. No studies
have analyzed time of swing for women or compared club-head velocity between
men and women. In the literature, however, it has been theorized that compared
to men, women have a slower club-head velocity.\textsuperscript{5} When comparing the average
female swing time with the male professionals and our male subjects, the female
swing was slower. The most probable reason for the slower swing time in the
female is due to the smaller amount of general muscle mass as compared to the
male. Thus, the female has an inability to generate as much force production during the golf swing. The smaller X-factor in women as compared to men in this study would seem to actually speed up their swing. The reason it was not faster may be due to a less forceful rapid stretch response (plyometric theory) at the top of backswing in women. This would result in a reduction of speed produced during the remainder of the swing as compared to men.

Injury Findings

It was stated previously that women incur fewer golf-related back injuries than men. The results from this study provide a few reasons as to why this occurs. The women golfers had less muscle activity in the trunk and hips during the takeaway phase and a smaller X-factor (trunk rotation) than the men at the top of backswing. Therefore, it appears that women on the average tend to produce less torque (rotational force) in the spine during the golf swing than men do. Since most of the forces during trunk rotation occur in the low back, it makes sense that most of the injuries to the spine occur in this region. Therefore, if women produce less torque on the spine than men do, it is likely that fewer injuries will occur in the low back of female golfers.

Limitations of Study

There are many ways in which this study could have been improved. Originally, the study was set up for a four-camera analysis of the golf swing, but due to the malfunction of one camera, only three were used. An additional camera would have allowed for a more accurate analysis of the golfer's swing.
The reflective markers used did not contrast well with the subjects' skin, making it difficult to differentiate them while digitizing. This created problems with the reliability and consistency of the marker placement during the digitizing process. While the subjects were videotaped, they had an EMG pack wrapped around their thigh and reflective markers on prominent body landmarks. This could possibly limit them from taking a normal swing motion.

Other limitations included the low number of subjects and the use of qualitative analysis rather than quantitative statistical analysis. Without a larger base of subjects, any statistical analysis lacks significance. Statistical tests could not be used to analyze the significance of the qualitative assessment of these data, so the null hypotheses postulated were not proven.

In regard to the placement of EMG surface electrodes, it has been found that overflow of activity exists between the internal and external obliques. Thus, it is difficult to discern which muscle is active and when. This could be another reason for the large activity levels recorded in the takeaway phase of the male golfers. Additionally, when determining the X-factor for these subjects, the authors were unable to exactly follow the method described by McTeigue et al due to the limitations of the equipment.

Clinical Implications

The results from this study, combined with those previously done on the trunk, should provide the information needed to create a golf-specific treatment program for low back injuries of both males and females. Literature pertaining to a low back exercise program designed for the golfer is currently
available. Jenkins et al\textsuperscript{17} suggests trunk stabilization programs, lumbar extension exercises, and general strengthening of the trunk musculature. Flexibility exercises are also recommended.\textsuperscript{5-7,16-18,25} For prevention of injury, many publications stress the importance of a good warm-up prior to play.\textsuperscript{5-7,16,18} Education to improve golf swing mechanics is also thought to be a primary mechanism for preventing re-injury in the golf population.\textsuperscript{7} Pink et al\textsuperscript{18} suggest a golf-specific exercise program which consists of warming up, stretching, strengthening, and cardiovascular conditioning.

Mallon\textsuperscript{25} notes that the most important aspect of training for a particular sport is based on the specificity principle. Creating a training program which consists of exercises that mimic the movements of a golf swing is an example of this principle. He believes this kind of program could potentially decrease the chance of overuse injuries in golf.\textsuperscript{25} A study looking at the usefulness of partial swings in the rehabilitation of the golfer has found it to be of some benefit.\textsuperscript{26} This is an example of an exercise following the specificity principle.

Fleisig\textsuperscript{16} states that exercises should focus on the muscles most active during the golf swing, ideally through the ROM where they are most active. For example, plyometric activities could provide strength and power during the takeaway and forward swing phases of male golfers and during the forward swing and acceleration phases in women. This would correlate with the greatest amount of trunk muscle activity in men and women during the swing. Exercises might include medicine ball tossing, weighted golf club swings, rapid high repetition golf swings, and many others. Strengthening of the abdominal
obliques, erector spinae, and gluteus maximus is necessary for dynamic trunk stabilization and power production during the golf swing.

Conclusion

The comparisons made between the male and female golfers from this study have provided some insight as to why back injuries are more prevalent in men. Males had larger X-factors, faster swing times, and more muscle activity at the point of greatest trunk motion. This produced a greater strain on the structures of the low back. If women do indeed have greater trunk flexibility than men, they would be less likely to reach extreme trunk ROM based on our X-factor results. Therefore, less force would be placed on the structures of the spine. These findings promote the idea that men are more predisposed to low back injuries while playing golf than women. To reduce this high incidence of back injuries, it would be prudent to target the male golfing population with education regarding injury prevention and trunk management.

This research study has shown that there are differences between male and female golfers during the golf swing in regard to trunk EMG activity, trunk rotation, and time of swing. When compared to other studies, however, the women golfers are actually comparable to the men in most categories. This inconsistency in research findings demonstrates the need for further study of the female golfer. Analyzing a larger number of women to provide significant statistical information in this area will allow for a better comparison of genders. Knowledge of male and female differences during the golf swing would be beneficial for further individualizing the rehabilitation of the golfer.
Research is also needed in the area of rehabilitation of the injured golfer (both male and female). Recent literature has produced a number of ideas for treatment of the golfer. However, according to McCarroll, current treatments given to injured golfers have varied greatly and lack consistency. Providing statistics to back up the efficacy of a golf-specific treatment program through research methods would enhance the validity and reliability of the exercises used for golf rehabilitation. Thus, it would reduce the inconsistency of golf-specific treatment methods and improve the quality of treatment provided for both male and female golfers.
According to a recent survey, 26.5 million golfers played at least one round in 1997, which is a seven percent increase from 1996. As the popularity of golf increases in the United States, so does the rate of golf-related injuries. Low back injury is the most common affliction of male golfers; it is the second most common injury among female golfers. For this reason, research analyzing the motion and the muscles involved in the golf swing is essential. However, in reviewing the literature analyzing the golf swing, it is found that relatively few studies of this subject have been completed. The purpose of this study is to determine specific trunk musculature activity and to analyze trunk and pelvis range of motion during the different phases of the golf swing.

The results will attempt to provide information on establishing training programs targeting the trunk with the purpose of reducing golf-related injuries to this area. This information will be beneficial to physical therapists working with professional, amateur, and recreational golfers, both in training and in rehabilitation of low back injuries. Normal, trained, healthy subjects will be used in this research. Human subjects are needed for this research study in order to determine which muscles are active and when they are active while performing the golf swing.
2. PROTOCOL: (Describe procedures to which humans will be subjected. Use additional pages if necessary.)

Subjects
The sample will consist of 10 female and 10 male University of North Dakota golf team members voluntarily recruited for this study. Subjects must be healthy and without existing trunk pathology. Subjects' age will be 18 or older. We will not accept subjects who are pregnant. All participants will sign the appropriate human subject consent forms.

Procedure
The study will be conducted at Red River Valley Sports Medicine Institute in Fargo, ND. Upon entering the facility, subjects will be given verbal instructions on purpose and procedure of the experiment and then will be asked to sign a consent form. EMG electrodes will be placed over the erector spinae, rectus abdominus, external obliques, internal obliques, gluteus maximus, and latissimus dorsi muscles bilaterally. Surface electrodes will be placed over motor points of the above muscles. If necessary, the skin may have to be shaved and cleansed with alcohol before attachment of the EMG electrodes to ensure adequate conduction. The EMG signals will be transmitted to a receiver unit and then fed into a computer for display and recording of data. Maximum voluntary contractions of the aforementioned muscles will be measured using manual muscle testing techniques administered by the testers. The muscle activity recorded during the maximal voluntary contraction will be considered as 100 percent activity level. This procedure is done to normalize the EMG data for later analysis.

Video analysis will be used to measure trunk range of motion during the activity. Reflective markers will be attached to the trunk and shoulders using double-sided tape. Video cameras will be placed around the subject and will film the subject's trunk movements during the golf swing. This will be recorded on videotapes and will be transferred to a computer for analysis.

Subjects will be allowed to warm up and to take practice swings with electrodes in place to ensure that the swing will not be impeded. Each subject will take five swings with a driver, hitting golf balls into a net. EMG and motion analysis data will be recorded of each swing. Subjects will be asked to take their normal golf swing with a driver. Club head speed will be measured at impact with a separate piece of equipment provided by Red River Valley Sports Medicine Institute and correlated with EMG and motion analysis data.

Data collection will consist of measurements of muscle activity and trunk range of motion focusing on the rotational component of the trunk and pelvis. Statistical analysis of the mean activity of each monitored muscle will be performed. The EMG data collected during the experimental trials will be expressed as a percentage of the EMG activity recorded during the maximal voluntary contraction prior to the experimental trials. The video image will be converted to a stickman-like figure, from which we can determine trunk and pelvis range of motion and rotational velocity. The EMG data will be synchronized with the video data to determine the level of EMG activity during the various stages of the golf swing.
3. **BENEFITS:** (Describe the benefits to the individual or society.)

The possible benefits of this study will include obtaining information on the golf swing that may lead to the development of training programs to prevent golf-related trunk injuries. By identifying specific trunk muscles active during the golf swing, a training program may be developed to specifically train these muscles so they are strengthened at the appropriate stages of the swing. By establishing normative data on muscle activity and trunk and pelvis motion during the various stage of the golf swing, we will provide information that could be used in future golf studies.

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.)

Physical risks to the subjects in this study are minimal. EMG and motion analysis equipment poses no risk of injury to the subjects. The possibility of muscle strains exists, but this risk should be minimal due to the condition of the athletes involved in the study and the warm-up period allowed. Light-weight plastic golf balls will be used to further reduce the risks of injury.

Data will be collected in a confidential manner and the collected data will be kept confidential. Names will not be used for any reason in this study and subjects will be assigned code numbers to ensure strict confidentiality. Participation in this study is voluntary and subjects are free to withdraw at any time and for any reason without fear of retribution. Data will be kept for a minimum of three years in the UND physical therapy department.
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.

The signed consent forms will be kept by David Relling in the University of North Dakota Physical Therapy Department for a period of three (3) years. A copy of the consent form is attached.

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)
RELEASE STATEMENT

I hereby give my permission to the University of North Dakota, its agents, successors, assigns, clients and purchasers of its services and/or products, to use my photograph (whether still, motion or television)

Name:
Signed: ____________________________________________
Date: ____________________________________________
Address: __________________________________________
City: ______________________________________________
State and Zipcode: __________________________________
The above referenced project was reviewed by a designated member for the University's Institutional Review Board on April 17, 1998 and the following action was taken:

- Project approved. EXPEDITED REVIEW No.
- Next scheduled review is on April 1999

- Project approved. EXEMPT CATEGORY No. No periodic review scheduled unless so stated in the Remarks Section.

- Project approved PENDING receipt of corrections/additions. These corrections/additions should be submitted to ORPD for review and approval. This study may NOT be started UNTIL final IRB approval has been received. (See Remarks Section for further information.)

- Project approval deferred. This study may not be started until final IRB approval has been received. (See Remarks Section for further information.)

- Project denied. (See Remarks Section for further information.)

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

PLEASE NOTE: Requested revisions for student proposals MUST include adviser's signature.
April 14, 1998

Mr. Dave Relling, M.S. PT
UND School of Medicine
Department of Physical Therapy
501 N. Columbia Road
P.O. Box 9037
Grand Forks, ND 58202-9037

Dear Mr. Relling,

I have had the opportunity to review the research proposal "Electromyographic and Motion Analysis of the Trunk and Pelvis During the Golf Swing". As the Medical Director of the Red River Valley Sports Medicine Institute, I approve and fully support this research endeavor. We look forward to working together with you.

Sincerely,

Mark A. Lundeen, MD
Medical Director RRVSMI
APPENDIX B
Figure 5. Integrated, "Ensemble" averaged EMG activity of male golfers during a full swing cycle.
Figure 6. Integrated, "Ensemble" averaged EMG activity of female golfers during a full swing cycle.
APPENDIX C
Figure 7. EMG activity during takeaway in male golfers
Figure 8. EMG activity during takeaway in female golfers
Figure 9. EMG activity during forward swing in male golfers
Figure 10. EMG activity during forward swing in female golfers
Figure 11. EMG activity during acceleration in male golfers
Figure 12. EMG activity during acceleration in female golfers
Figure 13. EMG activity during early follow-through in male golfers
Figure 14. EMG activity during early follow-through in female golfers
Figure 15. EMG activity during late follow-through in male golfers
Figure 16. EMG activity during late follow-through in female golfers
REFERENCES


