2007

The Effect of Hamstring Contractions in the Activation of the Abdominal Muscles during a Standard Abdominal Crunch

Deborah Sue Larson
University of North Dakota

Barry Pederson
University of North Dakota

Adam Suedel
University of North Dakota

Wayne Voth
University of North Dakota

THE EFFECT OF HAMSTRING CONTRACTIONS IN THE ACTIVATION OF THE ABDOMINAL MUSCLES DURING A STANDARD ABDOMINAL CRUNCH

Deborah Sue Larson

Barry Pederson

Adam Suedel

Wayne Voth

Doctor of Physical Therapy

University of North Dakota, 2007

A Scholarly Project

Submitted to 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

Doctor of Physical Therapy

Grand Forks, North Dakota

May 2007

This Scholarly Project, submitted by Deborah Sue Larson, Barry Pederson, Adam Suedel, and Wayne Voth in partial fulfillment of the requirements of 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 whom the work has been done and is hereby approved.

Shawn Decker
(Graduate School Advisor)

Thomas Mon
(Chairperson, Physical Therapy)

PERMISSION

Title The Effect of Hamstring Contractions in the Activation of the Abdominal Muscles during a Standard Abdominal Crunch

Department Physical Therapy

Degree Doctor of Physical Therapy

In presenting this Scholarly Project in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, we agree that the Department of Physical Therapy shall make it freely available for inspection. We further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised our work or, in his/her absence, by the Chairperson of the department. It is that any copying or publication or other use of this independent study or part thereof for financial gain shall not be allowed without our written permission. It is also understood that due recognition shall be given to us and the University of North Dakota in any scholarly use which may be made of any material in this Scholarly Project.

Signature Deborah Sue Larson

Signature

Signature Adam J. Sneddel

Signature Wayne P. Voth

Date 12/13/06

TABLE OF CONTENTS

List of Figures.....v

List of Tables.....vi

Acknowledgements.....vii

Abstract.....viii

Chapter I. Introduction.....1

Chapter II. Literature Review.....3

Chapter III. Methodology.....7

Chapter IV. Results.....15

Chapter V. Discussion.....19

Appendix A.....23

Appendix B.....31

Appendix C.....32

Appendix D.....34

References.....35

LIST OF FIGURES

Figure Page

1. Electrode Placements for Abdominal Musculature.....10

2. Electrode Placements for Hamstring Musculature.....11

3. Modified Abdominal Crunch Setup.....12

4. Switch placement and Use During a Crunch.....14

5. EMG Comparison Between Standard Abdominal Crunch and Modified Abdominal Crunch.....17

LIST OF TABLES

Table Page

1. Demographics of Participants 15

2. Statistical Results for Both Standard and Modified Abdominal Crunches 16

3. Post HOC Analysis of Interactions.....17

ACKNOWLEDGEMENTS

As a group we would like to thank our advisors: Dr. Schawnn Decker, Dr. Renee Mabey, Dr. Dave Relling, and Dr. Thomas Mohr for all their guidance and assistance in the completion of this project.

Individually we would each like to thank the following people:

I, Deborah Larson, would like to express my sincere gratitude to my parents, Ron and Mary Larson, and to the rest of my family and friends who have supported me through this busy, stressful, and wonderful part of my life ~ Thank you.

I, Barry Pederson, would like to thank the Lord Jesus Christ for all He has blessed me with, and all He has carried me through in my life. I would like to thank my wife, Becky, for her support, love, and patience with me throughout PT school. I would also like to thank my parents, Jim and Sue Pederson for their never-ending support and encouragement.

I, Adam Suedel, would like to thank my wife, Stephanie for her loving support, gentle motivation, and positive encouragement at just the right times. I would also like to thank my son, Daniel for providing me with the inspiration to persevere through the challenging times.

I, Wayne Voth, would like to thank my wife, Stacie, and family for encouraging me throughout the years. I would like to thank my savior Jesus Christ for the eternal assurance and tranquility He has brought in my life. It has been a wonderful beginning to a life long journey.

ABSTRACT

Purpose:

The purpose of this study was to determine the effect of a hamstring contraction on the abdominal musculature during a standard crunch. Studies in the past have looked at abdominal and core strengthening, exercise equipment, and exercise techniques and their effect on abdominal electromyography (EMG). Few published studies have looked at the effect on the abdominals during a modified crunch, which is a hamstring contraction during a standard crunch.

Methods:

Participants (n=30) for this study were between the ages of 18 and 60 with no history of acute or chronic back pain or major abdominal surgery. EMG was used to record the activity of four muscle groups including the: upper rectus abdominus (URA), lower rectus abdominus (LRA), external obliques (EO), and the biceps femoris during a standard crunch and also during a modified crunch. Data analysis compared EMG output to each participant's individual maximal voluntary contraction (MVC) for each muscle group analyzed.

Results:

There was a significant ($p<0.05$) increase in the average mean difference in the LRA of + 26.89% and EO of +46.3% in EMG activity during the modified crunch. URA displayed an increase of +2.25%; however, it was not found to be statistically significant.

Discussion:

In this study there was an increase in abdominal EMG output for the modified crunch; however, other factors that need to be considered include: the effects of gender, age, previous abdominal training, influence of pathologies, and other musculature involvement.

Chapter I

Introduction

Core and abdominal strengthening have become frequently researched topics in the physical therapy profession. The standard abdominal crunch is often used as an intervention for patients with low back pain (LBP). Abdominal crunches are relatively effective in abdominal strengthening and can be performed in any setting. Research has often compared the standard abdominal crunch to other exercise techniques and exercise equipment. Some types of exercise equipment have utilized a hamstring contraction during the abdominal crunch to make the exercise more efficient. [1]

Problem Statement:

While there is some research on the effect of a hamstring contraction for abdominal muscle strengthening, there are limited sources and these sources may involve research companies that may have a financial interest in the results.

Purpose:

The purpose of this study was to determine the effect on the abdominal musculature during a modified abdominal crunch, which is a hamstring contraction during a standard abdominal crunch.

Significance:

This study is relevant to physical therapy in that abdominal and core strengthening is often used for patient interventions for a variety of musculoskeletal impairments, especially back pain. One commonly prescribed core strengthening activity is the standard abdominal crunch due to its ease of instruction and safety for patient care. Methods to make the standard abdominal crunch more efficient would benefit abdominal strengthening programs. A modified abdominal crunch would be more feasible and cost effective as compared to other programs.

Research Question:

Does a modified abdominal crunch show increased EMG activity when compared to a standard abdominal crunch?

Null Hypothesis:

There is no significant difference in EMG activity during a modified abdominal crunch compared to the standard abdominal crunch.

Chapter II

Literature Review

Back Pain Prevalence in Society:

Back pain has many origins in the body including: discogenic, neurologic, muscular, facet joint, and sacroiliac (SI). [2] Determining specific origin of an individual's back pain has proven difficult over the years. One aspect of back pain that has not been difficult to determine is its prevalence in society. Another is once someone has experienced an acute episode of low back pain (LBP), they have an increased risk of developing chronic back pain (CBP) in their lifetime. [3]

The prevalence of someone experiencing an episode of acute LBP in their lifetime is estimated at 54% to 80% for the general population and those who experience an initial episode of acute LBP have a 60% chance of developing chronic LBP over the next five years.[4] Further more with increasing age comes increased frequency of severe back pain[5] and CBP increased from 44% to 58% in the seventh decade of life. [3]
Despite advances in medicine, increased safety measures in job settings, and an increased prevalence of automated production, the societal and economic impact of back pain continues to rise. Wasiak et al [6] found that individuals who seek recurrent care for back pain had a notably higher length of work disability and higher medical and compensation

costs than those without recurrence. With the difficulty of eliminating back pain and the cost of care associated with each back pain episode, prevention is a must.

General Core Strengthening:

Physical therapists currently use core strengthening in the prevention as well as the rehabilitation of back pain. Core strengthening is a broad term used to describe exercises that work the muscles of the trunk including: rectus abdominus, internal and external obliques, transverse abdominus, iliopsoas, longisimuss, spinalis, and quadratus lumborum.

The abdominal muscle contraction produces flexion moments causing abdominal pressurization necessary to stabilize the spine. [7] Abdominal and erector spinae musculature are in an agonist/antagonist relationship to brace the trunk. Individuals with LBP have shown decreased or absent firing of trunk musculature as compared to participants without back pain. [8] Core strengthening is theorized to be effective at preventing injury and re-injury.[9] Core exercises that facilitate trunk strengthening include: isometric stabilization, strengthening with Theraband, the standard abdominal crunch, therapeutic ball exercises, Pilates, and other mat exercises. [9] A standard abdominal crunch is a low to moderately challenging exercise that has shown significant benefits in abdominal strengthening, and showed similar EMG activation of the rectus abdominus and the external obliques as any other low to moderate intensity exercise. [10]

Unstable Surfaces:

Many exercise programs, as well as physical therapy, have used therapeutic balls to strengthen the abdominal muscles. Using a ball or another unstable surface during a

abdominal crunch is theorized to challenge the abdominals to stabilize and flex the trunk. This creates a multiplanar strengthening exercise. One study, conducted by Behm et al [11], compared the electromyography (EMG) results of eleven individuals performing six trunk exercises on stable and unstable surfaces, finding the unstable surface generated greater lower abdominal muscle activity by 27.9% during trunk exercises. [11]

In a study conducted by Vera-Garcia et al [12], eight men were tested using EMG while performing abdominal crunches on both stable and unstable surfaces. This study also found that there was greater rectus abdominus and external oblique activity while performing abdominal crunches on an unstable surface.

While there are documented benefits of exercising on an unstable surface, there are also some problems with this method of exercise. Strengthening on an unstable surface requires some training and practice before an individual can gain the maximum benefits. Individuals with current back pain, other back complications, or that are elderly may not possess the balance and coordination to safely use this type of equipment.

Modified Abdominal Crunch:

An article was published in 2005, reporting that a modified abdominal crunch consisting of a hamstring contraction while performing an abdominal crunch increased the EMG activity and work intensity of the abdominal muscles.[1] This study tested an abdominal fitness machine known as the Abvice®. The Abvice is an abdominal strengthening machine that includes a hamstring contraction during the abdominal crunch. The results of this study found that the Abvice resulted in an increased activity in the rectus abdominus and external obliques as compared to other exercise equipment.

This study was limited to 24 individuals, mostly women, and was compared to the AbRoller® and the AbRocker®. The article stated that this increase may be attributed to reciprocal inhibition. [1]

Reciprocal Inhibition and the Abdominals:

The theory of reciprocal inhibition states that when you activate a muscle to perform an action, the antagonistic muscle to that action is inhibited. This is regulated through the neural circuit pathways that are within the spinal cord. [13] When the Ia afferent nerve fiber is stimulated, it causes a contraction of the agonist muscle. At the same time, the alpha motor neuron to the antagonist muscle is activated. This is not necessarily a complete blocking of the antagonist muscle but more of a graded response. This graded response can be seen in many activities of the body, most notable in walking and running.

The muscles that aid the abdominals in trunk flexion need to be recognized in order to consider reciprocal inhibition. Some of muscles that aid in trunk flexion are iliopsoas and rectus femoris. Rectus femoris can assist due to the fact that it originates at the ASIS and inserts into the tibial tubercle. Iliopsoas can also assist in that it originates at the lumbar spine and inserts into the lesser trochanter. Applying reciprocal inhibition may eliminate the assistance from these muscles increasing the intensity of the abdominal muscle contractions. The antagonist muscles to the hip flexors are the hip extensors, also known as the hamstrings and the gluteal muscles. The hamstrings consist of biceps femoris, semitendonosis, and semimembranosis. According to the reciprocal inhibition theory, contraction of these muscles will inhibit the hip flexors and in turn increase the effort of the abdominal muscle(s).[13]

Chapter III

Methodology

This study was reviewed and approved by the University of North Dakota Institutional Review Board prior to the initiation of the study. A copy of the Human Subjects Review form appears in the Appendix A. During recruitment, which was done through word of mouth and flyers (Appendix B) to the general public, individuals were informed that their participation was strictly voluntary. The study components were explained to those wishing to be involved with the study. All participants were given and signed a written statement of informed consent (Appendix C).

Subjects:

The study population consisted of a random sampling of 30 people from the general population. There were 11 males and 19 females ranging in age from 18 to 50 (mean of 27). Inclusion or exclusion in the study was based on a short medical questionnaire (Appendix D). Participants were excluded if they had a history of abdominal surgeries, but exceptions were made for participants who had only an appendectomy. Other individuals from the population that were pregnant, or who suffered from a neurological condition preventing them from being of sound mind were excluded from this study as well. All inclusive subjects were required to attend one 45 minute long session in which all exercises and readings would be taken. All participants were tested independently at

the University of North Dakota Physical Therapy Department in Grand Forks, North Dakota.

Electromyography Testing Instrumentation:

EMG uses surface or fine wire needle electrodes to measure the electrical activity that takes place within a muscle during a contraction. Jacobs et al [3] found that surface EMG is valid for URA, LRA, and EO. In their study, surface electrodes and needle electrodes were inserted into the same muscles. There was not more than 15% root mean squared (RMS) difference between surface and needle EMG readings on any given muscle, except psoas in which there was not more than 20% RMS difference.[3] This indicates that for clinical research, surface EMG is valid in the determination of muscular activity.[3, 10] For the present study, surface electrodes were used due to the decreased cost, level of specialization, and decreased risk to patients as compared to needle EMG.

Electrode Instrumentation:

Self-adhesive, pre-gelled Ag/AgCl snap EMG surface electrodes (Model #272, Noraxon USA, Scottsdale, AZ) with an inter-electrode distance of 2.0 cm were used for this study. The EMG activity was transmitted from the telemetry transmitter to a TeleMyo 900 (Noraxon USA, Scottsdale, AZ) receiver, which was interfaced with an analog to digital interface card (Noraxon USA), and viewed on a standard laptop computer monitor prior to saving to the hard-drive (HP Pavilion ZV5000, Pentium 4 2.80 GHz processor).

Electrode Placement:

Prior to participant involvement in the study, EMG equipment was setup and tested for proper signal transmission and reception. Placement validity of the surface electrodes was determined in which the electrodes were placed on six muscles: rectus abdominus, internal oblique, external oblique, multifidus, latissimus dorsi, and iliocostalis lumborum bilaterally. [14] Internal oblique and multifidus were not used in our study to the difficulty of monitoring them with surface electrodes.

Participants' body hair was clipped if necessary and skin was prepped with rubbing alcohol. Nine electrodes were placed unilaterally according to placement charts (Appendix B): two placed over the LRA, two over the URA, two over the EO (Figure 1), two over the biceps femoris (BF), and one ground electrode over the ipsalateral fibular head (Figure 2). To ensure standardization and accuracy, the same investigator applied electrodes to all participants.

Exercises:

Exercises performed were a standard abdominal crunch and a modified abdominal crunch performed on the floor with heels hooked on a stable two inch cross bar (Figure 3). The order of the exercises performed was determined by the order in which participants volunteered for the study. Even-numbered participants began with the standard abdominal crunch while odd-numbered participants began with the modified abdominal crunch.

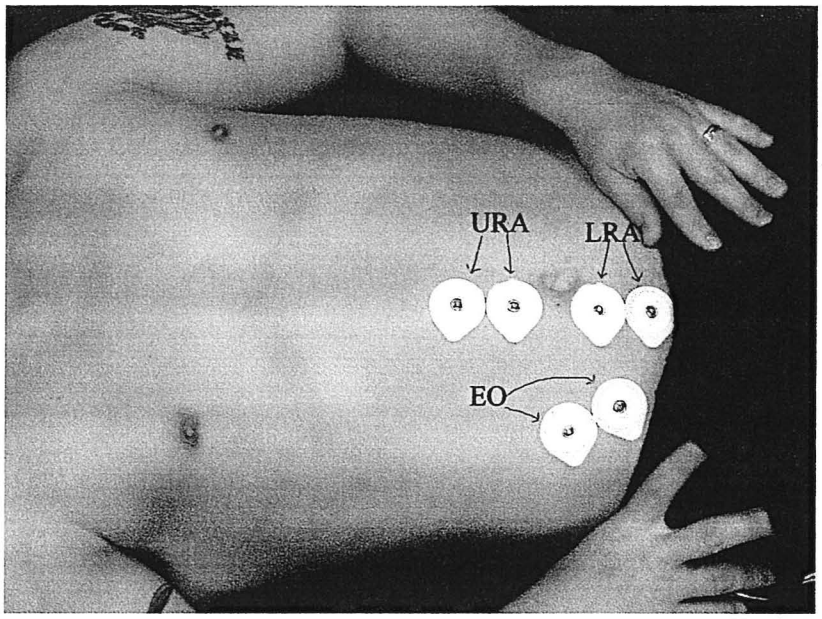

Figure 1. Electrode Placements for Abdominal Musculature. URA is 2 cm superior and 2 cm lateral to the umbilicus. LRA is 2 cm superior and 2 cm lateral to umbilicus. EO is 5 cm superior to the ASIS.

Data Collection:

Throughout the testing phase, EMG data was collected for baseline activity, MVC of abdominals, and MVC of hamstrings. This data was collected for both the standard abdominal crunch and the modified abdominal crunch.

Baseline EMG Recordings:

Baseline EMG recordings were taken with the participant lying supine on a mat, arms at side, and hips flexed to approximately 45 degrees and knees flexed to 90 degrees. EMG activity was calibrated and recorded for 10 seconds.

MVC of Abdominal Musculature:

The participant was instructed to perform an abdominal crunch. The participant was lying supine on the mat with the knees flexed to approximately 90° and hips flexed to approximately 45°. Arms were held at the participant's side. A researcher applied

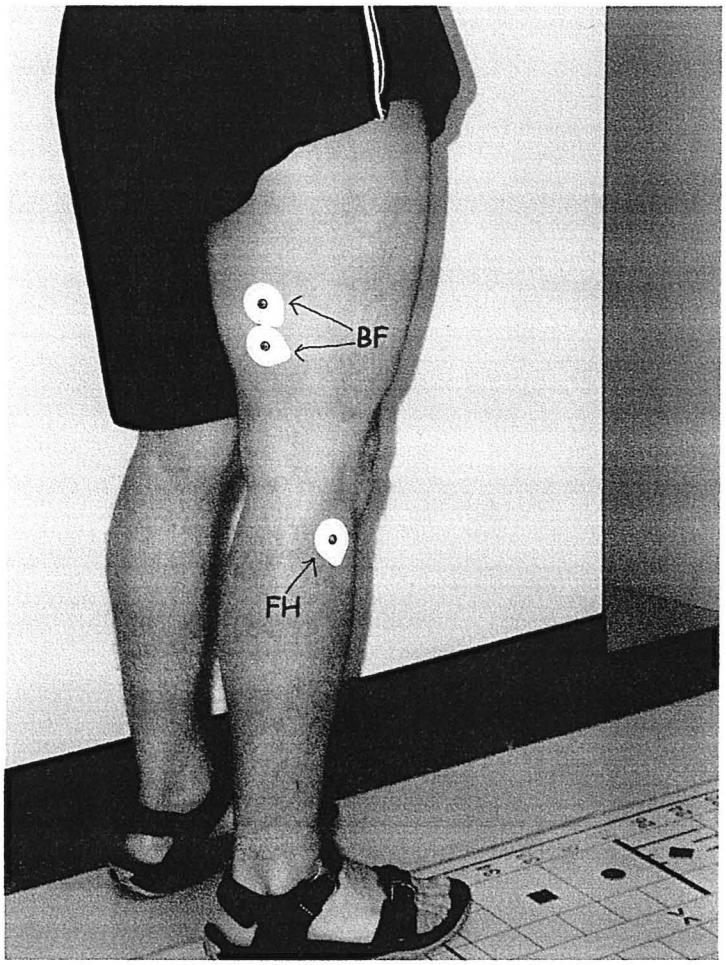

Figure 2. Electrode Placements for Hamstring Musculature. BF or the Biceps Femoris placement is at the midpoint of a line from the ischial tuberosity to the lateral femoral condyle. FH is the fibular head where the ground wire was placed.

resistance bilaterally to the shoulders of the participant. The participant was instructed to abdominal crunch until their shoulder blades were off the mat and to slide their arms along the mat towards their feet. The abdominal crunch was held for 5 seconds and EMG activity was recorded. This data was then used as a comparison for the two abdominal crunch methods.

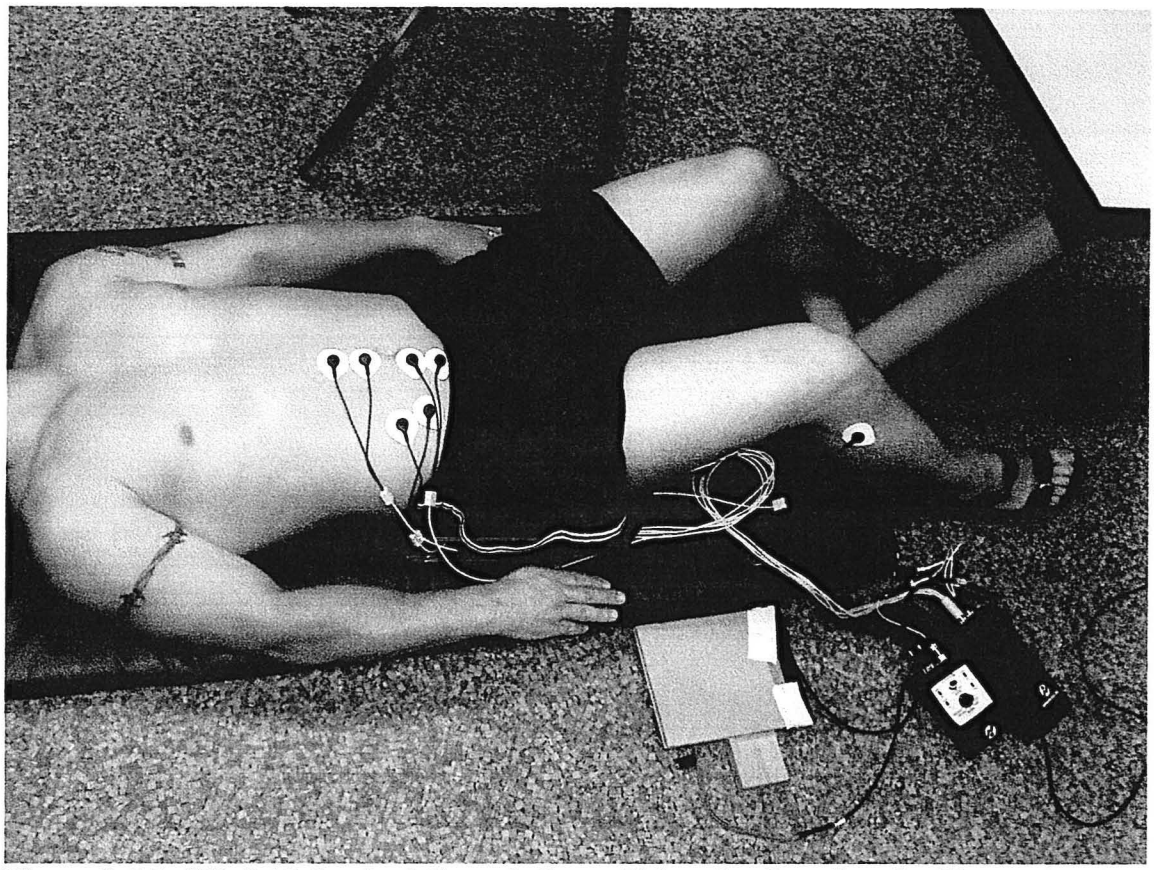

Figure 3. Modified Abdominal Crunch Setup Using the Crossbar for Hamstring Contraction.

This data was used as a comparison for the two abdominal crunch methods to determine if hamstring activity was significantly different.

Number of Abdominal Crunches to be Analyzed:

With any repetitive exercise study, there is a concern of the learning curve and fatigue affecting the results. Research has found that ten practice abdominal crunches were adequate in minimizing the effect of the learning curve prior to testing.[15] If there are too few abdominal crunches there is the risk of not having enough data, while too many abdominal crunches may lead to fatigue and poor results. In order to minimize the effect of the learning curve, the participants were randomized so odd-numbered

participants began with the standard abdominal crunch and even-numbered participants began with the modified abdominal crunch. The participants started with one to three practice abdominal crunches until the participant stated that they were comfortable with the exercise. Then, seven standard and seven modified abdominal crunches were performed with approximately a two to three minute rest in-between. Seven abdominal crunches were determined sufficient to reduce the learning curve and to minimize fatigue for this study.

Standard or Modified Abdominal Crunch:

Participants performed seven repetitions of a standard or modified abdominal crunch to a metronome beat of 40 beats per minute; the seventh repetition was held for five seconds. A switch was placed three inches in front of the participant's resting hand position (Figure 4). The participant performed each abdominal crunch and held down the switch during the metronome beat and then relaxed on the down beat. The switch placed the markers on the EMG output for the duration of the abdominal contraction. With the modified abdominal crunch, verbal cues were also included. The participants were instructed to "pull with their heels" to incorporate a hamstring contraction.

Data Analysis:

In order to obtain sufficient power for the statistical analysis, 30 participants were recruited for participation in the study (n=30). The independent variable for the study was the contraction of the hamstrings during the modified abdominal crunch. The dependent variable was the EMG measurements of the URA,

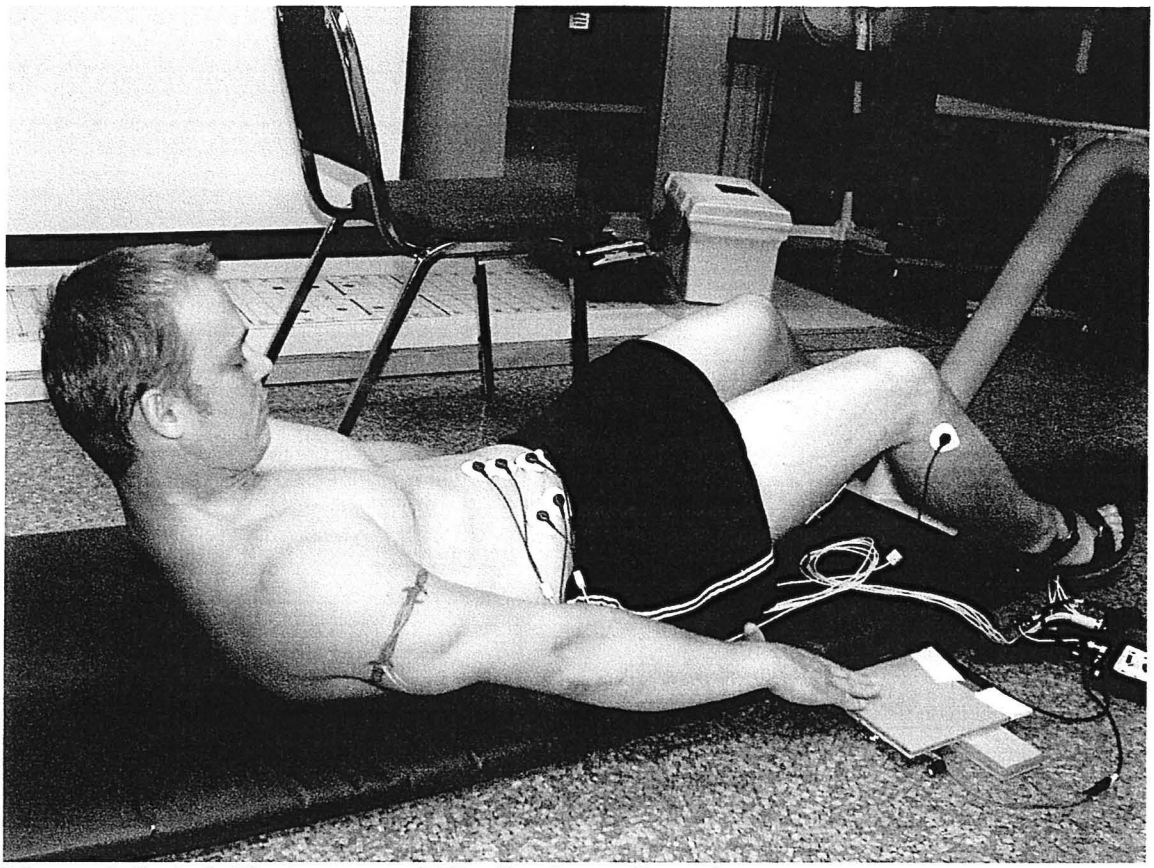

Figure 4. Switch Placement and Use During a Crunch.

LRA, and EO during the abdominal crunches. We used the MVC EMG data as a standardized comparison for the standard and modified abdominal crunch EMG data. A minimum of five consistent abdominal EMG readings for each participant were calculated to determine the mean EMG output for each participant's standard and modified abdominal crunch. These then were analyzed as a percentage of the participants' MVC EMG, and thus allowed the researchers to make final comparisons. All of the EMG data was processed using the program MyoResearch XP Master Package, version 1.03.15 (Noraxon). Statistical analysis was then performed using SPSS software version 11.

Chapter IV

Results

There were 30 participants in the study, with 28 of them included. It was decided to exclude the participants with the highest and lowest average mean difference between the standard and modified abdominal crunch in an effort to eliminate potential outliers in the final results. The demographics for the participants that were involved in our study are displayed in Table 1. Data was analyzed using a 2-way Analysis of Variance (ANOVA). When analyzing the muscles separately, there was no significant difference found in the URA , but there was a significant increase in EMG activity found in the LRA and the EO (Table 2). Post HOC analysis is shown in Table 3 and showed an interaction between the HS condition and the muscle groups.

Table 1. Demographics of Participants

	Age Ranges			
Gender	**18-28**	**29-38**	**39-48**	**49-58**
Female	**7**	**1**	**1**	**1**
Male	**17**	**0**	**1**	**1**

Upper Rectus Abdominus (URA):

The URA did not show a significant difference between the standard abdominal crunch and the modified abdominal crunch ($p<0.509$) The mean URA percentage of the

Table 2. Statistical Results for Both Standard and Modified Abdominal Crunches

	Count	Mean	Min	Max	Std Dev
URA Standard Abdominal Crunch	**28**	**89.24**	**44.50**	**137.3**	**23.07**
URA Modified Abdominal Crunch	**28**	**91.49**	**53.60**	**158.0**	**26.53**
LRA Standard Abdominal Crunch	**28**	**75.78**	**33.70**	**115.50**	**24.07**
LRA Modified Abdominal Crunch	**28**	**102.67**	**32.40**	**187.30**	**36.08**
External Oblique Standard Abdominal Crunch	**28**	**71.17**	**20.80**	**153.20**	**29.63**
External Oblique Modified Abdominal Crunch	**28**	**117.47**	**38.50**	**236.80**	**42.04**

MVC for the standard abdominal crunch was 89.24 (range was 44.50 to 137.30). This was compared to the mean URA percentage of the MVC for the modified abdominal crunch which was 91.49 (range was 53.6 to 158.0).

Table 3. Post HOC Analysis on Interactions

	F	Sig (p)	eta^2	Power
Interaction of Muscles and HS condition	**(2,54)**	**p<0.001**	**0.522**	**1.00**
Factor of Muscles (3 levels)	**(2,54)**	**p<0.693**	**0.013**	**0.106**
Factor of Hamstring Condition (2 levels)	**(1,27)**	**p<0.001**	**0.622**	**1.00**

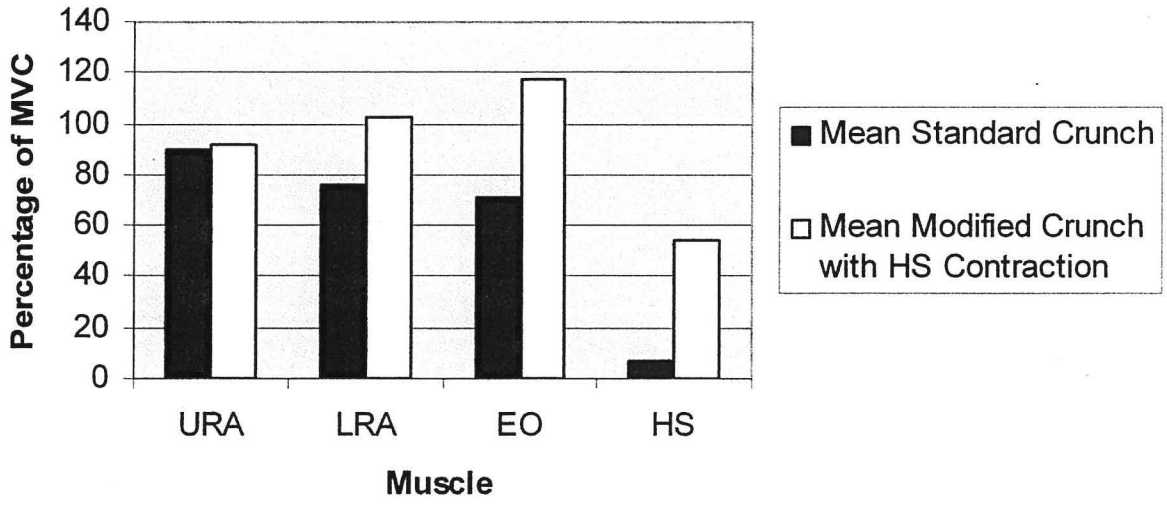

Figure 5. EMG Comparison Between Standard Abdominal Crunch and Modified Abdominal Crunch. Upper Rectus Abdominus (URA), Lower Rectus Abdominus (LRA), External Oblique (EO), Hamstrings (HS)

Lower Rectus Abdominus (LRA):

The LRA showed significantly greater activity during the modified abdominal crunch ($p<0.001$). The mean LRA percentage of the MVC for the standard abdominal crunch was 75.78 (range was 33.70 to 115.50). This was compared to mean LRA

percentage of the MVC for the modified abdominal crunch which was 102.70 (range was 32.40 to 187.30).

External Oblique (EO):

The EO showed significantly greater activity during the modified abdominal crunch ($p<0.001$). The mean EO percentage of the MVC for the standard abdominal crunch was 71.17 (range was 20.80 to 153.20). The mean EO percentage of the MVC for the modified abdominal crunch was 117.47 (range was 38.50 to 236.80).

Hamstrings (HS):

The hamstrings were more active during the modified abdominal crunch which was expected because of the hamstring contraction. The mean hamstring percentage of the MVC for the standard abdominal crunch was 7.35 (range was .90 to 52.30). This is compared to the mean hamstring percentage of the MVC for the modified abdominal crunch, which was 53.98 (range 12.10 to 110.20).

Chapter V

Discussion

A significant increase was found in LRA and EO EMG activity with a modified abdominal crunch as compared to the standard abdominal crunch. There was a non-statistical increase in URA.

Reciprocal inhibition may or may not be the only mechanism for the significant changes in abdominal EMG activity. The origin of rectus femoris is on the lateral aspect of the pelvis (the anterior superior iliac spine), and can be used to aid the abdominals in trunk flexion. It can be theorized that because the anatomical location of EO lies lateral to URA and LRA, increased EO muscle force will be required due to inhibition of rectus femoris and iliopsoas.[13]

For the modified abdominal crunch, participants were not supported at the anterior distal legs or dorsum of the feet. Studies have shown that exercises in which the legs are supported cause increased activity of the hip flexor muscles, namely the rectus femoris.[16, 17] For instance, a abdominal crunch performed on a decline bench requires activation of the rectus femoris muscles to extend the legs in order to stabilize the body. This activation of the rectus femoris may aid in trunk flexion, which would in turn reduce the workload of the abdominal muscles needed to flex the trunk. Iliopsoas, the other main hip flexor, also imparts a major compressive and anterior sheer force on the lumbar

spine.[18, 19] This may be undesirable for a patient with LBP or other spine pathology. For these reasons, activation of hip flexor muscles are undesirable when training abdominal musculature.[20]

Limitations:

We did not look into differences with gender, age, different levels of abdominal training, or participants with co-morbidities. More than half (n=19/30) of the participants were female, and the majority of participants were young, able-bodied college students with no co-morbidities. Also we are unaware if participants performed regular abdominal strength training.

Positioning may be difficult for certain populations. The position should be considered before using the modified abdominal crunch for an intervention. It may not be indicated for certain populations of patients with LBP due to pain or flexion contraindications for pathologies such as a herniated nucleus pulposus.

There were limitations in reproducibility due to the procedure of the experiment. During the study, the hip and knee angles were not objectively measured, but were visually approximated to 90° knee flexion and 45° hip flexion.

Verbal cues were given to the participants during the modified abdominal crunch because of a tendency to relax the hamstrings. Although ten practice repetitions are adequate for research purposes [12], the participants performed up to three practice abdominal crunches or until they stated that they were comfortable with the exercise. Performing ten practice abdominal crunches, may have eliminated the need for verbal

cuing for the hamstring contraction, but had the potential to introduce fatigue. Patients were allowed to practice prior to testing and rest before the experiment to prevent fatigue.

Results of this study may not be transferable to other methods of abdominal training, such as decline benches and other abdominal crunch benches.[21] On a decline bench, for instance, a person's legs may be at 0° hip flexion and 90° knee flexion, where the abdominals would be in a lengthened position. In comparison, the modified abdominal crunch in this study was completed with participants' hips at approximately 45° of flexion and 90° of knee flexion. Future studies should address whether or not different hip and knee flexion angles with different techniques or equipment change the EMG activity levels of the abdominal muscles when combined with a hamstring contraction.

Another limitation of the study is that it did not quantify the involvement of the hip flexor musculature. By measuring involvement of the hip flexors, it can be determined whether trunk flexion is done primarily by the abdominals or by the hip flexors, or by both. Future studies should replicate the current study with the addition of electrodes, possibly fine-wire, placed on the rectus femoris muscle and iliopsoas to measure hip flexor involvement. Quantifying hip flexor muscle activity during a modified abdominal crunch will also test the theory of reciprocal inhibition, particularly whether a hamstring contraction inhibits rectus femoris activity.

Clinical Relevance:

Abdominal strengthening exercises have been found to be effective in the LBP treatment because they assist with stabilizing the spine.[7] It has been found that those

who have back pain have decreased activation of the abdominals, which causes an increased risk of injury.[8] A modified abdominal crunch can increase the activation of the abdominals for further protection and prevention of back injury.[9] While therapeutic exercise balls can challenge the abdominals, the unstable surfaces may be unsafe for certain populations.[9] For these populations, a modified abdominal crunch would assist them in achieving the maximum benefit from their exercise.

Conclusion:

With the current popularity of abdominal strengthening, this study looked into a way to make a standard abdominal crunch more effective. The study did show there was a statistically significant increase in the EMG output of the LRA and EO during the modified abdominal crunch.

A modified abdominal crunch does not require a lot of time for training, a fitness facility, or expensive home exercise equipment. Patients can use it in a home exercise program, in any environment, and it removes the increased risks of using an unstable surface for training.

APPENDIX A

University of North Dakota Human Subjects Review Form

All research with human participants conducted by faculty, staff, and students associated with the University of North Dakota, must be reviewed and approved as prescribed by the University's policies and procedures governing the use of human subjects. It is the intent of the University of North Dakota (UND), through the Institutional Review Board (IRB) and Research Development and Compliance (RD&C), to assist investigators engaged in human subject research to conduct their research along ethical guidelines reflecting professional as well as community standards. The University has an obligation to ensure that all research involving human subjects meets regulations established by the United States Code of Federal Regulations (CFR). When completing the Human Subjects Review Form, use the "IRB Checklist" for additional guidance.

Please provide the information requested below:

Principal Investigator: Schawnn Decker, Deb Larson, Barry Pederson, Adam Suedel, Wayne Voth

Telephone: (701) 777-2831 E-mail Address: sdecker@medicine.nodak.edu

Complete Mailing Address: Schawnn Decker
Dept. of Physical Therapy
UND School of Medicine and Health Sciences
PO Box 9037
Grand Forks, ND 58202-9037

School/College: University of North Dakota Department: Physical Therapy

Student Adviser (if applicable): Schawnn Decker

Telephone: (701) 777-2831 E-mail Address: sdecker@medicine.nodak.edu

Address or Box #: PO Box 9037
Grand Forks, ND 58202-9037

School/College: University of North Dakota Department: Physical Therapy

Project Title: The effect of hamstring contractions in the activation of the abdominal muscles during a standard abdominal crunch.

Proposed Project Dates: Beginning Date: May 22, 2006 Completion Date: May 14, 2007
(Including data analysis)

Funding agencies supporting this research:

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

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

If your project has been or will be submitted to other IRBs, list those Boards below, along with the status of each proposal.

_____ Date submitted: _____ Status: ___ Approved ___ Pending

_____ Date submitted: _____ Status: ___ Approved ___ Pending

Type of Project: Check "Yes" or "No" for each of the following.

_X_ YES or ___ NO New Project

___ YES or _X_ NO Dissertation/Thesis

___ YES or _X_ NO Continuation/Renewal

_X_ YES or ___ NO Student Research Project

___ YES or _X_ NO Is this a Protocol Change for previously approved project? If yes, submit a signed copy of this form with the changes bolded or highlighted.

___ YES or _X_ NO Does your project involve medical record information? If yes, complete the HIPAA Compliance Application and submit it with this form.

___ YES or _X_ NO Does your project include Genetic Research? If yes, refer to Chapter 3 of the Researcher Handbook for additional guidelines regarding your topic.

___ YES or _X_ NO Does your project include Internet Research? If yes, refer to Chapter 3 of the Researcher Handbook for additional guidelines regarding your topic.

___ YES or _X_ NO Will subjects or data be provided by Altru Health Systems? If yes, submit two copies of the proposal. A copy of the proposal will be provided to Altru.

___ YES or _X_ NO Will research subjects be recruited at another organization (e.g., hospitals, schools, YMCA) or will assistance with the data collection be obtained from another organization?

If yes, list all institutions: _____

Letters from each organization must accompany this proposal. Each letter must illustrate that the organization understands their involvement in that study, and agrees to participate in the study. Letters must include the name and title of the individual signing the letter and, if possible, should be printed on letterhead.

Subject Classification: This study will involve subjects who are in the following special populations: Check all that apply.

_____ Minors (< 18 years)
_____ Prisoners
_____ Persons with impaired ability to understand their involvement and/or consequences of participation in this research
_X_ Other Voluntary participants age 18-60 from the local community
_X_ UND Students
_____ Pregnant Women/Fetuses

For information about protections for each of the special populations, refer to Chapter 5 of the Researcher Handbook.

This study will involve: Check all that apply.

_____ Deception
_____ Radiation
_____ New Drugs (IND)
_____ Non-approved Use of Drug(s)
_____ Recombinant DNA
_X_ None of the above will be involved in this study
_____ Stem Cells
_____ Discarded Tissue
_____ Fetal Tissue
_____ Human Blood or Fluids
Other _____

I. Project Overview

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

II. Protocol Description

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

1. Subject Selection.

a) Describe recruitment procedures (i.e., how subjects will be recruited, who will recruit them, where and when they will be recruited and for how long) and include copies of any advertisements, fliers, etc., that will be used to recruit subjects. If incentive payments will be made to anyone for enrolling participants, describe the incentive package.

b) Describe your subject selection procedures and criteria, paying special attention to the rationale for including subjects from any of the categories listed in the "Subject Classification" section above.

c) Describe your exclusionary criteria and provide a rationale for excluding subject categories.

d) Describe the estimated number of subjects that will participate and the rationale for using that number of subjects.

e) Specify the potential for valid results. If you have used a power analysis to determine the number of subjects, describe your method.

2. Description of Methodology.

a) Describe the procedures used to obtain informed consent.

b) Describe where the research will be conducted. Document the resources and facilities to be used to carry out the proposed research. Please note staffing, funding, and space available to conduct this research.

c) Indicate who will carry out the research procedures.

d) Briefly describe the procedures and techniques to be used and the amount of time that is required by the subjects to complete them.

e) Describe audio/visual procedures and proper disposal of tapes.

f) Describe the qualifications of the individuals conducting all procedures used in the study.

g) Describe compensation procedures (payment or class credit for the subjects, etc.).

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

3. Risk Identification.

a) Clearly describe the anticipated risks to the subject/others including any physical, emotional, and financial risks that might result from this study.

b) Indicate whether there will be a way to link subject responses and/or data sheets to consent forms, and if so, what the justification is for having that link.

4. Subject Protection.

a) Describe precautions you will take to minimize potential risks to the subjects (e.g., sterile conditions, informing subjects that some individuals may have strong emotional reactions to the procedures, debriefing, etc.).

b) Describe procedures you will implement to protect confidentiality (such as coding subject data, removing identifying information, reporting data in aggregate form, etc.).

c) Indicate that the subject will be provided with a copy of the consent form and how this will be done.

d) Describe the protocol regarding record retention. Please indicate that research data from this study and consent forms will both be retained in separate locked locations for a minimum of three years following the completion of the study.

Describe: 1) the storage location of the research data (separate from consent forms and subject personal data)
2) who will have access to the data
3) how the data will be destroyed
4) the storage location of consent forms and personal data (separate from research data)
5) how the consent forms will be destroyed

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

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

III. Benefits of the Study

Clearly describe the benefits to the subject and to society resulting from this study (such as learning experiences, services received, etc.). **Please note:** extra credit and/or payment are not benefits and should be listed in the Protocol Description section under Methodology.

IV. Consent Form

A copy of the consent form must be attached to this proposal. If no consent form is to be used, document the procedures to be used to protect human subjects, and complete the Application for Waiver or Alteration of Informed Consent Requirements. Refer to the RD&C website for further information regarding consent form regulations. **Please note:** Regulations require that all consent forms, and all pages of the consent forms, be kept for a minimum of 3 years after the completion of the study, even if the subject does not continue participation. The consent form must be written in language that can easily be read by the subject population and any use of jargon or technical language should be avoided. **The consent form should be written at no higher than an 8th grade reading level**, and it is recommended that it be written in the third person (please see the examples on the RD&C website). A two inch by two inch blank space must be left on the bottom of each page of the consent form for the IRB approval stamp. The consent form must include the following elements:

a) An introduction of the principal investigator

b) An explanation of the purposes of the research

c) The expected duration of subject participation

d) A brief summary of the project procedures

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

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

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

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

i) A description of how confidentiality of subjects and data will be maintained. Indicate that the data and consent forms will be stored in separate locked cabinets for at least three years following the completion of the study. Indicate where, in general, the data and consent documents will be stored and who will have access. The following statement must be included in all consent forms and informational letters: "Only the researcher, the adviser, [if applicable] and people who audit IRB procedures will have access to the data." Please make appropriate additions to the persons that may have access to your research data. Indicate how the data will be disposed of. Be sure to list any mandatory reporting requirements that may require breaking confidentiality.

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

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

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

m) Regarding participation in the study:

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

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

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

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

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

6) A statement indicating that the subject will receive a copy of the consent form.

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

Signatures:

(Principal Investigator) Date:

(Student Adviser) Date:

Requirements for submitting proposals:
Additional information can be found on the IRB web site at **www.und.nodak.edu/dept/orpd/regucomm/IRB/index.html.**

Original Proposals and all attachments should be submitted to Research Development and Compliance, P.O. Box 7134, Grand Forks, ND 58202-7134, or brought to Room 105, Twamley Hall.

Prior to receiving IRB approval, researchers must complete the required IRB human subjects' education. Please go to http://www.und.nodak.edu/dept/orpd/regucomm/IRB/IRBEducation.htm for more information.

The criteria for determining what category your proposal will be reviewed under is listed on page 3 of the IRB Checklist. Your reviewer will assign a review category to your proposal. Should your protocol require full Board review, you will need to provide additional copies. Further information can be found on the RD&C website regarding required copies and IRB review categories, or you may call the RD&C office at 701 777-4279.

In cases where the proposed work is part of a proposal to a potential funding source, one copy of the completed proposal to the funding agency (agreement/contract if there is no proposal) must be attached to the completed Human Subjects Review Form if the proposal is non-clinical; 7 copies if the proposal is clinical-medical. If the proposed work is being conducted for a pharmaceutical company, 7 copies of the company's protocol must be provided.

Please Note: Student Researchers must complete the "Student Consent to Release of Educational Record".

Revised 5/20/05

STUDENT RESEARCHERS: As of June 4, 1997 (based on the recommendation of UND Legal Counsel) the University of North Dakota IRB is unable to approve your project unless the following "Student Consent to Release of Educational Record" is signed and included with your "Human Subjects Review Form."

STUDENT CONSENT TO RELEASE OF EDUCATIONAL RECORD[1]

Pursuant to the Family Educational Rights and Privacy Act of 1974, I hereby consent to the Institutional Review Board's access to those portions of my educational record which involve research that I wish to conduct under the Board's auspices. I understand that the Board may need to review my study data based on a question from a participant or under a random audit.

The study to which this release pertains is

_____

_____

I understand that such information concerning my educational record will not be released except on the condition that the Institutional Review Board will not permit any other party to have access to such information without my written consent. I also understand that this policy will be explained to those persons requesting any educational information and that this release will be kept with the study documentation.

xxxxxx _____ _____

NAID # Printed Name

xxxxx _____ _____

Date Signature of Student Researcher

[1]Consent required by 20 U.S.C. 1232g.

INVESTIGATOR LETTER OF ASSURANCE OF COMPLIANCE WITH ALL APPLICABLE FEDERAL REGULATIONS FOR THE PROTECTION OF THE RIGHTS OF HUMAN SUBJECTS

I _____
(Name of Investigator)

agree that, in conducting research under the approval of the University of North Dakota Institutional Review Board, I will fully comply and assume responsibility for the enforcement of compliance with all applicable federal regulations and University policies for the protection of the rights of human subjects engaged in research. Specific regulations include the Federal Common Rule for Protection of the Rights of Human Subjects 45 CFR 46. I will also assure compliance to the ethical principles set forth in the National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research document, The Belmont Report.

I understand the University's policies concerning research involving human subjects and agree to the following:

1. Should I wish to make changes in the approved protocol for this project, I will submit them for review PRIOR to initiating the changes.

2. If any problems involving human subjects occur, I will immediately notify the Chair of the IRB, or the IRB Coordinator.

3. I will cooperate with the UND IRB by submitting Research Project Review and Progress Reports in a timely manner.

I understand the failure to do so may result in the suspension or termination of proposed research and possible reporting to federal agencies.

_____ _____
Investigator Signature Date

REPORT OF ACTION: EXEMPT/EXPEDITED REVIEW

University of North Dakota Institutional Review Board

Date: 7/19/2006 **Project Number:** IRB-200607-024

Principal Investigator: Decker, Schawnn; Larson, Deb; Pederson, Barry; Suedel, Adam; Voth, Wayne

Department: Physical Therapy

Project Title: The Effect of Hamstring Contractions in the Activation of the Abdominal Muscles During a Standard Abdominal Crunch

The above referenced project was reviewed by a designated member for the University's Institutional Review Board on July 27, 2006 and the following action was taken:

☒ Project approved. **Expedited Review** Category No. 7
Next scheduled review must be before: July 26, 2007

☒ **Copies of the attached consent form with the IRB approval stamp dated July 27, 2006 must be used in obtaining consent for this study.**

☐ Project approved. **Exempt Review** Category No. _____
This approval is valid until _____ as long as approved procedures are followed. No periodic review scheduled unless so stated in the Remarks Section.

☐ **Copies of the attached consent form with the IRB approval stamp dated _____ must be used in obtaining consent for this study.**

☐ Minor modifications required. The required corrections/additions must be submitted to RDC 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.)

REMARKS: Any unanticipated problem or adverse occurrence in the course of the research project must be reported within 5 days to the IRB Chairperson or RDC by submitting an Unanticipated Problem/Adverse Event Form.

Any changes to the Protocol or Consent Forms must receive IRB approval prior to being implemented (except where necessary to eliminate apparent immediate hazards to the subjects or others).

PLEASE NOTE: Requested revisions for student proposals MUST include adviser's signature. All revisions MUST be highlighted.

☒ Education Requirements Completed. (Project cannot be started until IRB education requirements are met.)

cc: Tom Mohr

Signature of Designated IRB Member 7-27-06 Date
UND's Institutional Review Board

the proposed project (clinical medical) is to be part of a research activity funded by a Federal Agency, a special assurance atement or a completed 310 Form may be required. Contact RDC to obtain the required documents.

(Revised 07/2004)

APPENDIX B

Participate in an

Abdominal Study

And have a chance to Win a $50 Gift Card

University of North Dakota
Institutional Review Board
Approved on JUL 27 2006
Expires on JUL 26 2007

Approximately 1 hour time commitment

UND School of Medicine and Health Sciences
Physical Therapy Department

Contact : Deb 791-7878 or Wayne 746-5744

Ab Study Contact: Deb 791-7878 or Wayne 746-5744

Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878 or Wayne 746-5744
Ab Study Contact: Deb 791-7878

APPENDIX C

Informed Consent

Title: The effect of a hamstring co-contraction in the activation of the abdominal muscles.

You are being invited to participate in a study conducted by Adam Suedel, Barry Pederson, Deb Larson, Wayne Voth, and Schawnn Decker from the Physical Therapy Department at the University of North Dakota. The purpose of this study is to look at the effect of a hamstring co-contraction on abdominal muscle contractions during a sit-up on a stable surface. Measurements from the abdominal muscles will be taken using electromyography (EMG). EMG is a method of measuring the electrical output of muscles during activation. Sit-ups will be done to metronome timing to determine the activation time. The sit-up will be done on a stable surface and then with a co-contraction of the hamstrings on a therapeutic ball during a sit-up.

This procedure will involve placing 8 electrodes on various locations on the abdominals and on the posterior thigh. Only healthy individuals, over the age of 18 will be asked to participate in this study. Anyone with a history of abdominal surgery, hamstring strain, hamstring surgery, or any other medical condition that affects the participant from performing a sit-up will not be eligible for this study. The benefit to you, as a participant, will be the experience of being involved in a scientific study and knowing that you will be contributing to the body of knowledge in exercise physiology and physical therapy.

You will be asked to perform five practice sit-ups on a stable surface prior to beginning EMG testing. EMG testing will take place during two sections of testing, each will consist of ten sit-ups to a metronome beat. The first section will be without a hamstring co-contraction and the second section will be with a hamstring co-contraction. This study will take approximately one hour of your time.

With any process of physical testing there are some degrees of risks. The investigators of this study have determined that the risks of injury or discomfort to the participants is minimal. During the process of recording the EMG information, we will need to place electrodes on the skin of the abdominals and posterior thigh using an adhesive material. The hair at the electrode placement sites may need to be clipped in order to receive proper electrical readings. After electrode removal, there may be some redness on the surface of the skin, but this should resolve quickly.

There will be no identification names or personal numbers used during this study or in the results. All information will be kept confidential and will be identified to the researchers by an assigned number. Data will only be released and available to the researchers, the advisor, and the individuals involved in the IRB auditing procedures. All data and consent forms will be kept within the University of North Dakota Physical Therapy Department for three years, upon which all electronic media will be erased and paper documents shredded.

The experiment may be stopped by you or the researcher at any time if you are experiencing discomfort, pain, fatigue, or any other symptom that may be detrimental to

your health. You have the right to discontinue any involvement with this study at any time if you have reservations whatsoever. Your decision to participate will not have any effect with on your relationship with the Physical Therapy Department or with the University of North Dakota in any way.

By participating in this study, you have the chance of winning a $50 gift card to local restaurant. We will be drawing a random number between 1 and 30 from a hat and if you are that participant number, we will present you with the certificate.

The researchers involved will be available to answer any questions that you currently have or any future questions that you have about this research study. Questions may be asked by calling Dr. Schawnn Decker at 701-777-6389 or Wayne Voth at 701-746-5744. If you have any other questions or concerns, please call the Office of Research and Program Development at 701-777-4279. A copy of this consent form will be available to all subjects within this study.

I have read this consent form and I agree with all that is within. I understand the benefits as well as the risks of being a participant in this research project.

Signature_____ **Date**_____

APPENDIX D

Screening Information

Participant's Number: _____

Please fill out the following to the best of your knowledge.

Age: _____ Height: _____ Weight: _____

Sex: Male Female

Do you have a history of low back pain that has lasted longer than 3 days? Yes No

If yes, when was the last episode? _____

Have you had any back or abdominal surgeries (C-sections and back fusions)? Yes No
Please List _____

Have you had an ACL repair using a hamstring graft? Yes No

Are you currently pregnant? Yes No

Do you participate in core stabilization, Pilates, or ball exercise routines? Yes No

If yes, how long have you been doing these exercises?

___Weeks ___Months ___Years

If yes, how many times a week do you do these exercises?

○ 1-2 ○ 3-4 ○ 5-6

Please list any past medical conditions: Check if applicable

____ High or low blood pressure

____ Cardiac Conditions
Please List _____

____ Skeletal or postural abnormalities of the spine
Please List_____

Do you have any conditions that would prevent you from lying on the floor and performing standard abdominal crunches? Yes No

Do you have any allergies or adverse skin reactions to rubbing alcohol, Band-Aid adhesives, or hair clipping? Yes No

REFERENCES

1. Avedisian L, Kowalsky D, Albro R, Goldner D, Gill R. Abdominal strengthening using the AbVice machine as measured by surface electromyographic activation levels. *J Strength Cond Res*. 2005;19:709–712.
2. Magee D. Lumbar spine. In: *Orthopedic Physical Assessment*. 4th ed. Philadelphia, Pa: Saunders; 2002:473-474.
3. Jacobs J, Hammerman-Rozenberg R, Cohen A, Stessman J. Chronic back pain among the elderly: prevalence, associations, and predictors. *Spine*. 2006;31:E203–E207.
4. Boswell MV, Shah RV, Everett CR, Sehgal N, Brown AM, Abdi S, et. al. Interventional techniques in the management of chronic spinal pain: evidence-based practice guidelines. *Pain Physician*. 2005;8:1-47.
5. Dionne C, Dunn K, Croft P. Does back pain prevalence really decrease with increasing age? A systematic review. *Age and Ageing*. 2006;35:229–234.
6. Wasiak R, Kim J, Pransky G. Work disability and costs caused by recurrence of low back pain: longer and more costly than in first episodes. *Spine*. 2006;31:219–225.
7. Gardner-Morse M, Stokes I. The effects of abdominal muscle coactivation on lumbar spine stability. *Spine*. 1998;23(1):86-91.
8. Newcomer K, Jacobson T, Gabriel D, Larson D, Brey R, An K. Muscle activation patterns in subjects with and without low back pain. *Arch Phys Med Rehabil*. 2002;83(6):816-21.

9. Kisner C, Colby LA. The spine: exercise interventions for the neck and trunk. In: *Therapeutic Exercise Foundations and Techniques.* 4th ed. Philadelphia, Pa: F.A. Davis Company; 2002:638-677.

10. Konrad P, Smitz K, Denner A. Neuromuscular evaluation of trunk training exercises. *J Ath Train.*2001;36:109-118.

11. Behm DG, Leonard AM, Young WB, Bonsey WA, MacKinnon SN. Trunk muscle electromyographic activity with unstable and unilateral exercises. *J Strength Cond Res.* 2005;19(1):193-201.

12. Vera-Garcia FJ, Grenier SG, McGill SM. Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys Ther.* 2000;80(6):564-9.

13. Lavoie BA, Devanne H, Capaday C. Differential control of reciprocal inhibition during walking versus postural and voluntary motor tasks in humans. *J Neurophysiol.* 1997;78:429-438.

14. Ng JK, Pamianpour M, Kippers V, Richardson CA. Reliability of electromyographic and torque measures during isometric axial rotation exertions of the trunk. *Clin Neurophysiol.* 2003;114:2355-2361.

15. Gunedni Z, Taskiran OO, Beyazova M. What is the optimal repetition number in electromyographic reaction time studies? *Clin Biomech.* 2005;20:754-758.

16. Guimaraes AC, Vaz MA, De Campos MI, Marantes R. The contribution of the rectus abdominis and rectus femoris in twelve selected abdominal exercises: an electromyographic study. *J Sports Med Phys Fitness.* 1991;31:222-230.

17. Andersson EA, Nilsson J, Ma Z, Thorstensson A. Abdominal and hip flexor muscle activation during various training exercises. *Eur J Appl Physiol Occup Physiol.* 1997;75:115-23.

18. Bogduk, N., M. Pearcy, and G. Hadfield. Anatomy and biomechanics of psoas major. *Clin. Biomech.* 1992;7:109-115.

19. Santaguida, P. L. and S. M. McGill. The psoas major muscle: a three dimensional geometric study. *J. Biomech.* 1995;28:339-345.

20. Hildenbrand K, Noble L. Abdominal muscle activity while performing trunk-flexion exercises using the Ab Roller, ABslide, FitBall, and conventionally performed trunk curls. *J Athl Train.* 2004;39:37-43.

21. Andersson EA, Ma Z, Thorstensson A. Relative EMG levels in training exercises for abdominal and hip flexor muscles. *Scand J Rehabil Med.* 1998;30:175-83.