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MUSCLE MOVEMENT PATTERN OF THE SELECTED EXTENSORS DURING PRONE HIP HYPEREXTENSION

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Jolynn Marie-Canfield Nelson

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MUSCLE MOVEMENT PATTERN OF THE SELECTED EXTENSORS DURING PRONE HIP HYPEREXTENSION

By

Jolynn Marie-Canfield Nelson

A THESIS

Submitted to
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ABSTRACT

MUSCLE MOVEMENT PATTERNS OF THE SELECTED EXTENSORS DURING PRONE HIP HYPEREXTENSION

By

Jolynn M.C. Nelson

The purpose of this study was to examine the onset times of contractions of the hamstrings, gluteus maximi, and lumbar paraspinal muscles during active prone hip hyperextension to assess if these muscle groups contracted in a consistent sequence. Nine subjects, each of whom had no history of back pain, participated in the control group. Six subjects, each of whom had a history of back pain, comprised the experimental group. Potential subjects participated in a clinical screening to rule out weakness in the legs due to neurologic problems. Each subject performed 10 repetitions of prone hip hyperextension on each side. The onset times of contraction were recorded electromyographically for bilateral hamstrings, gluteus maximi, lumbar erector spinae, and thoracic erector spinae during each trial. Order of muscle firing was examined within and between groups. Descriptive statistics were used to examine the variability that occurred in the pattern of muscle firing in both groups, since no consistent pattern of muscle firing was found in either group. Additionally, the multiple firings of single muscle groups within single trials were recorded and described.

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CHAPTER 1

INTRODUCTION

Low back pain is one of the most challenging and frequent diagnoses treated within the field of Physical Therapy. The majority of studies have found that 60-90% of the population experience low back pain at some point during their lives (Biering-Sorenson, 1984; Svensson, Vedin, Wilhelmsson, and Andersson, 1983). Physical therapists use a variety of exercises to strengthen the trunk and improve posture as part of the treatment for patients experiencing low back pain. A common intervention utilized by physical therapists is the strengthening of the muscles that provide trunk and hip extension and maintain erect posture. Usually, when instructing patients in performing the motion of hip hyperextension, therapists focus on how high the leg should be raised from the table, or how much resistance the patient could tolerate, rather than determining if this individual uses a compensatory strategy to perform the movement. More recent education has focused on the idea that the continued cycle of back pain may be a result of impairments in

the sequence of muscle firing. It was noted by Janda (1985) that postural/tonic muscles respond to dysfunction by facilitation, hypertonicity, and shortening. He also noted that phasic muscles respond to dysfunction by inhibition and weakness. As a result of these responses, these involved muscles no longer respond to movement in the same fashion, thus resulting in what is called muscle imbalance.

The initiation of hip hyperextension is brought about by a contraction of the hamstrings and gluteus maximus muscles, followed by activation of the contralateral and ipsilateral trunk extensors (Janda, 1985). This movement pattern is important in maintaining the correct position of the pelvis. If there is an alteration of this movement pattern, for example, a muscle in the sequence is inhibited and does not contract, muscular compensation will occur. As a result of the compensatory muscle action, somatic dysfunction can occur due to overuse of particular muscle groups. Also, if there were an alteration of this movement pattern, pain usually will result because of the compensatory strategy being utilized, in addition to somatic dysfunction. If the faulty pattern continues undiagnosed and untreated, the amount of hip extension would be reduced and compensated for by a change in the position of the pelvis, resulting in low back pain.

Need for Study:

Currently, muscle sequencing is not routinely assessed in the majority of low back evaluations. If muscle sequencing is evaluated, it may or may not be performed correctly, or consistently, between medical professionals. Therefore, there is a need to develop a valid, reliable, and objective measurement which can be performed in a clinical setting. Problematic, however, is that there is not an abundance of information regarding the analysis of movement patterns and their role in low back somatic dysfunction. With the continued development of methods to better measure muscular system balance, the treatment and prevention of chronic back pain may be better addressed.

The purpose of this study was to examine the onset times of contraction of the hamstrings, gluteus maximi, and lumbar paraspinal muscles during active prone hip hyperextension, to see if these muscles were recruited in a consistent sequence. The formal research hypotheses that were tested in this study were as follows:

1. There will not be a statistically significant difference in the order of muscle firing of the ipsilateral hamstrings, ipsilateral gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector

spinae muscles in participants of the control group during prone hip hyperextension.

2. There will not be a statistically significant difference in the order of muscle firing of the ipsilateral hamstrings, ipsilateral gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector spinae muscles in participants of the experimental group during prone hip hyperextension.

3. A statistically significant difference will not exist in the muscle firing order of the ipsilateral hamstrings, ipsilateral gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector spinae muscles between the control and experimental groups.

CHAPTER 2

LITERATURE REVIEW

Resisted strength testing has been the most widely taught and utilized tool of muscle functioning during prone hip hyperextension in the field of Physical Therapy. Janda and Jull (1987) and Lewit (1991) described the assessment of prone hip hyperextension as a movement by more than the gluteus maximus. They reported that movements, such as hip extension, were not just performed by a single muscle group, but rather, these movements were performed by a number of muscle groups. In the case of hip extension, Janda and Jull (1987) discussed a previous, but not published, study where Janda used electromyography to illustrate that the prime mover of hip hyperextension was the hamstrings group along with contributions from the gluteus maximus and the lumbar erector spinae muscles. The movement pattern found in the unpublished study by Janda which was discussed by

Janda (1985) and Janda and Jull (1987), was that the hamstrings contracted initially, followed immediately by the ipsilateral gluteus maximus, the ipsilateral lumbar erector spinae muscles, and lastly, by the contralateral lumbar erector spinae muscles. Janda and Jull (1987) observed that muscles reacted in a fairly consistent manner to dysfunction. They believed muscles either respond to dysfunction by over activation and tightness, or by inhibition and weakness. Those muscles that they described as responding to dysfunction by becoming tight and over active are called postural muscles. The postural muscles are described by Bookhout (1992) as muscles that maintain postural balance and are active during most movement patterns to provide stability. Conversely, the phasic muscles are involved in making the movement occur. Phasic muscles respond to dysfunction via inhibition and weakness. Janda and Jull (1987) classified the iliopsoas, hamstrings, and lumbar erector spinae muscles as postural in nature, therefore prone to tightness. They placed the gluteus maximus, medius, and minimus as phasic muscles, thus muscles prone to inhibition. The words phasic and tonic used to describe these two groups, neither correspond to the conventional description of muscle fiber types, nor to histological studies.

Janda and Jull (1987) believed that low back pain may be a symptom of muscle firing imbalance. They described the "pelvic crossed syndrome" as an imbalance which existed between hyperactive, tight hip flexors and lumbar erector spinae muscles, and relatively weakened gluteal and abdominal muscles. The resultant posture can negatively affect static and dynamic functioning. Lewit (1991) concluded that an increased load on the lumbar spine occurred while standing with the described pelvic crossed syndrome posture. This posture would be created by an increased lumbar lordosis, due to tight hip flexors and lumbar erector spinae muscles, and weak abdominal muscles. He continued to relate this posture to a dynamic situation, such as walking, stating that active hip extension was not executed by the inhibited gluteus maximus, but rather by the tight, hyperactive lumbar erector spinae. The activation of the hyperactive lumbar erector spinae resulted in hyperlordosis instead of extension of the hip. Ultimately, this scenario causes increased strain on the lumbar spine in the sagittal plane due to hypermobility of the lumbar spine.

Pierce and Lee (1990) utilized electromyography (EMG) to study twenty healthy subjects to determine if a statistically consistent sequence of muscle activation could be observed during prone right hip extension from a position of thirty degrees of flexion. The subjects were taught the movement and examined while moving their leg at a velocity of 30° per second. They concluded from their study that sequencing of muscle firing during this motion was extremely variable at both the individual and group levels. They were able to conclude that the biceps femoris was activated prior to the onset of hip extension, and this was the only consistent muscle firing pattern noted in their study.

Pierce and Lee (1990) felt that there was a varied amount of hip extension motion past the neutral position. Therefore, those participants who lacked hip range of motion beyond neutral would be performing trunk hyperextension during the prone leg lifting, to compensate for this lack of hip movement. It was difficult to conclude whether or not a consistent muscle firing pattern existed from the study by Pierce and Lee (1990), since they did not measure the same activity as described by Janda and Jull (1987).

Singer (1987) examined the musculoskeletal status of thirty-five physiotherapy students. The evaluation of muscle functioning included prone hip extension as described in the writings of Janda (1985) and Janda and Jull (1987). The purpose of Singer's (1987) study was to develop assessment skills, design an assessment sequence for data collection, and devise a recording form. Using observation and palpation skills and the technique described by Janda and Jull (1987), the components of the assessment examined were posture, joint restriction, and muscle function. As part of the muscle function evaluation, Singer (1987) examined prone hip extension, and used palpatory and observational skills to assess firing sequence. Exact details regarding how he noted sequence of muscle firing utilizing palpatory and observational skills were not described in Singer's methodology portion of his research. Singer concluded from his study that this process of palpating while simultaneously observing hip hyperextension was functional and efficient. Singer also found that most of the students had restriction in the postural muscles used during locomotion. Also, this group of students with postural muscle restrictions had the most pronounced lumbar lordosis, reduced active trunk flexion, demonstrated tightness of the iliopsoas and hamstring muscles, and weakness of the abdominal and gluteal musculature. This pattern, described by Janda and Jull (1987) was called the pelvic crossed syndrome. Although the students were diagnosed with pelvic crossed syndrome, none of them were experiencing low back pain at the time of the study.

A study by Jonsson (1970) investigated the function of the multifidi, longissimus, and iliocostalis muscles at different lumbar levels during a variety of movements. One of the movements Jonsson investigated was hip hyperextension in a prone position. He found that there was no significant difference in the EMG activity of the erector spinae muscle between lifting the ipsilateral or contralateral leg from the bed. Although Jonsson's study did not examine sequence of muscle firing, it illustrated symmetry of movement within a subject.

Overall, there was not an abundance of research that directly studied the sequence of muscle activation during prone hip hyperextension within a population of people without back/ spine problems, or within a population of individuals who have experienced back/spinal problems. The research that has been completed thus far has had discrepancies in the methodology that made it difficult to compare consistencies of muscle firing sequence involved during prone hip hyperextension. Also, there has not been any research located which investigated the sequence of muscle firing during prone hip hyperextension in individuals with back/spinal pain. Research which addressed the sequence of muscle firing would be of meaningful in the rehabilitation of individuals with back pain. A study of this nature would add significantly to the existing literature pertaining to this topic.

CHAPTER 3

METHODS and MATERIALS

The purpose of this study was to use electromyography (EMG) to examine the contraction onset times of the hamstrings, gluteus maximi, and lumbar paraspinal muscles during prone active hip hyperextension, to determine if these muscles were recruited in a consistent sequence. Two subject groups were studied, one with back pain and one without. It was postulated that the control group would perform hip hyperextension in the following muscle firing order: ipsilateral hamstrings, gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector spinae muscles.

This chapter is divided into the following sections: subjects, materials, experimental procedures, research design, and variables.

Subjects:

Nine volunteers were selected for the control group. Members of this group had no progressive history of back/spine pain or traumatic injury to their backs/spines, no past surgeries of any kind, and no central nervous system or neuromuscular disorders. The subjects of the control group had full active trunk range of motion, a negative modified Thomas test, and hamstrings and erector spinae lengths within the normal limits. Additionally, leg length differences, using both the true and apparent methods, were less than one centimeter. Each member of the control group also had to score fifteen on the McGill Short-Form Pain Questionnaire (Melzack 1987). The McGill Short-Form Questionnaire was utilized to quantify pain. This is an accepted instrument, commonly given and well known in the field of Physical Therapy. A score of 15 indicates no pain present, while a score of sixty on this questionnaire is the highest rank of perceived pain.

Six members were selected for the experimental group from a group of subjects who were referred to this study by a physician who conducted a physical evaluation on each potential subject. Members of this group had some degree of back pain and/or leg pain. The degree of back/spine pain was quantified by using the McGill Short-Form Pain Questionnaire. Subjects did not present with any neurologic deficit of leg weakness and did not need to have normal trunk range of motion. The members of the experimental group had no history of back surgery, nor were they in active treatment for their back problem. Additionally, the flexibility of bilateral erector spinae, iliopsoas, and hamstring muscles did not have to be within a normal range. Finally, the measure of the true and apparent leg lengths did not have to be less than one centimeter.

The pre-screening that was performed on subjects in both the control and experimental groups consisted of:

1. Active trunk range of motion: flexion, extension and lateral flexion using an inclinometer and method described by Mayer (1985). Appendix G.
2. Modified Thomas test: assessment of iliopsoas length described by Kendall and McCreary (1983). Appendix G.
3. Hamstring length: measured by a straight leg lift in supine position described by Kendall and McCreary (1983). Appendix G.
4. Lumbar erector spinae: measured by long sitting toe touch described by Kendall and McCreary (1983). Appendix G.

5. True leg length: measured using the technique described by Hoppenfeld (1976). A True Leg Length is a measure of actual length of the leg from the anterior superior iliac crest to the medial malleolus. Appendix G.
6. Apparent leg length: measured using the technique described by Hoppenfeld (1976). The Apparent Leg Length is an assessment of the leg measuring from the umbilicus to the medial malleolus. Apparent leg length takes the entire pelvis into the evaluation, and when measured bilaterally, can be an indicator of pelvic obliquity. Pelvic obliquity results when one side of the innominant is rotated anteriorly or posteriorly. Pelvic obliquity can result in somatic dysfunction of the pelvis, sacrum, and/or the lumbar spine. Appendix G.
7. McGill Short: Form Pain Questionnaire - Melzack (1987). Appendix F.

There were fifteen subjects, although originally it was thought that thirty-forty subjects could be found. The time commitment of two hours was a factor which limited a large number of volunteers from a pool of potential subjects.

Materials:

1. Inclinometer: an instrument used to measure degrees of movement. The inclinometer was used to measure the active trunk ranges of motion of: trunk flexion, extension, and lateral flexion, and hamstring flexibility. A reliability test was performed prior to gathering data for this study, to determine repeatability of results using the inclinometer by this researcher. The reliability of this researcher was high ($r = .94$ for lateral flexion; $r = 1.0$ for flexion; $r = 1.0$ for extension).
2. Tape measure: an instrument used to measure length. The tape measure was used to measure true and apparent leg lengths and hamstring and erector spinae lengths.
3. Surface self-adhering disposable electromyography electrodes that were pregelled. Paper tape was used to ensure adherence to skin during motion.
4. Physiograph: device used for recording EMG signals. A sixteen channel Myosystem 2000 electromyography unit, manufactured by Noraxon, was used.
5. Alcohol pads: used to clean skin for electrode placement.

6. 4x4 Cotton Gauze: used to abrade skin for better contact of electrodes for electrical impulses.
7. Disposable razor: used to shave area of electrode placement.
8. Disposable gloves.
9. McGill Short-Form Pain Questionnaire: A questionnaire designed to quantify degree of back pain.
10. A light with a hand switch.
11. A clock with a second hand.

Research Design:

The experiment began with a Repeated Measures Design. The following hypotheses were tested.

Hypothesis 1: There will not be a statistically significant difference in the order of muscle firing of the ipsilateral hamstrings, ipsilateral gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector spinae muscles in participants of the control group during prone hip hyperextension.

Hypothesis 2: There will not be a statistically significant difference in the order of muscle firing of the ipsilateral hamstrings, ipsilateral gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector spinae muscles in participants of the experimental group during prone hip hyperextension.

Hypothesis 3: A statistically significant difference will not exist in the muscle firing order of the ipsilateral hamstrings, ipsilateral gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector spinae muscles between the control and experimental groups.

Variables:

The independent variable was sequence of muscle firing (S.O.F.), while the dependent variables were the results of muscle contraction onset times were recorded electromyographically.

Experimental Procedures:

When the subjects first arrived at the laboratory, they were asked to read and sign an informed consent form (copy in Appendix E). The procedures used in this study were approved by the University Committee on Research Involving Human or Animal Subjects. In addition, each subject was verbally reminded that they could stop their participation in the study at any time.

A pre-screen assessment was performed on all subjects to determine if: for the control group, each subject met the criteria of the control group, and

to establish a baseline for members of the experimental group. Demographic information regarding gender, age, history of past surgeries, and presence of back/spine and/or radicular pain was collected (Appendix D). The McGill Short-Form Pain Questionnaire was administered to each subject (Appendix F). Standing active trunk flexion, extension, and lateral flexion (Mayer, 1985) were tested as part of screening. The Modified Thomas test, hamstring flexibility (straight leg measurement), and long-sitting test for hamstrings and erector spinae muscle length (Kendall and McCreary, 1983) were administered. A description of the pre-screen objective measures is in Appendix G. True and apparent leg length measurements were also a part of the pre-screen assessment. Two leg length measures were obtained and compared.

Each subject changed into shorts in the dressing room. They returned to the testing area and were instructed to lie prone on a plinth. The researcher identified the motor points of bilateral biceps femoris, gluteus maximi, and lumbar erector spinae muscles at two levels (T12-L1 and L3-L4) using a written description of their location, a pictorial chart, and palpation. The site of each electrode was placed at a location half of the distance between the motor point and the musculotendinous insertion of each particular muscle group (Basmajian and DeLuca, 1985).

Examination gloves were worn by the researcher during subject preparation and exit procedures. The site for electrode placement was prepared first by shaving it with a disposable razor, cleaning it with isopropyl alcohol, and then abrading the skin by rubbing cotton gauze over it to ensure adequate surface contact and to reduce skin resistance. The positive electrode was placed on the selected site parallel to the longitudinal axis of the muscle fibers. The negative electrode was placed directly next to the positive electrode. A ground electrode was applied to the acromion process on the right shoulder. All of the electrode wires were secured using paper tape. The electrode wires were then connected to the eight channels of the EMG system. The wire connected for the switch to elicit the trigger was also linked to the EMG system. The EMG system was used to simultaneously monitor surface electrode activity of bilateral hamstrings, gluteus maximi, lumbar erector spinae muscles, and thoracic paraspinal muscles.

Each subject was asked to perform leg raises while in the prone position. They were instructed to keep the leg being assessed straight at the knee, while hyperextending it at the hip. In addition, they were instructed to hyperextend the leg, as fast as possible, once the cue to elicit movement had been provided. The cue to raise the leg as fast as possible was given to get an automatic motor response. A visual demonstration of the prone hip hyperextension was provided by the researcher. After the demonstration, the researcher verified if the subject understood the activity, if not, it was re-demonstrated until the directions were understood. The subject practiced the activity ten times on each side. A minute rest period was provided before the actual data were gathered. For easy visual observation, a light was located in at eye level in front of each subject. Triggering of the light cued the subject to hyperextend at the hip as fast as they were able. Reaction time was not a consideration in this study as only the muscle firing sequence was of interest. A random sequence of rest times between trials was established prior to gathering the subject data to maintain consistency between subjects and to decrease anticipation. The maximum rest period was 60 seconds and the minimum rest period was 15 seconds. A rest occurred between each repetition until EMG silence was noted on the screen. After the rest period, the subject performed five trials of hip hyperextension, beginning with the right hip.

The order of data collection with random rest periods between trials are listed below:

Trial - right leg with rest period.	**Trial - left leg with rest period.**
One	Six
}15 seconds	}25 seconds
Two	Seven
}55 seconds	}60 seconds
Three	Eight
}50 seconds	}55 seconds
Four	Nine
}40 seconds	}40 seconds
Five	Ten
Eleven	Sixteen
}60 seconds	}20 seconds
Twelve	Seventeen
}50 seconds	}30 seconds
Thirteen	Eighteen
}20 seconds	}60 seconds
Fourteen	Nineteen
}55 seconds	}50 seconds
Fifteen	Twenty

Once the five repetitions were completed with the right leg, five repetitions were completed on the left, five more on the right, and an additional five on the left, for a total of twenty trials. Electromyographic data were recorded by the physiograph during each of the ten trials on each extremity. The triggering of the light also was recorded by the physiograph.

When all the signals were collected, the researcher removed the electrodes from the subject, and returned the subject to the dressing room. The subject was thanked for their participation and was informed that upon completion, study results would be available upon request.

Originally, this study was to be analyzed as a repeated measures design, with the muscle firing (S.O.F.) identified as the independent variable. However, due to the results, the performance of inferential statistics was deemed to be inappropriate.

Limitations:

Internal sources that limited this study included testing, EMG methodology, and subject selection. Testing was limiting because the subjects, instructed to raise their leg a total of ten times each side, could have become "test-wise", potentially impacting their performance. An error in the electrode placement and skin preparation, may also have contributed to error in the overall results. Because the subjects were all volunteers, the selection of subjects of the study may have been limited. Finally, subject selection for the experimental group was limited due to incidences of back pain and possible reluctance to hyperextend quickly.

External sources of limitation included the Hawthorne effect and pretest effects. The special attention given each member of the study may have altered the subjects' performances (Hawthorne effect). Since there was a period of practice to teach the movement that was to occur, a pretest effect could have impacted the performances of the subjects.

CHAPTER 4

RESULTS AND DISCUSSION

Fifteen volunteer subjects participated in this study. The participants in the experimental group were chosen because they had a history of back pain, some of the subjects experienced leg pain, and they were evaluated by a physician who had ruled out any muscle weakness due to a neurologic deficit. The six members of the experimental group participated in this study before being actively involved in treatment. The control group participants were selected because they had: no history of progressive back/spine problems, apparent and true leg length discrepancy no greater than one centimeter, no past surgeries of any kind, no central nervous system or neuromuscular disorders, a score of 15 on the McGill Short- Form Pain Questionnaire (Melzack, 1987), and a normal level of mobility based on the pre-screen battery. The age range of subjects in the experimental group was 27-45 years. The control group ages ranged from 23-41 years. The median ages were comparable between the two groups, with the experimental median age of 38.5 years, and the control group median of 35 years. Gender composition of the experimental group was three females and three males. The gender breakdown in the control group was five females and four males. The study demographics are shown in Table 1. Although the design of the study was for ten subjects in each group, the time commitment of two hours was a restrictive factor eliminating a large number of volunteers from the pool of potential subjects.

TABLE 1. STUDY PARTICIPANTS DEMOGRAPHICS

	EXPERIMENTAL	CONTROL
AGE (YEARS)		
Range	27 - 45	23 - 41
Median (yrs.)	38.5	35
Mean (yrs.)	37	33.22
GENDER		
Female	3	5
Male	3	4

Median trunk ranges of motion were utilized in order to establish a level of functional mobility as a criterion required to participate in the control group. It was noted that the motions of trunk flexion and right and left lateral flexion were similar between the experimental and control groups, while there were greater differences in trunk extension. The control group had a measure of 24° for their median value, and the experimental group had 5.5° for their median measure of trunk extension, a difference of 18.5° between the two groups, with the experimental group having less movement in trunk extension. Furthermore, flexibility involving the hamstrings was examined to ascertain that each subject demonstrated normal hip movement. The hamstring flexibility measures were found to be 7° higher for the control group for each side. Means were included in the parentheses to the right of the median in Table 2. Overall, with the exception of trunk extension, the two groups were comparable. See Table 2 for these results.

TABLE 2. PARTICIPANT MOBILITY

MEDIAN RANGE OF MOTION	EXPERIMENTAL	CONTROL
Trunk flexion (mean)	27.17° (29°)	30° (34.11°)
Trunk Ext. (mean)	5.5° (11.17°)	24° (22.22°)
Trunk sidebending right (mean)	7° (7.83°)	8° (8.22°)
Trunk sidebending left (mean)	9° (11.67°)	10° (13.33°)
HAMSTRING FLEXIBILITY		
Right (mean)	66° (67.83°)	73° (71.44°)
Left (mean)	68°(65°)	75° (76.11°)

Right and left measures were equal for each of the true and apparent leg lengths in the control group and for four of the six members of the experimental group. One subject in the experimental group had a 1.8 centimeter difference between the right and left true leg length measurements, while the apparent measures were equal. The differences in length found in this subject could indicate a difference in the boney structure of the leg, since the difference was found in the true leg length measures only. The remaining subject presented with a 0.4 centimeter asymmetry with the true leg length measure and a 1.0 centimeter difference in the apparent leg length measure. Pelvic obliquity may be indicated by the greater difference in apparent leg length measures. Pelvic obliquity could interfere with the orientation of the muscles around the pelvis, therefore, possibly resulting in altered muscle firing.

Results of the McGill Short-Form Pain Questionnaire in the experimental group had scores ranging from 18 - 40, with a median score of 26. These scores translated into the participants of the experimental group having a mild amount of pain at the time of testing. See Table 3 for individual scores for the experimental group. Since all the members of the control group had a score of fifteen, their scores were not included in this table.

TABLE 3. EXPERIMENTAL GROUP: SHORT - FORM McGILL PAIN QUESTIONNAIRE

	201	202	203	204	205	206	MEDIAN	MEAN
SCORE	40	19	18	35	23	29	26	27.33

The EMG data were collected from a sixteen channel Myosystem 2000 electromyography (EMG) unit. The results were analyzed for the onset time of each muscle group using Myosoft software. The settings for the onset time analysis were onset time of ten and subsist time of five. Readings were analyzed for order of firing and patterning, both within and between groups. When examined, the data were not normally distributed, which rendered any parametric statistical analyses inappropriate. In addition, non-parametric statistics were attempted, but were not able to be performed on the data due to the lack of consistent pattern of muscle firings. Therefore, the results of this study were descriptive in nature.

EMG readings for bilateral hamstrings, bilateral gluteus maximi, bilateral lumbar paraspinal muscles, and bilateral thoracic paraspinal muscles were recorded and examined for the order of firing. All participants in both groups illustrated a degree of variability within subjects. Surprisingly, multiple firings of single muscle groups were observed during the prone hip hyperextension. Moreover and most critically, the expected sequencing of firing was not observed for any subject in either the control or experimental group.

All subjects in the control group demonstrated inconsistent order of muscle firing. As an illustration of the inconsistencies within the control group, the sequence of muscle firing for prone right hip hyperextension during the ten trials for Subject 101 are shown in Table 4. The variability in sequencing of muscle contractions for each of the ten trials is illustrated. All of the muscles connected with electrodes to the EMG and the trigger are displayed. Trial 101-1 versus Trial 101-5 both had the trigger occur first, the right lumbar paraspinal muscles contracted third, and the left lumbar paraspinal muscles contracted fifth. All other muscle groups contracted at different times.

An example of multiple firings of a muscle group within a trial, also is illustrated in Table 4. Trial four (101-4) represents a multiple firing of the right thoracic paraspinal muscles. It was noted that for this subject during right hip hyperextension, there was only one incidence of multiple firings of a single muscle group, that being the thoracic paraspinal muscles, which contracted twice in Trial 101-4. Unexpected multiple contractions of the same muscle group occurred within trials for most subjects.

TABLE 4. SUBJECT 101 SEQUENCE OF RIGHT HIP HYPEREXTENSION FROM PRONE POSITION

TRIAL	101-1	101-2	101-3	101-4	101-5	101-6	101-7	101-8	101-9	101-10
TRIG	1	1	1	2	1	1	1	1	1	1
R TH-1	9	6	3	1	4	4	7	7	7	7
R TH-2	0	0	0	8	0	0	0	0	0	0
L TH	6	5	7	7	2	6	4	3	3	4
R LUM	3	3	4	5	3	3	6	6	6	2
L LUM	5	7	5	6	5	5	3	5	4	5
R MAX	4	4	6	4	7	8	9	8	8	8
L GMAX	8	9	9	9	9	7	5	4	5	6
R HAM	2	2	2	3	6	9	8	9	9	9
L HAM	7	8	8	0	8	2	2	2	2	3

KEY: TRIG=TRIGGER R TH= RIGHT THORACIC PARASPINALS L TH= LEFT THORACIC PARASPINALS R LUM= RIGHT LUMBAR PARASPINALS L LUM= LEFT LUMBAR PARASPINALS R GMAX= R GLUTEUS MAXIMUS L GMAX= LEFT GLUTEUS MAXIMUS R HAM= RIGHT HAMSTRING L HAM=LEFT HAMSTRING

As an example of the range of inconsistencies within individuals of the control group, the sequence of muscle firings for the right leg during the ten trials for Subject 106 are shown in Table 5. Incidents of multiple firings were observed in both the experimental and control groups: Subject 106 had the most incidences of multiple firings of single groups of muscles within a trial, for any subject. The variability in sequencing of muscle contractions for each of the ten trials is illustrated in Table 5.

TABLE 5. SUBJECT 106 SEQUENCE OF RIGHT HIP HYPEREXTENSION FROM PRONE POSITION

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	2	1	2	2	3	3	1	4	2	1
RTH1	1	6	3	1	1	1	2	1	4	5
RTH2	8	0	8	3	5	6	6	6	0	10
RTH3	0	0	0	0	0	12	12	11	0	14
RTH4	0	0	0	0	0	13	17	0	0	17
RTH5	0	0	0	0	0	0	19	0	0	19
RTH6	0	0	0	0	0	0	21	0	0	23
RTH7	0	0	0	0	0	0	0	0	0	27
RTH8	0	0	0	0	0	0	0	0	0	32
LTH1	4	3	5	4	8	7	3	3	1	3
LTH2	0	0	0	0	0	9	7	10	6	7
LTH3	0	0	0	0	0	14	10	12	0	20
LTH4	0	0	0	0	0	15	18	0	0	25
LTH5	0	0	0	0	0	0	20	0	0	28
RLUM1	5	5	7	7	2	2	5	2	5	6
RLUM2	0	0	0	0	4	11	13	8	0	9
RLUM3	0	0	0	0	0	16	16	0	0	12
RLUM4	0	0	0	0	0	18	22	0	0	16
RLUM5	0	0	0	0	0	0	0	0	0	18
RLUM6	0	0	0	0	0	0	0	0	0	22
RLUM7	0	0	0	0	0	0	0	0	0	26
RLUM8	0	0	0	0	0	0	0	0	0	31
LLUM1	6	4	8	8	7	5	4	5	7	2
LLUM2	9	0	0	0	0	10	0	0	0	11
LLUM3	0	0	0	0	0	0	0	0	0	15
LLUM4	0	0	0	0	0	0	0	0	0	21
LLUM5	0	0	0	0	0	0	0	0	0	24
LLUM6	0	0	0	0	0	0	0	0	0	29
RMAX1	7	8	6	6	10	8	9	9	0	8
RMAX2	10	0	0	0	0	17	11	13	0	13
RMAX3	0	0	0	0	0	19	14	0	0	0
LMAX1	11	7	9	9	9	4	8	7	3	4
LMAX2	0	0	0	0	0	0	15	0	0	30
RHAM	3	2	1	5	6	20	23	14	0	33
LHAM	0	0	0	0	0	0	0	0	0	0

KEY: **TRIG=**TRIGGER **R TH=** RIGHT THORACIC PARASPINALS **L TH=** LEFT THORACIC PARASPINALS **R LUM=** RIGHT LUMBAR PARASPINALS **L LUM=** LEFT LUMBAR PARASPINALS **R GMAX=** R GLUTEUS MAXIMUS **L GMAX=** LEFT GLUTEUS MAXIMUS **R HAM=** RIGHT HAMSTRING **L HAM=**LEFT HAMSTRING

Specifically, if one were to examine Trial 2 versus Trial 7 for Subject 106 below, the following muscle firing orders were illustrated:

TRIAL 2	TRIAL 7
Trigger	Trigger
Right Hamstring	Right Thoracic-1
Left Thoracic	Left Thoracic-1
Left Lumbar	Left Lumbar
Right Lumbar	Right Lumbar-1
Right Thoracic	Right Thoracic-2
Left G. Max	Left Thoracic-2
Right G. Max	Left G. Max-1
	Right G. Max-1
	Left Thoracic-3
	Right G. Max-2
	Right Thoracic-3
	Right Lumbar-2
	Right G. Max-3
	Left G.Max-2
	Right Lumbar-3
	Right Thoracic-4
	Left Thoracic-4
	Right Thoracic-5
	Left Thoracic-5
	Right Thoracic-6
	Right Lumbar-4
	Right Hamstring

** Number at side indicates the number of times this muscle group fired.

The right hamstring muscles fired second in Trial 2 which was anticipated. The right gluteus maximus muscle was eighth to fire, compared to the predicted third. The left lumbar paraspinal muscles in Trial 2 were fourth and had been predicted to be fourth. Lastly the right lumbar paraspinal muscles were, as predicted, at fifth. Trial 7 was markedly different from Trial 2.

Subject 106 was an excellent example of multiple firing as well. These multiple firings of muscle groups for Subject 106 are illustrated for all trials in Table 5. Trial 7 had three contractions of the right gluteus maximus, four of the right lumbar paraspinal muscles, and six of the right thoracic paraspinal muscles. The total muscle contractions in Trial 2 were eight, while in Trial 7, there were 23 muscle contractions for the same motion. Contrary to research (Janda, 1985; Lewit, 1991; Singer, 1987) and clinical observation, consistent sequential muscle firing did not occur in any trial for any subject investigated. Moreover, as multiple contractions were not addressed in the literature, these types of contractions were unexpected. All results of the individual muscle firing sequences are contained in Appendix A for both the control and experimental groups.

Within the experimental group, subjects confirmed the research hypothesis that they would not use the order of muscle firing of ipsilateral hamstring, ipsilateral gluteus maximus, contralateral lumbar paraspinal muscles, and ipsilateral lumbar paraspinal muscles. An example of the random sequence of muscle contractions that were recorded during prone hip hyperextension for Subject 201 of the experimental group is illustrated in Table 6. The remaining individual results of the experimental group are in Appendix A. This random pattern of muscle firings is consistent with the observations made in the clinic and in the literature (Greenman and

Bookhout, 1993; Bookhout, 1992), in which treatment of individuals with back pain was discussed. No multiple firings were recorded for Subject 201.

TABLE 6. RIGHT HIP HYPEREXTENSION FOR SUBJECT 201 OF EXPERIMENTAL GROUP

TRIAL	201-1	201-2	201-3	201-4	201-5	201-6	201-7	201-8	201 -9	201 -10
TRIG	1	3	1	1	2	2	1	1	1	1
R TH	4	1	4	3	3	3	3	2	3	3
L TH	5	5	7	4	7	7	4	4	4	8
R LUM	3	2	3	5	4	8	7	7	7	7
L LUM	6	6	5	7	6	5	6	6	6	5
R MAX	7	0	6	6	5	0	0	0	0	0
L MAX	0	0	0	0	0	6	8	8	8	6
R HAM	2	4	2	2	1	1	2	3	2	2
L HAM	0	0	0	0	0	4	5	5	5	4

KEY: TRIG=TRIGGER R TH= RIGHT THORACIC PARASPINALS L TH= LEFT THORACIC PARASPINALS R LUM= RIGHT LUMBAR PARASPINALS L LUM= LEFT LUMBAR PARASPINALS R GMAX= R GLUTEUS MAXIMUS L GMAX= LEFT GLUTEUS MAXIMUS R HAM= RIGHT HAMSTRING L HAM=LEFT HAMSTRING

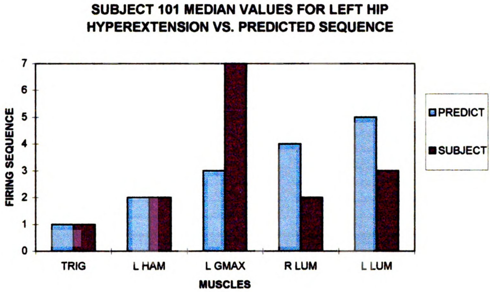
The median values for each muscle's firing sequence for all trials of right and left hip hyperextensions trials were examined in both the control and experimental groups. The calculation of the median muscle firing sequence was performed to determine if subjects within a group had a consistent pattern, other than the one hypothesized for the control group. The median pattern of muscle order firing of the ten trials for the control group during left hip hyperextension is shown in Table 7. It was noted that there was not a consistent sequence that occurred for the control group. The only consistent result was that the trigger occurred first with all subjects, except Subject 106. Additionally, the median sequence of muscle firing for each subject in the experimental group was found to be inconsistent with the group as a whole. Since the results were inconclusive, with no pattern of muscle firing order emerging, the median firing sequence data for both sides for the control and experimental group were placed in Appendix B.

TABLE 7. MEDIAN MUSCLE FIRING SEQUENCE FOR THE LEFT HIP HYPEREXTENSION - CONTROL GROUP

	TRIG	LHAM	RHAM	LGLUT	RGLUT	LLUM	RLUM1	RLUM2	LTH1	LTH2	LTH3	RTH1	RTH2
101	1	2	4	7	6	3	2	0	5	0	0	3	0
102	1	6	7	7	7	3	4	0	5	0	0	2	0
103	1	3	6	7	7	4	5	0	2	0	0	3	0
104	1	6	7	2	7	4	5	0	3	0	0	3	0
105	1	6	2	6	6	3	5	0	0	0	0	4	0
106	2	0	6	8	7	6	4	6	1	3	6	4	5
107	1	3	5	7	6	4	3	0	0	0	0	2	0
108	1	2	3	8	7	4	5	0	6	0	0	6	0
109	1	2	6	8	8	4	5	0	7	0	0	1	3

From Table 7, Subject 101's median sequence of muscle firings was compared with the expected sequence of muscle firings to illustrate a representation of this variability of muscle firings. This information is presented in Figure 1. The blue color indicated the predicted pattern of firing. Because this example was the left hip which hyperextended, the left hamstring, left gluteus maximus, right lumbar paraspinal muscles, and left lumbar paraspinal muscles were expected to fire, respectively. The purple color represented the median sequence of muscle firing for Subject 101 during left hip hyperextension. The trigger was first, left hamstring fired second, the same as the predicted order. Firing of remaining muscle groups did not occur in the predicted sequence.

FIGURE 1.



Further evaluation of the data was performed to examine the percent of time a particular muscle group contracted in a particular sequence position. The results of the left hip hyperextension continued with the same inconsistent pattern. The trigger occurred first 89% of the time. The left hamstring was second or sixth at 33% and third 22%, left gluteus maximus was seventh at 44%, left lumbar paraspinal muscles fourth at 55%, and right lumbar paraspinal muscles occurred fifth at 55%. The anticipated sequence did not occur. A complete tabulation of median sequence of percent

occurrence for the control group's left hip hyperextension is presented in Table 8. Further charts of percent occurrence of muscle firings for right and left hip hyperextensions for both the control and experimental groups are in Appendix C.

TABLE 8. PERCENT OCCURRENCE OF MEDIAN MUSCLE CONTRACTION - LEFT HIP HYPEREXTENSION-CONTROL GROUP

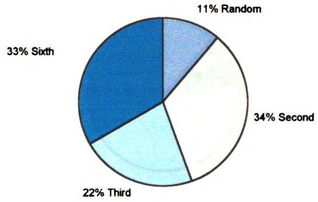
SEQUENCE	TRIGGER	L HAM	R HAM	L GMAX	R GMAX	L LUM	R LUM	L TH	R TH
0	0	11%	0	0	0	0	0	22%	0
1	89%	0	0	0	0	0	0	11%	11%
2	11%	33%	11%	11%	0	0	11%	11%	22%
3	0	22%	11%	0	0	33%	11%	11%	33%
4	0	0	11%	0	0	55%	22%	0	22%
5	0	0	11%	0	0	11%	55%	22%	0
6	0	33%	33%	11%	33%	0	0	11%	11%
7	0	0	22%	44%	55%	0	0	11%	0
8	0	0	0	33%	11%	0	0	0	0
9	0	0	0	0	0	0	0	0	0

KEY: TRIG=TRIGGER R TH= RIGHT THORACIC PARASPINALS L TH= LEFT THORACIC PARASPINALS R LUM= RIGHT LUMBAR PARASPINALS L LUM= LEFT LUMBAR PARASPINALS R GMAX= R GLUTEUS MAXIMUS L GMAX= LEFT GLUTEUS MAXIMUS R HAM= RIGHT HAMSTRING L HAM=LEFT HAMSTRING

Following are exemplary pie charts, included to further illustrate percentage of occurrence of the median muscle firing pattern for an individual muscle in one of the tested groups. For the control group's left hip hyperextension, the median occurrences of firing for the left hamstring were almost equal at second at 34% and sixth at 33% of the time, as seen in Figure 2. It was expected that the left hamstring would fire second after the trigger had signaled the subject to lift their leg.

FIGURE 2.

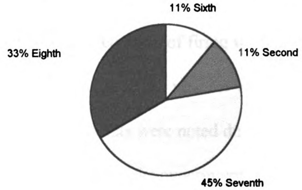
MEDIAN SEQUENCE FOR LEFT HAMSTRING DURING LEFT HIP HYPEREXTENSION - CONTROL



The percentage of times the left gluteus maximus fired in a particular order during left hip hyperextension is shown in Figure 3. The left gluteus maximus contracted in almost equal proportions at second (11%) and sixth (11%) and at seventh (45%) and eighth (33%). Although, the prediction for contraction of the left gluteus maximus muscle was for it to contract third, it can be seen that within the control group, the median firing order for the left gluteus maximus was not primarily third for any individual.

FIGURE 3.

MEDIAN SEQUENCE OF LEFT GLUTEUS MAXIMUS DURING LEFT HIP HYPEREXTENSION - CONTROL



A trend was noted in the first five trials versus the second five trials of hip hyperextension in the sequence of contraction of the right hamstring muscles. The median values for timing of the contractions of the right and left hamstrings for the control subjects (101-109) and the experimental subjects (201-206) were illustrated in Table 9. The subject numbers were placed in the first column. The median hamstring values were arranged with the first and second set of five trials for the right leg adjacent to each other in columns two and three, respectively. A similar arrangement for the median hamstring muscle values for the left leg were placed in the fourth and fifth columns, respectively. It was anticipated that the hamstrings would contract second, immediately following the trigger. As seen in Table 9, for subjects of the control group during right hip hyperextension, the median sequence of firing for the hamstrings was two for three participants, three for three participants, and five for three participants. There was a change which occurred in the second set of five repetitions, in that the firing occurred later in the sequence. The median sequence of firing was seven for one participant, eight for three participants, nine for four participants, and twenty for one participant. Similar results were noted during right hip hyperextension for participants of the experimental group. The median sequence for the right hamstrings during the first five repetitions was two for two participants, three for one participant, five for one participant, and six for two participants. The second set of five repetitions based on the median sequence of firing was zero for two participants, two for one participants, seven for one participant, and eight for two participants. Initially it was thought that fatigue may have played a role in the later set of contractions for the right hamstrings during right hip hyperextension. However, when the median values for the left hamstrings were examined, the results were not similar to the right side. For the left hamstrings, the median scores for the first set of repetitions were higher than the median values for the second set of repetitions, indicating later firings of the muscles for the first set of repetitions. These findings for the left hamstrings were in opposition to the findings for the right hamstrings. Data were verified for correct order of repetitions. It was unknown what caused this apparent switch in firing order, but merits further investigation. Contributing factors may include fatigue, leg dominance, and stabilization by the opposite leg.

TABLE 9. FIRST FIVE TRIALS VS. SECOND FIVE TRIALS FOR HAMSTRINGS DURING PRONE HIP HYPEREXTENSION - CONTROL & EXPERIMENTAL GROUPS

SUBJECT	1st FIVE TRIALS RIGHT LEG	2nd FIVE TRIALS RIGHT LEG	1st FIVE TRIALS LEFT LEG	2nd FIVE TRIALS LEFT LEG
101	2	9	8	2
102	5	8	9	3
103	3	9	9	3
104	5	9	9	3
105	2	8	8	3
106	3	20	0	0
107	3	7	7	2
108	2	8	0	2
109	5	9	0	2
201	2	2	0	4
202	6	0	9	3
203	2	0	0	3
204	5	8	6	2
205	3	7	8	2
206	6	8	9	5

Overall, and contrary to research and clinical observation, no ordered sequence of muscle firing was recorded for either the control or experimental groups. Furthermore, multiple contractions of single muscle groups within trials occurred. These multiple firings of single muscle groups within a trial were not addressed in the literature. Additionally, muscle fatigue may have played a role in the variability seen in the sequence of firing, but it was difficult to measure in the current design of this study.

CHAPTER 5

CONCLUSIONS

Patterning of muscle firing is important in retraining individuals who present with symptoms of back pain, lumbosacral somatic dysfunction, and postural changes due to muscle tightness and muscle weakness. Improper sequencing of muscle firing when performing prone hip hyperextension has ramifications functionally in walking. It is believed by this researcher that during gait, when hip extension past neutral occurs, individuals who have inhibited components of the pattern studied, may also lack the ability to perform portions of the gait cycle correctly. What most probably results are compensatory patterns to allow for walking to be as functional as possible. If the most functional pattern of muscle firing for hip extension past neutral can be identified, people with back pain can be further served. Prone hip hyperextension at high speed to assess differences in order of sequencing that might occur within groups and between groups was examined in this study. No pattern of muscle firing sequencing was found within or between groups. As no consistent muscle firing order within a group could be determined, differences in the muscle firing order of the ipsilateral hamstrings, ipsilateral gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector spinae muscles between the control group and experimental group could not be statistically substantiated.

Because of this finding, inferential statistics could not be performed since the hypotheses addressed differences in patterning of muscle firing sequence. Instead, a descriptive analysis was performed.

The muscle firing order during active prone hip hyperextension was remarkably variable both within and between subjects of the control group. Because of these results, the research hypothesis that stated there would not be a statistically significant difference in order of muscle firing by participants during prone hip hyperextension, could not be rejected. This finding of variability did concur with other research (Pierce, et al., 1990) addressing prone hip extension.

The speed with which the motion was performed may have impacted the pattern of movement. The subjects were all instructed to lift the leg as quickly as they could, once they saw the trigger. Watson (1996) and Greenman and Bookhout (1993), noted that there becomes less time for feedback loops to occur from the afferent system, therefore, the postural muscles do not have the time to react. Since the phasic muscles do not rely on a feedback system, they can react faster. The reasoning presented in the literature could account for the variability found in this study. Pierce and Lee (1990) reported that the variability in muscle firing order in their study may have been a result of the slow hip extension movement (approximately 30°/second). The information provided in the Pierce and Lee (1990) study lends support that the speed of movement and muscle firing sequencing at the hip needs to be further investigated.

In addition, variability of muscle firings for active prone hip hyperextension within and between subjects of the experimental group were found. In this instance, the research hypothesis stated that there would not be a statistically significant difference in the order of muscle firing of the ipsilateral hamstrings, ipsilateral gluteus maximus, contralateral lumbar erector spinae muscles, and ipsilateral lumbar erector spinae muscles in participants of the experimental group during prone hip hyperextension. This hypothesis could not be rejected. Inability to reject this hypothesis was based on the absence of consistent pattern of muscle firings in either group.

The third hypothesis, that no difference in the muscle firing order of the examined muscles would exist between the control and experimental groups, could not be rejected. Inability to reject this hypothesis was based on the absence of consistent pattern of muscle firing in either group.

Multiple firings were not expected to occur during the movement of hip hyperextension. A possible explanation for their occurrence could be due to the amount of hip hyperextension a subject was allowed to perform. The EMG signals were collected from the time the muscle initiated the leg movement, and the leg was returned to the plinth. The actual magnitude of hip hyperextension was not controlled between subjects, or between trials for each subject. The varied degrees of hip movement may explain why some subjects demonstrated multiple firings. For example, a subject could have extended their hip higher than actual joint movement allowed by further extending their trunk. This trunk extension may have elicited additional contraction of muscles that had already contracted. Pierce and Lee, (1990) did not report any multiple firings in their study with slow (30°/sec) limited hip extension to 30°.

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Clinical implications of this study for the field of Physical Therapy were that more research is necessary, examining the effects of varied speeds and degree with which active prone hip hyperextension is performed. Additionally, the examination of muscle firing sequence timing problems, and examination of the muscle firing patterns that result need to be researched. It is still felt by this researcher that timing problems, especially a lack of gluteal activation, may frequently cause persons with low back dysfunction to perform hip hyperextension incorrectly. Lack of gluteal contraction, in many cases, causes hypertonicity in one or both sides of the lumbar paraspinal muscles. These individuals then present clinically with a higher and deeper lumbar lordosis and increased anterior pelvic tilt. This description is a component of the pelvic crossed syndrome described by Janda and Jull (1987). It also is observed clinically, that there is a decrease in these postural changes with training and education interventions. Training and re-education of the pattern of muscle firings during prone hip hyperextension described and investigated in this study have been successful in decreasing the pelvic crossed syndrome.

It is felt that the number of subjects in this study was a limiting factor. The fact that there were only nine in the control group and six in the ex

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experimental group limited the strength of the findings. However, at least with the control group, a pattern of firing was expected to be found. Because of the variability in order of muscle firing sequences and the speed of prone hip hyperextension studied, the author suggests that more studies be performed at different speeds and at a consistent degree of hip hyperextension, to ascertain when the breakdown of the sequenced patterning occurs.

Suggestions for further study include researching varied speeds of a consistent amount of hip hyperextension and the patterning of muscle firings that occurs during that motion. Muscle fatigue, leg dominance, and trunk stabilization may have played roles in the variability that occurred. Researchers in this area may want to consider examining fewer repetitions and track the same movement with a day or more between trials varying which side, right or left, begins first. The variation in which lower extremity starts first would help resolve the question of any patterning results due to fatigue. Additionally of interest to clinicians, would be attaching EMG electrodes to the abdominal muscles to assess their role in lumbar stabilization during prone hip hyperextension. Lastly, further studies to assess patterns of muscle firing during functional movements such as forward bending, returning to extension from forward bending, walking on varied terrain, and stair climbing need to be performed. These studies should compare asymptomatic subjects with those who have a history of back pain.

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APPENDICES

APPENDIX A

Sequence of Individual Muscle Firing

I. Right Hip Hyperextension

Subject 101- Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	2	1	1	1	1	1	1
R TH1	9	6	3	1	4	4	7	7	7	7
R TH2	0	0	0	8	0	0	0	0	0	0
L TH	6	5	7	7	2	6	4	3	3	4
R LUM	3	3	4	5	3	3	6	6	6	2
L LUM	5	7	5	6	5	5	3	5	4	5
R GMAX	4	4	6	4	7	8	9	8	8	8
L GMAX	8	9	9	9	9	7	5	4	5	6
R HAM	2	2	2	3	6	9	8	9	9	9
L HAM	7	8	8	0	8	2	2	2	2	9

Subject 102-Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	3	1	1	1	2	1	2
R TH	2	2	7	1	2	2	0	1	2	1
L TH	7	4	4	6	7	4	5	3	4	3
R LUM	5	3	6	2	4	3	4	4	6	5
L LUM	6	5	2	5	5	7	3	5	3	6
R GMAX	3	6	3	4	6	8	8	7	9	8
L GMAX	8	8	8	8	8	9	6	8	7	7
R HAM	4	7	5	7	3	6	7	9	8	9
L HAM	9	9	9	9	9	5	2	6	5	4

Subject 103-Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	2	1	1	1	1	2	1	1	1	1
R TH1	1	6	2	6	6	6	5	7	6	2
R TH2	6	0	0	0	0	0	0	0	0	0
L TH1	5	5	5	5	2	1	4	4	2	6
L TH2	0	0	0	0	0	5	0	0	0	0
R LUM	4	3	4	4	4	7	6	6	5	3
L LUM	7	4	6	3	5	3	3	2	3	4
R GMAX	5	7	7	7	7	10	8	9	8	7
L GMAX	8	8	0	8	8	8	7	5	7	8
R HAM	7	2	3	2	3	9	9	8	9	9
L HAM	0	9	0	9	9	4	2	3	4	5

Subject 104-Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	2	1	1	1	1	1	1
R TH1	6	6	4	7	5	6	3	4	5	5
L TH	2	3	2	1	2	7	2	7	7	7
R LUM	3	7	5	3	4	5	4	6	6	6
L LUM	4	2	6	4	7	3	7	5	4	4
R GMAX	5	4	3	6	6	8	8	8	8	8
L GMAX	8	9	7	8	9	4	6	3	3	2
R HAM	7	5	8	5	3	9	0	9	9	9
L HAM	0	8	0	9	8	2	5	2	2	3

Subject 105-Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	1	1	1	1	1	0	1
R TH1	7	4	5	3	5	4	3	3	0	3
R TH2	0	0	0	0	0	8	0	0	0	0
L TH	0	0	0	0	0	0	0	0	0	0
R LUM	4	5	4	4	4	5	5	5	0	5
L LUM	3	3	3	5	3	3	3	4	0	2
R GMAX	5	6	6	6	6	6	6	7	0	7
L GMAX	6	8	7	7	7	7	7	6	0	6
R HAM	2	2	2	2	2	9	9	8	0	0
L HAM	0	7	0	0	0	2	2	2	0	4

Subject 106-Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	2	1	2	2	3	3	1	4	2	1
R TH1	1	6	3	1	1	1	2	1	4	5
R TH2	8	0	8	3	5	6	6	6	0	10
R TH3	0	0	0	0	0	12	12	11	0	14
R TH4	0	0	0	0	0	13	17	0	0	17
R TH5	0	0	0	0	0	0	19	0	0	19
R TH6	0	0	0	0	0	0	21	0	0	23
R TH7	0	0	0	0	0	0	0	0	0	27
R TH8	0	0	0	0	0	0	0	0	0	32
L TH1	4	3	5	4	8	7	3	3	1	3
L TH2	0	0	0	0	0	9	7	10	6	7
L TH3	0	0	0	0	0	14	10	12	0	20
L TH4	0	0	0	0	0	15	18	0	0	25
L TH5	0	0	0	0	0	0	20	0	0	28
R LUM1	5	5	7	7	1	2	5	2	5	6
R LUM2	0	0	0	0	2	11	13	8	0	9
R LUM3	0	0	0	0	4	16	16	0	0	12
R LUM4	0	0	0	0	0	18	22	0	0	16
R LUM5	0	0	0	0	0	0	0	0	0	18
R LUM6	0	0	0	0	0	0	0	0	0	22
R LUM7	0	0	0	0	0	0	0	0	0	26
R LUM8	0	0	0	0	0	0	0	0	0	31
L LUM1	6	4	4	8	7	5	4	5	7	2
L LUM2	9	0	0	0	0	10	0	0	0	11
L LUM3	0	0	0	0	0	0	0	0	0	15
L LUM4	0	0	0	0	0	0	0	0	0	21
L LUM5	0	0	0	0	0	0	0	0	0	24
L LUM6	0	0	0	0	0	0	0	0	0	29
R GMAX1	7	8	6	6	10	8	9	9	0	8
R GMAX2	10	0	0	0	0	17	11	13	0	13
R GMAX3	0	0	0	0	0	19	14	0	0	0
L GMAX1	11	7	9	9	9	4	8	7	3	4
L GMAX2	0	0	0	0	0	0	15	0	0	30
R HAM	3	2	1	5	6	20	23	14	0	33
L HAM	0	0	0	0	0	0	0	0	0	0

Subject 107-Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	1	1	1	1	1	2	1
R TH1	2	3	9	9	3	4	4	3	4	4
R TH2	5	0	0	0	0	0	0	0	0	0
L TH	8	2	3	5	2	10	0	0	0	0
R LUM1	4	4	5	2	4	5	3	4	1	5
R LUM2	0	0	0	0	0	0	0	8	5	0
L LUM	7	6	8	6	5	3	5	10	9	3
R GMAX	6	7	4	4	7	6	8	6	8	8
L GMAX1	10	9	7	8	9	7	6	5	6	6
L GMAX2	0	0	0	0	0	0	0	9	0	0
R HAM1	3	5	2	3	6	8	7	7	7	7
R HAM2	0	0	0	0	0	9	0	0	0	0
L HAM	9	8	6	7	8	2	2	2	3	2

Subject 108-Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	6	7	6	4	5	4	7	7	4	6
L TH	5	6	2	7	4	5	5	6	2	3
R LUM	3	3	4	3	2	6	4	5	5	7
L LUM	7	5	5	6	6	3	3	4	6	4
R GMAX	4	4	7	5	7	9	9	8	7	8
L GMAX	8	8	9	8	8	7	6	3	8	5
R HAM	2	2	3	2	3	8	8	9	9	0
L HAM	9	9	8	0	9	2	2	2	3	2

Subject 109-Control

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	2	3	1	1	1	1	1	1	1
R TH1	0	1	1	2	7	5	5	5	6	2
R TH2	0	6	2	0	0	0	7	0	0	0
R TH3	16	9	7	0	0	0	10	0	0	0
R TH4	0	0	0	0	0	0	12	0	0	0
R TH5	0	0	0	0	0	0	16	0	0	0
R TH6	0	0	0	0	0	0	18	0	0	0
L TH1	3	11	10	6	4	4	13	7	5	5
L TH2	11	0	0	0	15	0	19	0	0	0
L TH3	15	0	0	0	0	0	0	0	0	0
R LUM1	5	5	6	3	6	3	4	4	7	4
R LUM2	10	0	0	0	0	0	6	0	0	0
R LUM3	0	0	0	0	0	0	8	0	0	0
R LUM4	0	0	0	0	0	0	9	0	0	0
R LUM5	0	0	0	0	0	0	14	0	0	0
R LUM6	0	0	0	0	0	0	15	0	0	0
R LUM7	0	0	0	0	0	0	17	0	0	0
L LUM1	4	4	4	4	5	0	11	2	2	3
L LUM2	0	0	0	0	10	0	0	0	0	0
R GMAX	6	7	8	7	16	6	0	8	8	8
L GMAX1	7	8	9	8	3	7	3	6	4	7
L GMAX2	9	0	0	0	0	0	0	0	0	0
R HAM1	2	3	5	5	8	2	20	9	9	9
R HAM2	0	0	0	0	9	0	0	0	0	0
R HAM3	0	0	0	0	11	0	0	0	0	0
R HAM4	0	0	0	0	12	0	0	0	0	0
R HAM5	0	0	0	0	13	0	0	0	0	0
R HAM6	0	0	0	0	14	0	0	0	0	0
L HAM1	8	10	11	9	2	8	2	3	3	6
L HAM2	12	0	0	0	0	0	0	0	0	0
L HAM 3	13	0	0	0	0	0	0	0	0	0
L HAM4	14	0	0	0	0	0	0	0	0	0

II. Control Group - Left Hip Hyperextension

Subject 101-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	1	1	1	1	1
R TH1	5	6	5	2	4	5	5	4	3	6
R TH2	0	0	0	6	0	0	0	0	0	0
L TH	7	7	7	5	7	6	7	3	2	5
R LUM	3	4	2	4	3	8	6	7	4	7
L LUM	6	8	6	9	5	3	3	5	5	3
R GMAX	4	5	4	7	6	7	8	8	7	8
L GMAX	9	9	9	10	8	4	4	6	8	4
R HAM	2	3	3	3	2	9	9	9	9	9
L HAM	8	2	8	8	9	2	2	2	6	2

Subject 102-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	2	1	1	1	1	1	1	1	1
R TH	2	1	2	2	2	2	2	3	2	2
L TH	7	5	6	5	6	6	6	4	3	5
R LUM	6	3	3	3	5	5	4	7	5	6
L LUM	3	6	4	6	3	4	3	5	4	4
R GMAX	4	7	7	4	7	8	8	8	8	9
L GMAX	9	9	8	8	8	7	7	6	7	7
R HAM	5	4	5	7	4	9	9	9	9	8
L HAM	8	8	9	9	9	3	5	2	6	3

Subject 103-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	2	1	2	1	1	1	1	1	1	1
R TH1	1	2	1	6	6	4	5	5	3	4
R TH2	7	0	7	0	0	0	0	0	0	0
L TH	3	4	4	2	3	10	2	3	5	2
R LUM	5	3	5	4	4	5	6	6	6	6
L LUM	6	5	3	5	5	3	3	4	2	5
R GMAX	8	7	8	7	7	7	9	9	8	8
L GMAX	9	8	10	8	8	6	7	7	7	9
R HAM1	4	6	6	3	2	8	8	8	9	7
R HAM2	0	0	0	0	0	9	0	0	0	0
L HAM	0	9	9	9	9	2	4	2	4	3

Subject 104-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	2	8	3	7	5	6	3	7	4	4
L TH	4	3	5	2	2	5	7	4	7	7
R LUM	3	7	6	6	7	7	6	5	6	3
L LUM	7	4	7	4	6	4	4	6	5	6
R GMAX	6	2	2	3	3	9	8	8	8	9
L GMAX	9	5	8	8	8	3	2	2	2	2
R HAM	5	6	4	5	4	8	9	9	9	8
L HAM	8	9	9	9	9	2	5	3	3	5

Subject 105-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	5	4	4	4	4	5	4	2	4	2
L TH	0	0	0	0	0	0	0	0	0	0
R LUM	3	5	5	5	3	6	6	4	5	5
L LUM	2	3	3	3	2	2	3	3	3	4
R GMAX	6	7	6	6	6	7	7	7	7	6
L GMAX	7	6	7	7	7	4	5	6	6	7
R HAM	4	2	2	2	5	8	0	0	0	8
L HAM	8	8	8	8	8	3	2	5	2	3

Subject 106-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	2	6	5	3	1	3	3	4	4	1
R TH1	9	1	2	1	16	1	8	2	8	7
R TH2	0	3	10	4	0	7	13	9	21	0
L TH1	1	8	4	2	4	4	9	3	2	0
L TH2	5	0	7	6	11	5	11	8	10	2
L TH3	0	0	12	0	0	8	0	10	12	4
L TH4	0	0	0	0	0	11	0	0	17	0
L TH5	0	0	0	0	0	0	0	0	20	0
R LUM1	4	5	3	5	5	2	7	6	1	3
R LUM2	0	7	9	8	13	6	12	0	3	6
R LUM3	0	0	0	0	0	0	0	0	5	0
R LUM4	0	0	0	0	0	0	0	0	6	0
R LUM5	0	0	0	0	0	0	0	0	13	0
R LUM6	0	0	0	0	0	0	0	0	15	0
R LUM7	0	0	0	0	0	0	0	0	16	0
R LUM8	0	0	0	0	0	0	0	0	18	0
R LUM 9	0	0	0	0	0	0	0	0	22	0
R LUM10	0	0	0	0	0	0	0	0	23	0
L LUM1	7	2	7	7	7	9	6	5	7	5
L LUM2	0	4	0	0	9	0	0	0	19	0
L LUM3	0	0	0	0	14	0	0	0	0	0
R GMAX1	6	9	9	9	3	12	14	7	11	9
R GMAX2	0	0	0	0	12	0	0	0	14	0
L GMAX1	8	10	11	11	6	0	10	11	9	8
L GMAX2	0	0	0	0	8	0	0	0	0	0
L GMAX 3	0	0	0	0	10	0	0	0	0	0
L GMAX4	0	0	0	0	15	0	0	0	0	0
R HAM1	3	11	13	10	2	0	1	1	24	10
R HAM2	0	0	0	0	0	0	2	0	0	0
R HAM3	0	0	0	0	0	0	4	0	0	0
R HAM4	0	0	0	0	0	0	5	0	0	0
L HAM	0	0	0	0	0	0	0	0	0	0

Subject 107-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	2	1	1	1	1	1	1
R TH1	3	3	2	1	2	3	3	3	3	8
R TH2	0	0	6	8	0	0	0	0	0	0
L TH	0	0	0	5	0	0	0	0	0	0
R LUM1	4	2	3	6	3	4	10	5	7	4
R LUM2	0	0	0	0	0	0	0	8	0	0
L LUM	5	5	7	7	4	5	4	9	0	3
R GMAX1	7	6	5	3	6	8	7	7	5	6
R GMAX2	0	0	0	0	0	0	8	0	0	0
L GMAX1	8	8	9	10	8	7	5	4	4	5
L GMAX2	0	0	0	0	0	0	9		0	0
R HAM	2	4	4	3	5	6	6	6	6	7
L HAM	6	7	8	9	7	2	2	2	2	2

Subject 108-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	3	5	6	5	6	5	4	4	4	6
L TH	6	4	5	7	5	4	5	6	6	4
R LUM	2	3	3	3	3	6	6	5	5	5
L LUM	7	6	4	6	4	3	3	3	3	3
R GMAX	5	7	7	4	7	9	9	9	8	9
L GMAX	8	8	8	8	9	7	7	7	7	7
R HAM	4	2	2	2	2	8	8	8	0	8
L HAM	9	0	0	0	8	2	2	2	2	2

Subject 109-Control

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	4	1	13	3	1	1	1	1	1	2
R TH1	1	5	1	1	6	4	2	7	5	1
R TH2	2	8	2	2	0	0	0	0	0	7
R TH3	3	0	3	4	0	0	0	0	0	0
R TH4	10	0	4	10	0	0	0	0	0	0
R TH5	0	0	5	0	0	0	0	0	0	0
R TH6	0	0	7	0	0	0	0	0	0	0
R TH7	0	0	8	0	0	0	0	0	0	0
R TH8	0	0	9	0	0	0	0	0	0	0
R TH9	0	0	10	0	0	0	0	0	0	0
R TH10	0	0	11	0	0	0	0	0	0	0
R TH11	0	0	12	0	0	0	0	0	0	0
R TH12	0	0	14	0	0	0	0	0	0	0
L TH	9	6	16	9	2	6	6	5	4	5
R LUM	8	3	15	6	3	7	4	4	2	4
L LUM	6	4	17	7	5	2	3	3	0	0
R MAX	7	7	19	8	8	0	9	8	6	6
L MAX	11	9	20	11	7	5	5	6	7	8
R HAM	5	2	18	5	0	8	8	9	3	3
L HAM	0	0	6	0	4	3	2	2	0	9

III. Experimental Group - Right Hip Hyperextension

Subject 201-Experimental

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	3	1	1	2	2	1	1	1	1
R TH	4	1	4	3	3	3	3	2	3	3
L TH	5	5	7	4	7	7	4	4	4	8
R LUM	3	2	3	5	4	8	7	7	7	7
L LUM	6	6	5	7	6	5	6	6	6	5
R GMAX	7	0	6	6	5	0	0	0	0	0
L GMAX	0	0	0	0	0	6	8	8	8	6
R HAM	2	4	2	2	1	1	2	3	2	2
L HAM	0	0	0	0	0	4	5	5	5	4

Subject 202-Experimental

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	2	3	1	2	2	1	1	2	4	1
R TH1	1	1	7	1	1	3	4	8	1	5
R TH2	4	0	0	8	9	0	0	0	7	0
R TH3	9	0	0	0	0	0	0	0	0	0
L TH1	3	7	4	4	3	7	2	1	2	4
L TH2	0	0	0	0	0	0	0	3	3	0
L TH3	0	0	0	0	0	0	0	7	9	0
R LUM	5	8	3	6	7	5	3	6	8	6
L LUM	7	5	6	5	4	4	5	5	6	3
R GMAX	8	4	5	7	5	8	7	9	10	8
L GMAX	11	2	9	10	8	6	8	10	11	7
R HAM	6	6	2	3	6	0	9	11	0	0
L HAM	10	9	8	9	0	2	6	4	5	2

Subject 203-Experimental

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	8	7	8	7	5	3	2	6	4	4
L TH	6	6	6	5	6	6	6	5	2	2
R LUM	3	3	3	4	3	2	3	3	3	3
L LUM	4	2	4	3	2	4	4	4	5	5
R GMAX	5	5	5	6	7	8	8	7	8	8
L GMAX	7	8	7	8	8	7	7	8	7	7
R HAM	2	4	2	2	4	0	0	0	0	0
L HAM	0	0	0	9	9	5	5	2	6	6

Subject 204-Experimental

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	5	5	3	1	1	1	1	1	1	1
R TH	1	1	7	5	5	5	7	7	7	7
L TH	4	0	0	0	0	0	0	0	0	0
R LUM	6	3	2	2	2	3	6	5	6	6
L LUM	3	2	6	4	4	6	4	3	4	4
R GMAX	7	6	1	3	3	2	5	6	5	5
L GMAX	0	0	8	0	0	0	3	4	3	3
R HAM	2	4	5	6	6	4	0	8	8	8
L HAM	8	7	4	0	0	7	2	2	2	2

Subject 205-Experimental

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	1	1	1	1	1	1	1
R TH1	14	8	3	8	8	7	5	4	5	3
R TH2	0	0	0	0	9	0	0	0	0	0
L TH	13	4	7	4	11	9	9	6	3	5
R LUM1	3	2	4	3	7	6	3	5	6	4
R LUM2	8	0	0	0	0	0	0	0	0	0
R LUM3	12	0	0	0	0	0	0	0	0	0
L LUM1	2	6	6	5	3	3	4	3	4	7
L LUM2	9	0	0	0	10	0	0	0	0	0
R GMAX	6	5	5	6	6	8	8	9	9	6
L GMAX1	7	9	9	9	4	4	6	7	7	9
L GMAX2	11	0	0	0	0	0	0	0	0	0
R HAM1	5	3	2	2	5	5	7	8	8	2
R HAM2	10	0	0	0	0	0	0	0	0	0
L HAM	4	7	8	7	2	2	2	2	2	8

Subject 206-Experimental

TRIAL	1	2	3	4	5	6	7	8	9	10
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	4	3	4	5	3	4	5	3	4	3
L TH	7	5	7	7	5	6	7	4	3	5
R LUM	3	4	5	3	4	3	6	5	7	2
L LUM	5	7	8	6	7	7	3	7	6	4
R GMAX	8	8	6	8	8	9	8	9	8	9
L GMAX	2	2	2	2	2	2	2	2	2	6
R HAM	6	6	3	4	6	8	9	8	9	8
L HAM	9	9	9	9	9	5	4	6	5	7

IV. Experimental Group - Left Hip Hyperextension

Subject 201-Experimental

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	6	3	3	3	3	3	8	7	3	2
L TH	3	4	4	7	7	0	7	8	0	3
R LUM	4	5	5	4	4	7	6	5	6	6
L LUM	7	7	6	5	6	5	4	4	5	5
R GMAX	5	6	7	6	5	0	0	0	0	0
L GMAX	0	0	0	0	0	6	5	6	7	7
R HAM	1	2	2	2	2	2	2	2	2	0
L HAM	0	0	0	0	0	4	3	3	4	4

Subject 202-Experimental

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	2	3	1	4	1	2	2	2	2	1
R TH1	1	2	2	1	7	7	7	5	8	5
R TH2	8	10	8	2	0	0	0	0	0	0
R TH3	0	0	0	3	0	0	0	0	0	0
R TH4	0	0	0	10	0	0	0	0	0	0
L TH1	7	1	5	7	2	1	1	1	1	8
L TH2	0	7	0	0	0	6	3	7	3	0
L TH3	0	0	0	0	0	0	6	0	7	0
R LUM	5	5	6	8	5	7	8	6	6	6
L LUM	6	8	7	9	6	4	5	4	5	3
R GMAX	4	6	4	6	4	8	9	9	11	7
L GMAX	10	11	10	12	9	10	10	8	9	4
R HAM	3	4	3	5	3	0	0	0	1	0
L HAM	9	9	9	11	8	3	4	3	4	2

Subject 203-Experimental

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	6	6	7	7	6	5	3	2	6	4
L TH	2	3	5	4	5	6	2	6	4	6
R LUM	3	5	4	3	4	4	4	4	2	2
L LUM	4	2	2	2	3	3	5	5	5	5
R GMAX	8	7	6	6	7	8	8	8	8	8
L GMAX	7	8	8	8	8	7	7	7	7	7
R HAM	5	4	3	5	2	0	0	0	0	0
L HAM	0	0	0	0	9	2	6	3	3	3

Subject 204-Experimental

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	8	6	3	3	5	8	7	8	5	6
L TH	0	0	0	0	0	0	0	0	0	0
R LUM	6	3	5	5	3	4	6	6	7	7
L LUM	4	5	4	4	6	7	4	4	4	4
R GMAX	5	4	0	7	2	3	5	5	8	5
L GMAX	3	0	0	6	0	5	3	3	3	3
R HAM	7	2	2	0	4	6	8	7	6	8
L HAM	2	7	6	2	7	2	2	2	2	2

Subject 205-Experimental

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	2	1	1	1	0
R TH1	2	2	7	2	4	5	4	5	4	0
R TH2	0	0	0	0	0	0	0	9	0	0
L TH	4	5	6	5	7	9	5	10	7	0
R LUM	3	4	4	3	3	4	3	7	6	0
L LUM	7	7	5	8	5	3	6	8	3	0
R GMAX	6	6	3	6	9	8	9	6	9	0
L GMAX	9	9	9	9	6	6	7	3	5	0
R HAM	5	3	2	4	8	7	8	4	8	0
L HAM	8	8	8	7	2	1	2	2	2	0

Subject 206-Experimental

TRIAL	11	12	13	14	15	16	17	18	19	20
TRIG	1	1	1	1	1	1	1	1	1	1
R TH	4	5	6	5	6	4	4	3	3	4
L TH	7	7	3	6	7	7	6	6	4	7
R LUM	5	4	5	4	4	5	3	4	5	5
L LUM	8	6	8	7	8	6	7	7	7	6
R GMAX	6	8	7	8	5	8	8	8	8	8
L GMAX	2	2	2	2	2	2	2	2	2	2
R HAM	3	3	4	3	3	9	9	9	9	9
L HAM	9	9	9	9	9	3	5	5	6	3

APPENDIX B

Median Muscle Firing Pattern

I. Control Group - Right Hip Hyperextension

R SIDE	TRIG	R HAM	L HAM	R GMAX-1	R GMAX-2	L GMAX	L LUM	R LUM-1	R LUM-2	L TH	R TH-1	R TH-2	R TH-3
101	1	6	3	7	0	8	4	2	0	0	5	0	0
102	1	6	7	5	0	8	4	3	0	3	2	0	0
103	1	6	3	5	0	7	2	3	0	3	4	0	0
104	1	7	2	6	0	5	3	4	0	2	4	0	0
105	1	2	1	6	0	7	3	5	0	0	4	0	0
106	2	6	0	5	9	8	5	2	5	3	1	4	7
107	1	6	4	6	0	7	5	3	0	2	3	0	0
108	1	3	2	8	0	9	5	4	0	6	7	0	0
109	1	6	7	8	0	7	3	4	0	5	2	0	0

II. Control Group - Left Hip Hyperextension

L SIDE	TRIG	L HAM	R HAM	L GMAX	R GMAX	L LUM	R LUM-1	R LUM-2	L TH-1	L TH-2	L TH-3	R TH-1	R TH-2
101	1	2	4	7	6	3	2	0	5	0	0	3	0
102	1	6	7	7	7	3	4	0	5	0	0	2	0
103	1	3	6	7	7	4	5	0	2	0	0	3	0
104	1	6	7	2	7	4	5	0	3	0	0	3	0
105	1	6	2	6	6	3	5	0	0	0	0	4	0
106	2	0	6	8	7	6	4	6	1	3	6	4	5
107	1	3	5	7	6	4	3	0	0	0	0	2	0
108	1	2	3	8	7	4	5	0	6	0	0	6	0
109	1	2	6	8	8	4	5	0	7	0	0	1	3

III. Experimental Group - Median Muscle Firing Pattern For Right Hip Hyperextension

R SIDE	TRIG	L HAM	R HAM	L GMAX-1	L GMAX-2	R GMAX	L LUM	R LUM	L TH	R TH
201	1	2	2	3	0	0	5	5	4	3
202	1	5	3	8	0	7	4	6	2	1
203	1	4	1	8	0	7	3	2	6	5
204	1	3	0	2	6	5	4	4	0	7
205	1	2	4	7	0	5	3	3	6	5
206	1	7	6	2	0	7	5	3	4	2

IV. Experimental Group - Median Muscle Firing Pattern For Left Hip Hyperextension

L SIDE	TRIG	L HAM	R HAM	L GMAX	R GMAX	L LUM	R LUM	L TH-1	L TH-2	R TH
201	1	2	3	4	4	7	7	6	0	5
202	2	7	3	8	8	5	6	1	1	4
203	1	2	1	7	8	3	4	5	0	6
204	1	2	7	3	5	4	6	0	0	7
205	1	2	4	6	5	5	3	5	0	3
206	1	7	5	2	8	6	4	5	0	3

APPENDIX C

Percent Occurrence Of Muscle Firing Patterns Based On Medians

I. Control Group - Right Hip Hyperextension

SEQUENCE	TRIG	L HAM	R HAM	L GMAX	R GMAX	L LUM	R LUM	L TH	R TH
0	0	11%	0	0	0	0	0	22%	0
1	88%	11%	0	0	0	0	0	0	11%
2	12%	22%	11%	0	0	11%	22%	22%	22%
3	0	22%	11%	0	0	33%	33%	33%	11%
4	0	11%	0	0	0	22%	33%	0	33%
5	0	0	0	11%	33%	33%	11%	11%	11%
6	0	0	67%	0	33%	0	0	11%	0
7	0	22%	11%	44%	11%	0	0	0	11%
8	0	0	0	33%	22%	0	0	0	0
9	0	0	0	11%	0	0	0	0	0

II. Control Group - Left Hip Hyperextension

SEQUENCE	TRIGGER	L HAM	R HAM	L GMAX	R GMAX	L LUM	R LUM	L TH	R TH
0	0	11%	0	0	0	0	0	22%	0
1	89%	0	0	0	0	0	0	11%	11%
2	11%	33%	11%	11%	0	0	11%	11%	22%
3	0	22%	11%	0	0	33%	11%	11%	33%
4	0	0	11%	0	0	55%	22%	0	22%
5	0	0	11%	0	0	11%	55%	22%	0
6	0	33%	33%	11%	33%	0	0	11%	11%
7	0	0	22%	44%	55%	0	0	11%	0
8	0	0	0	33%	11%	0	0	0	0
9	0	0	0	0	0	0	0	0	0

III. Experimental Group - Right Hip Hyperextension

SEQUENCE	TRIG	L HAM	R HAM	L GMAX	R GMAX	L LUM	R LUM	L TH	R TH
0	0	0	17%	0	17%	0	0	17%	0
1	100%	0	16%	0	0	0	0	0	17%
2	0	33%	16%	33%	0	0	16%	17%	17%
3	0	16%	17%	17%	0	33%	33%	0	17%
4	0	16%	17%	0	0	33%	17%	33%	0
5	0	16%	0	0	33%	33%	17%	0	33%
6	0	0	17%	0	0	0	17%	33%	0
7	0	16%	0	17%	50%	0	0	0	16%
8	0	0	0	33%	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0

IV. Experimental Group - Left Hip Hyperextension

SEQUENCE	TRIG	L HAM	R HAM	L GMAX	R GMAX	L LUM	R LUM	L TH	R TH
0	0	0	0	0	0	0	0	16%	0
1	83%	0	17%	0	0	0	0	17%	0
2	17%	67%	7%	16%	0	0	0	0	0
3	0	0	33%	16%	0	16%	17%	0	33%
4	0	0	17%	17%	17%	17%	33%	0	16%
5	0	0	16%	0	33%	33%	0	50%	17%
6	0	0	0	17%	0	17%	33%	17%	17%
7	0	33%	17%	17%	0	17%	17%	0	17%
8	0	0	0	17%	50%	0	0	0	0
9	0	0	0	0	0	0	0	0	0

APPENDIX D

DATA COLLECTION SHEET

Subject No.:____________

Date:__________________

Name:____

Group:_________________________

D.O.B.:____________________________ Sex: Male_____ Female_____

1. Have you ever injured your back? Yes___ No___

2.Past surgical history: ____

____

TEST	RESULT
Trunk flexion	
Trunk extension	
Trunk S.B.-right **Trunk S.B.-left**	
True leg length	
Apparent leg length	
Hamstring flexibility	
Mod. Thomas Test	
Hams/Erector spinae length	

APPENDIX E

WRITTEN INFORMED CONSENT STATEMENT

Subject's Name:____

I have freely consented to take part in a scientific study entitled, "Muscle Movement Patterns of the Selected Extensor's During Prone Hip Hyperextension." This research study is designed to measure movement patterns of the hamstrings, gluteus maximus, and lumbar erector spinae. The database will include individuals with back/spinal disorders, and individuals without back/spinal disorders. All of the tests will be conducted in the Clinical Center-Dept. of Rehabilitation Medicine and no invasive measurement techniques will be used.

If I am apprehensive about lying on my stomach and performing leg lifts I will withdraw from taking part in that activity and also understand that I am free to withdraw from this study at any time without penalty. Additionally, no permanent identifiable photographic data will be retained without my permission. I understand all results will be treated with strict confidence, and I will remain anonymous. On request and within these restrictions, results will be made available to me upon my request.

I understand that in the unlikely event of injury resulting from research procedures, Michigan State University, its agents, and employees will assume that responsibility as required by law. Emergency medical treatment for injuries or illness is available where the injury or illness is incurred in the course of an experiment. I have been advised that I should look toward my own health insurance program for payment of said medical expenses.

Date:______________

Signed:__________________________________
Address:__________________________________
____
Telephone number:_________________________

Witness:_____________________________

Principal Investigator: J. Nelson P.T.
A114 Clinical Center
Dept. P.M.R. 355-7648

Advisor: D. Ulibarri, PhD.
101 I.M. Circle
355-4733

APPENDIX F

McGill Short-Form Pain Questionnaire

Patient's Name________________________ Date___________

	NONE	MILD	MODERATE	SEVERE
THROBBING	1)___	2)___	3)______	4)_____
SHOOTING	1)___	2)___	3)______	4)_____
STABBING	1)___	2)___	3)______	4)_____
SHARP	1)___	2)___	3)______	4)_____
CRAMPING	1)___	2)___	3)______	4)_____
GNAWING	1)___	2)___	3)______	4)_____
HOT-BURNING	1)___	2)___	3)______	4)_____
ACHING	1)___	2)___	3)______	4)_____
HEAVY	1)___	2)___	3)______	4)_____
TENDER	1)___	2)___	3)______	4)_____
SPLITTING	1)___	2)___	3)______	4)_____
TIRING-EXHAUSTING	1)___	2)___	3)______	4)_____
SICKENING	1)___	2)___	3)______	4)_____
FEARFUL	1)___	2)___	3)______	4)_____
PUNISHING-CRUEL	1)___	2)___	3)______	4)_____

PPI:

0 NO PAIN _____

1 MILD _____

2 DISCOMFORTING _____

3 DISTRESSING _____ ________________________________

4 HORRIBLE _____ NO PAIN WORST POSSIBLE PAIN

5 EXCRUCIATING _____

Reprinted with permission. Melzack R. The Short-Form McGill Pain Questionnaire. *Pain* 1987; 30:191-197.

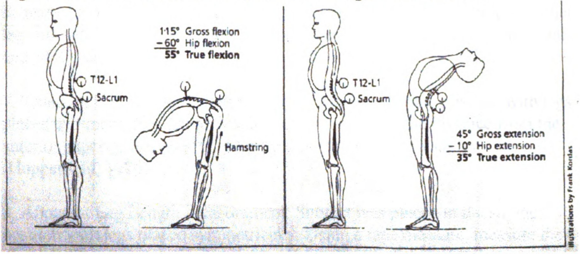
APPENDIX G

DEFINITIONS

1. Active Trunk Flexion: The subject was standing tall. Two inclinometers were used to measure the motion. The interspace of T12-L1 and the sacrum (center of posterior superior iliac spines) were marked using non-permanent marker. One inclinometer was placed over the sacrum, while the other was placed over the T12-L1 interspace. The value of the T12-L1 measure represented gross flexion. The value from the sacral inclinometer represented hip flexion. The subject flexed forward and both inclinometers were read. The value of true trunk flexion was determined by subtracting gross flexion from hip flexion (Mayer, 1985).See Figure 4.

2. Active Trunk Extension: The inclinometers were set-up in the same fashion as active trunk flexion, except the subject extended backward. The value of true extension was determined by subtracting gross extension (measured from T12-L1 interspace) from hip extension (measured from sacrum) (Mayer, 1985). See Figure 4.

Figure 4. Trunk Flexion and Extension Using an Inclinometer



Mayer, T. (1985). Using physical measurements to assess low back pain. Journal of Musculoskeletal Medicine, 6, 44-59.

3. Active Trunk Sidebending: The inclinometers were set in the same fashion as trunk flexion. The T12-L1 represented gross sidebending, and the sacral inclinometer represented lateral pelvic bend. The subject was asked to sidebend to one side, measurements were taken. The subject was then asked to sidebend to the other side and measurements were taken. The true value of active trunk sidebending was calculated by subtracting the gross sidebending from the lateral pelvic sidebending (Mayer, 1985)

4. Modified Thomas Test: A test that can be used to measure the iliopsoas. The subject was positioned supine with the legs placed at the edge of the plinth. The leg not being assessed was held in flexion with the foot against the examiner's thigh. The leg being assessed is placed in extension at the hip, and the knee is in 90°of flexion. This represented normal flexibility. A positive test for tight iliopsoas was if the hip were at 15° of flexion at the hip. (Kendall and McCreary, 1983).

5. Lumbar Erector Spinae Length: The subject was positioned in long sitting. They were asked to touch their toes with their finger tips while keeping the knee's straight. This represented normal flexibility (Kendall and McCreary, 1983).

6. Hamstring Flexibility: The subject was in a supine position. The hamstrings group being assessed was flexed at the hip to 70°, while the other leg was held down on the table. This represented normal flexibility (Kendall and McCreary, 1983).

7. True Leg Length Measurement: Subject was in a supine position with legs placed symmetrically. Using a tape measure, measure the distance from the anterior superior iliac spines to the medial malleoli of the ankles (Hoppenfeld, 1976).

8. Apparent Leg Length Measurement: Subject was placed in the supine position with legs placed symmetrically. Using a tape measure, measure the distance from the umbilicus to the medial malleolli of the ankles (Hoppenfeld, 1976).