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Effects of core stability exercises and hamstring stretches on hip range of motion

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EFFECTS OF CORE STABILITY EXERCISES AND HAMSTRING STRETCHES ON
HIP RANGE OF MOTION

A Thesis

Presented to

The Faculty of the Department of Human Performance

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

By

Paul-Wayne J. Mahlow, ATC, CSCS

December 2003

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Abstract

EFFECTS OF CORE STABILITY EXERCISES AND HAMSTRING STRETCHES ON HIP RANGE OF MOTION

by Paul-Wayne J. Mahlow

A review of literature indicates a lack of research on effects of muscle imbalances on the range of motion (ROM) of the body's joints. Intercollegiate athletes from a NCAA Division II university were randomly assigned to one of four groups. Participants learned either hamstring stretches, core stabilization exercises, both hamstring stretches and core stabilization exercises, or were controls. All groups were measured for hip ROM in the straight leg raising test position initially and each week thereafter for six weeks. Data were analyzed in a two-way, 4 (group) x 7 (test week) ANOVA with repeated measures on the last factor. The analysis failed to reveal statistically significant main effect of group or interaction effect of group by test week. The repeated measure, test week, significantly affected hip ROM as measured by degrees of hip flexion. In-season data collection might have confounded the group effects in this study.

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DEDICATION

All of my work past, present, and future, is dedicated to Jesus Christ and to my loving family. Pam, I love you and I am excited to begin the journey of parenthood with you. Matthew William, I will always do my best to help you grow into manhood. To my family, I love you Pop, Mother, Amanda, Erin, Keki, Elizabeth, Andrew, Britt, Jodi, and Zechariah. Doug, Sharon, Jen, Mike, and Kaela, I very happy you are a part of my family now!

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Chapter 1

Introduction

Core stability is the ability to control body posture and momentum created by movement in the torso, pelvic, and shoulder regions of the body. Ideally, core stability eliminates muscle imbalances around the joints of the body to help increase strength and improve normal range of motion in the joints of the body at the same time (Kola, 2000). Improving the alignment and orientation of the body's joints through restoration of muscle balance is one of the goals of core stability exercise programs (Kola, 2000; Sahrmann, 2001). Currently, large athletic corporations, personal trainers, pilates instructors, and rehabilitation specialists are creating products and programs that claim to improve core stability.

Lengthening tight muscles and strengthening inactive muscles can help restore muscle balance. The concepts of preventative strengthening to improve flexibility and improving strength through proper body mechanics to limit muscle imbalance should be appealing to many in sports medicine. Professionals in athletics and sports medicine are constrained by time in that coaches and team management often want injured athletes participating as soon as possible. Core stability was suggested to the San José State University's Athletic Trainers' Club as a way to quickly and efficiently improve strength, flexibility, and balance by equalizing muscle forces of the body (Iglehart, 2001).

Many people, including intercollegiate athletes, suffer from muscle imbalances in various areas in the body. Intercollegiate athletes depend on their bodies for high performance. The combination of muscle tightness and muscle weakness resulting in muscle imbalance around the pelvis has been termed by Jull and Janda (1987) the "pelvic

crossed syndrome.” The body’s postural muscles, including the erector spinae, iliopsoas, rectus femoris, and hamstrings tend to tighten and lack range of motion to increase joint stabilization in response to physical stress or injury. The body’s phasic muscles that tend to lengthen and lose effective joint stabilization in response to inactivity or injury include the rectus abdominis, internal and external obliques, the gluteals, and the quadriceps (Norris, 1993). This imbalance promotes a forward pelvic tilt, increased lumbar lordosis, and a slightly flexed position of the hip. These positions can lead to further problems, especially lower back injuries, hip tightness, and tight hamstrings (Jull & Janda, 1987). Jull and Janda point out what appears to be a relationship between lumbo-pelvic stability and hamstring flexibility in the pelvic crossed syndrome. If the preventative treatment of core stabilization can improve muscle imbalances in the body, then it should be able to improve the relationship between lumbo-pelvic stability and hamstring flexibility. One way to monitor for signs of pelvic crossed syndrome would be through range of motion measurements around the lumbar spine and pelvis to make sure the postural muscles were not losing range of motion while the phasic muscles were gaining range of motion. Flexibility and joint range of motion can be measured in the number of degrees an isolated joint can move. Range of motion measurements act as a guideline for joint flexibility, and can indicate a lack of flexibility, a normal range of flexibility, or there is excessive flexibility that may result in an unstable joint (Kendall, McCreary, and Provance, 1993).

Jull and Janda (1987) and Norris (1993; 2001a; 2001b) suggested a three-stage approach to treat muscle imbalances of the lumbar spine, pelvis, and thighs. Chaitow

(2001) agreed with Norris and with Jull and Janda in the patterns of dysfunction chapter in his text. The treatment approach begins with returning tightened or overactive muscle to their original length, then strengthening weak or inhibited muscles, and finally creating sound patterns of movement promoting good movement and ideally preventing reoccurrence of muscle imbalances (Jull & Janda, 1987). This approach is very similar to standard rehabilitation protocol for a chronic injury: regain range of motion, strengthen through the entire range of motion, and teach functional movements once the range of motion has been strengthened (J. Wilkinson, PT, ACI; personal communications, September, 1998). The approach of lengthening, then strengthening seems to be at odds with performing core stability exercises as a preventative means of improving the relationship between lumbo-pelvic stability and hamstring flexibility.

Competitive athletes frequently lack hamstring length as indicated by range of motion measurements in many clinics and athletic training rooms (Ekstrand & Gillquist, 1983). Many athletes end up missing large amounts of practice and competition, up to 3 to 6 weeks per injury due to minor or moderate hamstring strains (Herrington, 2000).

The present study investigated whether core muscles of the abdomen could help properly align the spine, decreasing excess work by the hamstring group, leading to more flexibility and greater range of motion in the hamstrings. Using athletes with no recent history of injury, multiple approaches were attempted to increase hamstring length: core stability exercises, hamstring stretches, and a combination of core stability exercises and hamstring stretches; all were measured by the passive straight leg raising test to determine if any approach improved hamstring flexibility more than another approach.

The participants in these three different treatment groups were also compared to a control group that neither performed core stability exercises nor hamstring stretches.

Statement of Purpose

The purpose of the present study was to examine the effect of core stability exercises, static stretching exercises, a combination of core stability exercises and static stretching exercises, and a control on hamstring flexibility as measured on hip flexion in the passive straight leg raising test position.

Hypotheses

The following null hypotheses were proposed for the study:

1. Type of exercise and test week would not affect amount of hip flexion in the passive straight leg raising test position.
2. Type of exercise would not affect amount of hip flexion in the passive straight leg raising test position.
3. Test week would not affect amount of hip flexion in the passive straight leg raising test position.

Limitations

Limitations are possible shortcomings or influences that cannot be controlled or results of delimitations imposed by the investigator (Thomas & Nelson, 1996).

Anticipated uncontrollable influences in the present study concern the participants' activity levels. All participants were volunteers recruited from an intercollegiate athletic team of a Division II university in the west. The athletes continued practice, weightlifting workouts, and participation in games during data collection for the present

study. Additional workouts outside of those workouts and competitions scheduled for the university's team could have interfered with the effects of the study. Participation time was limited to no more than 20 minutes per session per participant in an attempt to limit participant mortality with long workouts, yet still be able to have enough time to complete two or three sets of exercises in the present study. Participant mortality was also a concern given their studies and other activity commitments. To attempt to create a workable time schedule for everyone involved, scheduling exercise sessions into the athletes' busy days was done as far in advance as possible. Participating athletes were contacted to confirm exercise appointments to prevent missed treatments. The participants were student athletes, making it difficult to control for posture during class and study time. No EMG recording was done in the present study because the deep muscles in the abdomen would require fine wire placement in the abdomen; not only would this have taken time to prepare each participant every session, but it would have made recruiting volunteers difficult.

Delimitations

Delimitations have been placed on the present study to create a workable research problem (Thomas & Nelson, 1996). All participants were enrolled students and part of the athletic department at the Division II university in the west where testing occurred. All athletes were from the same team to reduce variation in workouts. Intercollegiate athletes were studied because extended deliberate practice is needed to reach high levels of performance, and the best performers try to improve their performances by focusing on their weaknesses (Ericsson, 1998). All participants in the present study were free of

back, hip, or leg injuries during the six months prior to data collection as defined by the NCAA guidelines. Participants were screened for these health factors prior to the study to provide the study supervisor with any risk factors, contraindications, and special needs to develop a sound and effective exercise prescription while minimizing risk to the participants (ACSM, 2000). The effects of core stability on a healthy population should be measured before attempting to apply the concept to rehabilitation of an injured population. Participants were randomly placed into one of the four groups.

Definition of Terms

Core stability is a general term for balanced muscle strength through the shoulders, torso, and hips that allows efficient joint movement and good control of body momentum while moving.

Static stretch is to elongate or extend the muscle in length (Grossman, Sahrman, & Rose, 1982). In static stretching, a position of stretch is held for a specified length of time without movement.

Range of motion (ROM) is the measure of the number of degrees an isolated joint can move. Hamstring range of motion (ROM) is a continuous dependent variable. As per Kendall, McCreary, and Provance (1993), hamstring ROM was measured by the amount of hip flexion with concurrent knee extension in the passive straight leg-raising test (SLR). A measurement was made at the hip joint and measured in degrees by a large goniometer.

Injury is defined by the NCAA as occurring as a result of participation in an organized intercollegiate sport practice or contest; requires medical attention by a team

physician or athletic trainer; and results in a student athlete's restriction in practices or competitions for one or more days beyond the day of injury. Per the NCAA, injuries incurred not practicing or playing are not to be considered injuries reported to the surveillance system (2002-03 NCAA injury surveillance system).

Importance of the Study

Studying the effects of core stability on hamstring range of motion could lead to a better understanding of the hamstrings and how they are a part of pelvic and low back movements. Improving understanding as to whether strengthening, stretching, or a combination of the two is the most efficient means of treating hamstring injuries could improve quality of care for hamstring injuries. Improved lumbar and pelvic alignment can create a more effective use of muscles around the pelvis and lumbar spine.

Core stability research is not a keyword or Medical Subject Heading (MeSH) term, and scholarly information was found dispersed through many different areas of study. Hamstring information was easier to locate in databases such as Medline, Pubmed and Sciencedirect. Many of those articles that do address core stability in some way do not address improving function in intercollegiate level athletes (Arokoski, Valta, Airaksinen, & Kankaanpaa, 2001; Blackburn & Portney, 1981; Delisle, Gagnon, & Sicard, 1997; Elia, Bohannon, Cameron, & Albro, 1996; Gracovetsky, Kary, Pitchen, Levy, & Ben Said, 1989; Hodges & Richardson, 1999, 1997, 1996; Mayhew, Norton, & Sahrmann, 1983; Panjabi, 1992a & b; Stokes & Aberly, 1980; Walker, Rothstein, Finucane, & Lamb, 1987). Much of the orthopedic research is done as case studies and

there are few randomized, controlled trial studies. The present study was done with volunteer athletes randomly assigned in a controlled trial study.

The present study is important for the economy of time and money.

Intercollegiate student athletes are busy and do not have much extra time. The chance to have intercollegiate athletes participate in a scientific experiment is a great opportunity due to time pressure from coaches, academic requirements, and their own personal workout schedules rarely leave much extra time for research participation. The utilization of intercollegiate athletes for the present study is important for those involved with sports medicine because the application of some studies that had non-athletic participants can be difficult. The present study attempted to minimize the time issue for the participants; they participated in the university athletic weight room where they already exercise and never spent more than 20 minutes participating in the assigned level of activity. Participants focused on the quality of their movements and not the amount of repetitions or time spent on their treatments.

Chapter 2

Review of Literature

The literature review is presented in categories of hamstring range of motion (ROM), lumbo-pelvic stability, abdominal strength, and neural factors of motor control. Range of motion (ROM) is the amount of motion that is available at a specific joint (Norkin & White, 1985). Lumbo-pelvic stability is the combined stability of the lumbar spine and the pelvic girdle. The transverse abdominis is an abdominal muscle which generally and non-specifically stabilizes the torso before limb movement occurs; no other abdominal group studied shows a “feedforward” movement pattern like the transverse abdominis (Hodges & Richardson, 1997). Neural factors of motor control address the concept that people can change movement patterns of limbs or the order of recruitment of muscles.

The majority of research reviewed appears to reference muscular stabilization to protect the spine against further lumbar spine injury (Arokoski, Valta, Airaksinen, & Kankaanpaa, 2001; Blackburn & Portney, 1981; Gracovetsky, Kary, Pitchen, Levy, & Ben Said, 1989; Graves, 1994; Hodges & Richardson, 1996; Jull & Richardson, 2000; Panjabi, 1992a, 1992b; Richardson, Jull, Hodges, & Hides, 1999; Robison, 1992; Saal, 1992; Walker, Rothstein, Finucane, & Lamb, 1987). A focus on protecting the lumbar spine is prevalent to the extent that many of the studies about hamstring stretching are from the viewpoint of improving lumbar movement (Kendall, McCreary, & Provance, 1993; Li, McClure, & Pratt, 1996; Sahrman in Li et al., 1996 discussion; Stokes & Aberly, 1980; van Wingerden, Vleeming, Kleinresink, & Stoeckart, 1997).

Hip Flexion Range of Motion

Measuring Hip Flexion.

Literature on hamstring range of motion (ROM) varies with respect to how range of motion is measured or how muscle groups are stretched (Bandy, Irion, & Briggler, 1997; Gajdosik, 1991; Gajdosik, Albert, & Mitman, 1994; Sihvonen, 1997; Li, McClure, & Pratt 1996). Hamstring length increases with different forms of stretching. Gajdosik tested the validity and the reliability of the straight leg raising test (SLR) and found it to be reliable and valid, but an indirect clinical test of hamstring length (Gajdosik, 1991; Gajdosik, Rieck, Sullivan, & Wightman, 1993). Effectiveness of static stretch on the hamstrings is most easily gauged by measuring the range of motion at the hip joint while keeping the knee extended, as in the passive straight leg raising test position. Hamstring muscle length was not measured directly, but instead was represented indirectly by angular measurements of unilateral hip flexion with knee extension, as in the straight leg raising test (Gajdosik et al., 1993). The passive straight leg raising test is appropriate for screening participants for hamstring length; it is easy to apply, valid, and routinely used in clinical settings (Gajdosik, 1997; Gajdosik et al., 1993). In one study, participants stretched until they felt firm resistance and slight discomfort in the back of their thighs (Gajdosik et al., 1994).

Passive straight leg raising test has been shown to be valid for indirect measurement of hamstring length and commonly used in clinical settings (Gajdosik, 1997; Gajdosik et al., 1993). The passive straight leg raising test also is as externally

valid as any sitting test because most athletes do not compete in a position where their ischeal tuberosities are in a weight bearing position.

Gajdosik, Rieck, Sullivan, and Wightman (1993) studied four different types of tests designed to measure hamstring length. Gajdosik et al. (1993) compared these four different tests that assess hamstring muscle length: the passive straight leg raising test with the pelvis and opposite thigh stabilized with a strap; passive straight leg raising test with the low back flat; active knee extension with the hip flexed at 90 degrees; and passive knee extension with the hip flexed to 90 degrees. For all tests, the test leg remained relaxed in plantar flexion because dorsiflexion of the foot may limit the angle during the straight leg raising test and the knee extension tests (Gajdosik et al., 1993). Participants and examiners both reported difficulty in actively maintaining a flattened low back while keeping the legs relaxed for the passive straight leg raising test with the low back flat; therefore, the examiner could not ensure the participants' positions remained unchanged during the test (Gajdosik et al., 1993). All 30 participants had the right hamstring muscle length assessed by the four different tests. This repeated measure found that there was very little difference in range of motion measurements between the passive straight leg raising test with stabilizing straps and the passive straight leg raising test with low back flat. It was found that there was a statistically significant positive correlation between the active knee extension and passive knee extension tests, but there was a statistically significant difference between the mean angles of the two knee extension tests (Gajdosik et al., 1993).

Duration of Stretch.

Varying the duration of stretch has been tested. Bandy, Irion, and Briggler (1997) found that one static stretch of 30 seconds a day, five times a week for six weeks was found to increase hamstring range of motion. No statistically significant differences from more bouts or longer duration of hamstring stretch were found.

Bandy et al. (1991) used 93 men and women between the ages of 21 and 39 years old, required to be tight in the hamstrings, but measured hamstring flexibility with a different but equally valid test as the passive straight leg raising test. Participants in the Bandy et al. (1991) study stretched in a standing position (versus laying supine), and met five times per week. Bandy et al. (1991) did find statistically significant results in a 6 week duration of study with stretches conducted 5 times each week, indicating a study of 10-12 weeks was not necessary to find statistically significant changes in hamstring range of motion.

Li, McClure, and Pratt (1996) attempted to normalize lumbopelvic rhythm in forward flexion by stretching the hamstrings. The stretching group did 10 bouts of 15 seconds of static stretching, followed by 15 seconds of rest. This occurred every day for three weeks (Li et al., 1996). They used a common stretch for physical therapists to assign to their patients for home exercise. The participant is instructed to lay supine with hips positioned near a doorframe, raise one leg and rest it against the doorframe while keeping the knee extended and the other leg flat on the floor (Li et al., 1996). The amount of stretch can be increased by moving the hips closer to the base of the doorframe, or decrease the stretch by moving the hips further from the base of the

doorframe. Statistically significant results were found in the amount of straight leg raise that the participants could perform when compared to the control group. After the straight leg measurement, subjects were digitally analyzed in forward bending. Li et al. (1996), concluded that there is no relationship between hamstring muscle length and lumbopelvic posture. The studies relied on patient sensation for feedback range from firm resistance or light discomfort (Gajdosik et al., 1994 & Bandy et al., 1997) to mild discomfort in an effort to achieve maximal stretching (Li et al., 1996).

Worrell, Smith, and Winegardner (1994) taught 19 healthy university students a static hamstring stretch that was performed for 20 minutes a day, 5 days a week for 3 weeks. Analysis comparing pretest and posttest measurements indicated a mean gain of 8.0 degrees and a 21.3% gain using static stretching for increasing hamstring range of motion, but these gains were not statistically significant ($p = 0.082$). Worrell et al. concluded that gains were made but not statistically significant due to large intersubject variation causing a low statistical power (1994).

Doebler et al. (2000) had 40 active college students warm up and then perform static hamstring stretches for 15, 30, 90, or 120 seconds for 3 times a week over 4 weeks. Analysis compared to a non-stretch control group indicated only significance for the 120 second stretch group. Doebler et al. (2000) attributed the lack of statistically significant effects for the shorter stretch times on low statistical power. Static hamstring stretches of less than 120 seconds are not always found to be statistically significant, even if stretches of much shorter duration are commonly used in studies and in clinics.

Postural Influences.

Bohannon, Gajdosik, and LeVeau (1985) studied the relative contributions of the pelvis and leg when measuring range of motion in passive straight leg raising tests. Originally, Bohannon et al. (1985) hypothesized that the pelvis would move only after the lower leg had taken up all of its available passive range of motion, but they discovered that the pelvis began moving early, almost as soon as the passive straight leg raising test began. The pelvic rotation occurred despite attempts to stabilize the pelvis by limiting the untested leg's movement (Bohannon et al., 1985). The relative contribution of pelvic rotation increased as the angle of passive straight leg raising test increased (Bohannon et al., 1985). They determined through measurement and film analysis of the participants in the passive straight leg raising test that for every 2.7 degrees of movement, 1.7 was from the straight leg raise and 1 degree was from pelvic rotation (Bohannon et al., 1985). Bohannon et al. (1985) concluded that hamstring tightness indicated by the passive straight leg raising test does not force the pelvis to rotate more in compensation, but that the pelvis and legs work together. No EMG monitoring of hamstrings, hip extensors, hip flexors, or back extensors was done during Bohannon et al.'s study; this makes their claim of tension on muscles other than the hamstring being subject to tension in the passive straight leg raising test a questionable claim. It would help clarify the results if further testing of a wide variety of muscles surrounding the hips were measured to determine their synergy during movement. Further testing of other muscles and structures in the area was suggested to increase understanding of the factors that help determine movement during the passive straight leg raising test (Bohannon et al., 1985).

Bohannon et al.'s findings lacked support for Stokes and Abery's (1980) study that tighter hamstrings produce greater curvature in the lumbar spine (lordosis), especially when the knees are straightened. The difference between the two studies could be the means of testing. Bohannon et al. (1985) had participants lay supine, passively flexing the hip while maintaining knee extension; Stokes and Abery (1980) measured participant hip flexion in standing toe touch, in sitting with knees flexed to 90 degrees, and in sitting with knees flexed to 45 degrees ("partially flexed"). Stokes and Abery pointed out that the sitting position changes the pelvis, especially the ischeal tuberosities where the hamstrings originate, to a weight bearing position. Stokes and Abery found statistically significant correlation between participants with tight hamstrings and their inability to adjust their lumbar spine when asked to move their legs into a different position; it appeared to the examiners that the spine was already flexed significantly in the first sitting position where the knees flexed to 90 degrees and could not adjust further to adapt to the second position where the knees extended to only 45 degrees of flexion (Stokes & Abery, 1980). The Stokes and Abery study is an important consideration for athletes who are away from competition: in the classroom, in the car, or studying at home. Shortened hamstrings can affect the lumbar spine significantly while in the sitting position (Stokes & Abery, 1980).

Gajdosik et al. (1994) found that shortened hamstrings are associated with decreased range of motion in the pelvic angle, which can lead to an increase in lumbar flexion to compensate for lost range of motion. Shortened hamstrings are believed to

affect lumbar spine curvature and posture while standing in a number of ways (Kendall, McCreary, & Provance, 1993).

Kendall, McCreary, and Provance (1993) described four different postures: the ideal alignment, kyphosis-lordosis posture, flat back posture, and sway back posture. In ideal alignment, the hamstrings test within normal clinical limits for strength and length. Kendall et al. (1993) described the ideal alignment as the following common anatomical landmarks aligned: the lateral malleolus, the head of the fibula, the greater trochanter of the hip, the armpit, and the auditory canal of the ear.

The kyphosis-lordosis posture is one of increased flexion of the thoracic spine (kyphosis) and hyperextension of the lumbar spine (lordosis). In kyphosis-lordosis posture, the hips are slightly flexed, resulting in greater trochanter of the hip and the auditory canal of the ear being anterior to the head of the fibula and lateral malleolus of the ankle, and slightly elongated hamstrings that may or may not be weak (Kendall et al., 1993).

Flat back posture is most noticeable from the extremely flat (straight) lumbar spine. Hamstring muscles are strong but lack length in the flat back posture, and frequently abdominal muscles are strong in this posture as well. Flat back posture has the greater trochanter of the hip and auditory canal of the ear being extremely anterior to the head of the fibula and lateral malleolus of the ankle. Flat back posture relates to muscle dysfunction around the pelvis and a straight spine (Kendall et al., 1993).

Sway back posture appears similar to flat back posture because of a flat lumbar spine and hyperextended knees, but muscle dysfunctions includes abdominal, upper back

(thoracic) and neck (cervical) muscles. These muscle dysfunctions result in the sway back posture including a forward head, an overly curved thoracic spine (kyphosis), and a posterior displacement of the upper trunk (Kendall et al., 1993). Like in the flat back posture, the hamstrings are strong but lacking length in the sway back posture due to both postures having a posterior tilt of the pelvis to balance the straight lumbar spine region.

The hamstrings in the flat back and sway back posture are primary hip extensors because of the inactive gluteal muscle groups. Primary hip extension is difficult for the hamstrings because of their length, causing a constant need for contraction to maintain a posterior tilt of the pelvis; this results in shortened hamstrings. Kendall et al. specifically stated that, “the word ‘sway-back’ not be used synonymously with the word ‘lordosis’” (Kendall et al., p.85). Sway back and overly lordotic postures are commonly confused because of symptoms of spinal pain, disordered spinal curvature, and muscle imbalance.

Sahrman suggested that hamstring muscle ROM can be used to detect lumbar-pelvic dysfunctions, but it should not be considered the sole source of low back pain (Sahrman, 1996). Shortened bicep femoris, part of the hamstring muscle group, has been shown to be part of a possible arthrokinematic reflex where increased hamstring tension prevents an anterior pelvic tilt, reducing load in the lumbar spine by decreasing lumbar lordosis (van Wingerden, Vleeming, & Kleinrensink, 1997). Weak abdominal muscles cause the hamstrings to become primary movers in a synergistic action of posterior pelvic tilting, but people have been taught to change that movement pattern (Mayhew, Norton, & Sharmann, 1983; Sahrmann, 2001). Overused hamstring muscles easily become

strained in running sports as a result of inadequate participation by hip extensors and spine flexors (Sahrmann, 2001).

Lumbo-Pelvic Stability

Pelvic Crossed Syndrome.

The “pelvic crossed syndrome” (Jull & Janda, 1987) is an example of how muscle imbalances can affect people. In this syndrome, the body attempts to maintain posture with as little effort as possible by tightening the iliopsoas and lumbar erector spinae, both postural muscles. Hip flexor muscles such as the iliopsoas can be considered overly tight if the hip joint remains flexed while in the Thomas test position. The hamstrings, another postural muscle group, are normally tight as well. “[Hamstring tightness] may be a compensatory mechanism to lessen [anterior] pelvic tilt or the overactivity and tightness could be a functional compensation for the inhibited glutei” (Kendall et al., p. 261). Phasic muscles, like the gluteals and abdominals become elongated and weak in response to inactivity or injury. A gluteal muscle should maintain muscle tone; if it is flaccid or appears to sag there is a good chance of gluteal inhibition. “Such an imbalance can adversely affect both the static posture and dynamic function of this region, notably during walking” (Kendall et al., pp. 260-261). These muscle imbalances can lead to lower back pain (LBP) and high shear forces in the spine that can damage spinal discs. Muscle imbalances affect walking, running, cutting, and jumping activities. The pelvic crossed syndrome posture does not fit easily into any of Kendall et al.’s four commonly encountered postures.

“The pelvic crossed syndrome is characterized by the imbalance between shortened and tight hip flexors and lumbar erector spine and weakened gluteal and abdominal muscles (Jull & Janda, p. 260).” Muscles that span more than one joint will tend to tighten in an attempt to limit the degrees of freedom available, thus making the affected region more stable, but at the cost of muscle length and loss of movement (Jull & Janda, 1987). Jull and Janda (1987) investigated altered movement patterns to determine if strength deficits, susceptibility to fatigue, muscle shortening, and increased motor activity (similar to spasm) were occurring randomly or as part of a generalized muscle pattern. It was determined that muscle pathologies are part of a generalized response pattern of the nervous system by comparing muscle pathologies to deficiencies as seen in strokes, cerebral palsy, spastic contractions, or muscle contractures which occur from impairment in motor control in the central nervous system (Jull & Janda, 1987). Jull and Janda (1987) recommended therapists should stretch tight muscles before attempting to strengthen tight muscles because tightness inhibits muscles and become less active with resistance training. Once normal length is achieved, exercises can be initiated to strengthen and return weakened muscles to successful motor execution (Jull & Janda, 1987). “Poor quality and control of movement can be of major importance in either the production or perpetuation of adverse stresses in the lumbar spine” (Jull & Janda, p. 269).

Norris (2001a) lists the three steps of muscle imbalance that can be tested: tightening of the two-joint (biphasic) movers, loss of endurance in one-joint (monophasic) stabilizers, and a resulting length change and tension change combination

which may alter muscle pull around a joint. Muscle imbalances can easily worsen because the postural muscles tighten to maintain posture to the extent that phasic muscles have to loosen or weaken to allow joint movement (Norris, 1993). This pattern of imbalance will compromise joint biomechanics quickly, causing more damage to an already unstable location.

Pelvic Tilt.

Pelvic tilt can affect lumbar spine curvature. The hamstring muscles originate from the ischeal tuberosities at the base of the pelvic girdle and can play a role in determining pelvic tilt. Some hamstring muscles extend the hip as well as flex the knee. Sihvonen (1997) noted that hamstring activity in relation to lumbar activity phases had not been previously investigated. Lumbar-pelvic rhythm is controlled and coordinated by the simultaneous, but independently timed activity of the hamstrings and back muscles (Sihvonen, 1997). EMG analysis of the lumbar spine and hamstrings during forward flexion supported the theory that both muscle groups are active during the movement, but the movement pattern is altered in response to lumbar pain (Leinonen, Kankaanpaa, Airaksinen, & Hanninen, 2000). It was found that muscle activity in back and hamstring muscle groups during forward flexion is dramatically altered by lumbar pain (Leinonen, Kankaanpaa, Airaksinen, & Hanninen, 2000). Normal forward flexion begins with simultaneous activity in the spine and hamstring muscles and transitions into gluteus maximus finally activating while the spinal and hamstring muscles relax in full flexion (known as flexion relaxation). Patients with lumbar pain activated their spinal muscles

much earlier and relaxed when the gluteus maximus relaxed; the hamstrings stayed active after both these muscle groups had relaxed (Leinonen et al., 2000).

Overworked hamstrings actively bracing the lumbar spine could lead to tight, and therefore, shortened hamstrings. According to Kendall, McCreary, and Provance (1993), “Weakness of anterior abdominal muscles allows the pelvis to tilt forward. . . As the pelvis tilts forward, the low back is drawn into a position of lordosis (p. 351).”

Lumbar Position.

A correlational study was conducted by Walker et al. (1987) to determine if there was a connection between lordosis of the lumbar spine, pelvic tilt, and abdominal muscle performance. Measures of hamstring and spinal musculature were not included in the study. Healthy young men were tested for pelvic tilt, lordosis, and abdominal muscle function; muscle function was tested using the leg lowering test. Pearson correlation tests indicated no relation among abdominal strength, pelvic tilt, and lumbar lordosis (Walker et al., 1987). No statistically significant relationship was found among hip extension ROM, standing pelvic tilt, standing lumbar lordosis, or abdominal strength (Heino, Godges, & Carter, 1990). Walker et al. (1987) stated that abdominal muscles are not active in normal standing; this appears contradictory to the description of multiple postures emphasizing spinal curvatures and pelvic tilt in Kendall et al. (1993).

Youdas, Garrett, Egan and Therneau (2000) compared 30 middle-aged men ($M = 54.9$ years old, $SD = 9$) with chronic lower back pain to 45 men without chronic lower back pain across several lumbo-pelvic measurements and found that participants with chronic lower back pain had no more standing lumbar lordosis or pelvic tilt than the

healthy participants, but the healthy participants had statistically significantly more abdominal strength than the injured control group as measured by scores on the double-leg lowering test (Youdas et al., 2000). In the study conducted by Youdas et al. (2000) they found that abdominal strength during controlled movements, similar to movements used in the present study, is more important than measurements of pelvic tilt and lumbar lordosis in differentiating between healthy and chronically dysfunctional backs. The findings of Youdas et al. (2000) appear to support those reported by the Walker et al. (1987) study.

Treatment Progression.

Tight back extensors or hip flexors (especially the iliopsoas) should be lengthened before the abdominal muscles and hip extensors are strengthened to function optimally (Kendall et al., 1993). Kendall, McCreary, and Provance's *Muscles: Testing and Function* released its fourth and most recent edition in 1993. The first edition was printed in 1949. *Muscles: Testing and Function* is described as the gold standard and is used by most physical therapy school in the country, according to Dr. Linda Wanek, Interim Director of the joint physical therapy program of University of California, San Francisco and San Francisco State University (L. Wanek, personal communication, December 12, 2002). Kendall et al. (1993) is in wide use in the rehabilitation community; therefore, its concepts of stretching before strengthening and postural descriptions are well known to the sports medicine and rehabilitation professions.

Levels of pelvic and core stabilization are difficult to measure (Saal, 1992). Saal (1992), as others have, proposed a ranking system for core stability and functional

strength, but no scoring system has been accepted on a widespread basis to date. Many muscles involved with core stabilization are postural muscles used for long duration, low intensity performance. Stamina is much more important in building core stability than maximal strength or power; therefore, one repetition lifts of maximal resistance are not an accurate predictor of core stability (Saal, 1992). In order to increase stamina in the core stability exercises, high repetitions and low loads were used in the present study in agreement with Saal's (1992) concepts.

Norris (1993) is a proponent of restoring length to the postural muscles caught in pelvic crossed syndrome rather than strengthening the phasic muscles with resistance training. Exercise programs should initially focus on improving stamina, flexibility, and strength; later the program will progress to add speed and skill work (Norris, 1993). Norris (2001a) differentiates between instability and hypermobility. Hypermobility joints have greater range of motion than normal, but the body is able to control the increased range of motion. Instable joints have greater range of motion than normal, but the increased range of motion is excessive enough that there is a loss of protective muscular control for the entire range of motion (Norris, 2001a). For an unstable joint, quantity and quality of movement will be altered, even under small loads (Norris, 2001a).

Stabilization Model.

Panjabi (1992a) proposed a model of spinal stability based on three subsystems: passive musculoskeletal, active musculoskeletal, and neural control. The passive musculoskeletal subsystem includes the vertebrae, the facet articulations, discs, spinal ligaments, joint capsules, and passive mechanic properties of the spinal muscles (Panjabi,

1992a). The passive subsystem does not produce or generate spinal movements as the active subsystem does (Panjabi, 1992a). The active musculoskeletal subsystem is made of the muscles and tendons around the spine (Panjabi, 1992a). The neural control subsystem is comprised of force and motion transducers (found in ligaments, muscles, and tendons), as well as neural control centers; deformation of soft tissues is capable of providing a comprehensive set of signals that allows stability requirements to be determined (Panjabi, 1992a). The neural control subsystem attempts to compensate for sudden or gradual deficiencies by initiating changes in the active stabilizing subsystem (Panjabi, 1992a). Although these three subsystems are conceptually separate, they are functionally interdependent (Panjabi, 1992a). The stabilization system of the spine was designed to monitor tissue deformity and adjust proper muscle tension in appropriate locations to accommodate changes in posture, movement, and spinal loads (Panjabi, 1992a).

The three systems are highly coordinated and optimize spinal stability under normal ranges of spinal movements and against normal spinal loads (Panjabi, 1992a). The subsystems can compensate for each other, within limits, in a spinal disorder (Panjabi, 1992a, 1992b). The neural control unit attempts to remedy a stability loss by increasing the stabilization of the active and passive systems (Panjabi, 1992a, 1992b). The increase in stabilization may protect the spine against excess spinal movement, but it may accelerate degeneration, abnormal muscle loading and muscle fatigue (Panjabi, 1992a). If the subsystems cannot adequately compensate for the stability loss, chronic dysfunction or pain may develop (Panjabi, 1992a). Disuse, degeneration, disease or

injury may reduce the stabilizing capacity or the spinal stabilizing system as a whole, compromising the system's compensatory interactions in the case of unexpected or abnormal loading or movements (Panjabi, 1992a).

Goals for stabilization exercises are to condition and teach proper motor recruitment of the active stabilizing subsystem to help stabilize the passive stabilizing subsystem of the spine (Panjabi, 1992b). Panjabi (1992b) pointed out that an important part of spinal stability is to allow movements while increasing stability towards the end ranges of motion. An important part of Panjabi's goals for spinal stability is to allow movement within the safety of the neutral zone (1992b). Saal (1992) stated the quality of exercise and not quantity of exercise is important with lumbo-pelvic stabilizing exercises, especially since postural muscles are being exercised on such small amplitudes of their maximum strength.

Pelvic Stabilization Studies.

Pelvic stabilization is very difficult to achieve without instruction and practice (Graves et al., 1994; Elia, Bohannon, Cameron, & Albro, 1996). It was shown by Elia et al. (1996) that participants with no experience in pelvic stabilization were unable to stabilize their pelvis while moving their legs. Physical therapists, who participated as controls, were highly experienced in pelvic stabilization and were successful in stabilizing their pelvis during leg movement (Elia, Bohannon, Cameron, & Albro, 1996). Pelvic stabilization is an important movement in the core stability exercises used in the present study.

Graves et al. (1994) found pelvic stabilization is required to effectively train spinal muscles correctly. They found both groups of participants made similar gains in resistive exercise training, but the group that trained with pelvic stabilization had far greater improvement in the production of torque than the participant group that trained without pelvic stabilization. Graves et al. (1994), suggested that torque was increased through the back extension ROM due to the pelvic stabilization that occurred during training to isolate the back extensor muscles; the participants who trained without pelvic stabilization used hip extensors, like the gluteals and hamstrings, that normally help with pelvic stabilization as back extensors. Graves et al.'s (1994) description of participants who were untrained in pelvic stabilization appears similar to Jull and Janda's (1987) description of people experiencing muscle imbalances.

Graves et al. (1994) had their participants achieve stabilization of the pelvis by using a resistance machine with thigh straps and a bolster to prevent pelvic movement during lumbar extension. Using straps and bolsters limits the present study's ecological validity for postural stability because the goal of postural stability is to be able to move the limbs or the spine without requiring additional and external support. Graves et al. (1994) did not examine muscle function in three planes; all movement in their study was done in the sagittal plane and no movement in the frontal or transverse planes.

Using electromyographic analysis, Blackburn and Portney (1981) found that performing Williams' flexion exercises with a posterior pelvic tilt statistically significantly decreases lumbar muscle activity compared to performing the same exercises with an anterior tilt. Blackburn and Portney (1981) found that exercises

performed with posterior pelvic tilt were very similar in muscle activity to exercises performed with a neutral pelvis. The electromyography results of the study by Gracovetsky, Kary, Pitchen, Levy, and Ben Said (1989) also found that pelvic tilt exercises allowed participants to adjust the amount of their lumbar spine lordosis. Using neutral or posterior pelvic tilt to help decrease lumbar muscle activity during exercises similar to Sahrman's progression of exercises should give other muscles in the lumbo-pelvic region the opportunity for successful motor execution.

Delisle, Gagnon, and Sicard (1997) instructed their participants in pelvic tilt. While analyzing data, it was discovered that participants instructed in pelvic tilting were able to change their spinal curvature, but not at all spinal segments. The ability to voluntarily alter spinal curvature through muscle contraction is very important to the concept that core stabilization exercises can alter the position of the pelvis, allowing for more ideal posture and balanced muscle use.

Mayhew, Norton, and Sahrman (1983) performed an electromyographic study of the relationship between hamstring and abdominal muscles during a unilateral straight leg raise. Right and left hamstrings were compared to right and left abdominal muscles (specifically, the external obliques) during a unilateral straight leg raise. Mayhew et al. (1983) found that participants who push down with the contralateral leg (the leg not being raised) do not use as much abdominal musculature as those who do not push down with their contralateral leg. Mayhew et al. (1983) presumed the downward leg pressure was produced by the hip extensor muscles (gluteals, hamstrings) to counteract the pressure of the hip flexor muscles of the leg being raised causing an anterior tilt of the pelvis.

Stabilizing for movement in this way may play a significant role in developing and perpetuating muscular and mechanical imbalances depending on the strength or weakness of an individual prime mover (Mayhew et al., 1983). Mayhew et al. (1983) found that the back extensors are protecting the spine presumably by pushing against the table the participants are laying on; no electromyographical measurement of the lumbar musculature was recorded in the present study. The Mayhew et al. (1983) study has a similar ecological validity problem as the Graves et al. (1994) study: people participating in walking, running, changing direction or other similar activities do not have the luxury of stabilizing themselves against a table when they move. It is of ecological value that Mayhew et al. did find although most participants normally stabilized with their contralateral leg during a unilateral straight leg raise, they can consciously alter the pattern to decrease hamstring use and increase abdominal use (Mayhew et al., 1983). Mayhew et al.'s finding that movement can be voluntarily altered supports the idea that people can change previous movement patterns to move appropriately.

Abdominal Strength

Saal (1992) conceptualized the abdominal muscles as “guy [sic] wires” that attach to the pelvic platform as well as the lumbar spine; therefore, these muscles can alter the lumbo-pelvic posture. The more muscle stiffness around the spine, the more stable the spine (McGill & Cholewicki, 2001). More muscle stiffness is not necessarily better, however. Inappropriate magnitudes of muscle force and stiffness can cause a joint to buckle or experience shear forces (McGill & Cholewicki, 2001; Panjabi, 1992 a, 1992b). McGill and Cholewicki (2001) pointed out that studies show optimal joint stiffness can

be achieved during contractions as low as 25% of a maximum isometric contraction. The critical issue is optimally activating synergists and antagonists. Large muscle forces are rarely required for most activities of daily living (ADLs); the goal is maintaining consistent, relatively low level contraction for long periods of time (McGill & Cholewicki, 2001).

Anatomical Considerations.

Few muscles in the body have attachment sites on the lumbar spine, and even fewer can alter spinal alignment with activation. The abdominal muscle groups have received attention by those who are exercise instructors for spinal dysfunction and low back pain because of the ability of abdominal muscles to alter spinal position through muscle contraction.

Some abdominal muscles are so specialized that they are directed by the nervous system to contract in preparation of movement. Hodges and Richardson (1997) termed the anticipatory stabilization of the spine “feedforward postural reactions.” Feedforward postural stabilization decreases the amount of shear or other reactive forces on the spine resulting from limb movement (Hodges & Richardson, 1997; Hodges & Richardson, 1999).

Transverse Abdominis.

Using EMG to study healthy participants, the abdominal muscles transverse abdominis, internal obliques, and the external obliques were all active before movement of the legs (Hodges & Richardson, 1997). Feedforward postural response occurs before limb movement begins. Transverse abdominis is the only abdominal muscle that has the

same timing for activity regardless of the direction of limb movement (Hodges & Richardson, 1997; Hodges & Richardson, 1999). Hodges and Richardson (1999) found that the transverse abdominis contracted before any other muscle during limb movement. The separation of timing and behavior of the transverse abdominis from the other abdominal muscles suggests that the transverse abdominis may be controlled and recruited independently of the motor commands for limb movement (Hodges & Richardson, 1999).

The transverse abdominis appears to lose normal anticipatory function in people experiencing lower back pain, exhibiting delays in muscle activation (Jull & Richardson, 2000; Hodges & Richardson, 1996). Jull and Richardson (2000) have presented spinal segmental stability training as a motor learning exercise protocol; they have found loss of stabilizer strength is not as important as loss of motor control of the spinal stabilizers. Initial and primary focus with regard to rehabilitation of a spinal dysfunction should be retraining the transverse abdominis and multifidus, another spinal stabilizer, to fire normally again to regain normal spinal stability and support (Jull & Richardson, 2000). The aim of spinal motor rehabilitation training is to restore the muscles' automatic stabilizing function; as this is achieved, the integration of local and global movement systems should be the next goal (Jull & Richardson, 2000). Other rehabilitation experts also emphasize motor control during rehabilitation of muscle dysfunction by beginning with simple, stabilizing co-contractions and progressing to more advanced contractions during movement (Gentile, 1987, 2000; Jull & Janda, 1987). Cognitive training of spinal stabilization in patients with delays in transverse abdominis activation for a duration of

10 weeks showed improvement but not full recovery in transverse abdominis activation; back pain was proportionally decreased as well (Jull & Richardson, 2000; Hodges & Richardson, 1996).

Muscle Classification.

Surface EMG study showed the external oblique muscles in the abdomen were activated through proper instruction during therapeutic strengthening activities (Arokoski, Valta, Airaksinen, & Kankaanpaa, 2001). Arokoski et al. (2001) discussed the division of abdominal muscles into two groups: the local stabilizing system and the global stabilizing system.

The local stabilizing system is made of deep muscles like the transverse abdominis and internal obliques; this system stabilizes the spine. The global stabilizing system is made of external abdominal muscles and spinal muscles; this system is responsible for major trunk movements. Arokoski et al. (2001) found that muscles in both groups increased activity when additional spinal loading occurred or unbalanced limb movements altered body position.

Muscle Imbalance.

Muscle imbalance is described using another classification of muscles: postural muscles that tend to tighten, and phasic muscles that tend to lengthen or weaken. The iliopsoas and hamstrings are both reported by Norris (1993) to be postural muscles that tighten, while the internal obliques, external obliques, rectus abdominis, quadriceps, and gluteals are all phasic muscles that tend to weaken or lengthen in response to inactivity or injury. The interaction of phasic muscles weakening and loosening combined with

postural muscles tightening in response to injury or inactivity can lead to “pelvic crossed syndrome” (Jull & Janda, 1987).

Norris (2001a) found the structural and functional characteristics of stabilizing muscles like the transverse abdominis, multifidus, internal oblique, and quadratus lumborum are better equipped for maintaining posture than mobilizing muscles that are set up for rapid and forceful movements. Stabilizers tend to be found deep under many layers of muscle, composed of slow twitch fibers that may lengthen or become inhibited when dysfunctional. Mobilizers tend to be superficial muscles composed of fast twitch fibers; the mobilizers tend to shorten or tighten when dysfunctional. Norris (1993, 2001a, 2001b) theorized a different muscle pattern of imbalance than Jull and Janda’s pelvic crossed syndrome (1987) or Kendall et al.’s anterior pelvic tilt with lumbar lordosis (1993). Despite their differences of what is dysfunctional, they are in agreement that stretching the tight muscles before strengthening the weak muscles, as well as beginning exercise movements slow and simple and building in difficulty (Jull & Janda, 1987; Kendall et al., 1993; Norris, 2001a, 2001b).

Norris (2001a) theorized that people with chronic low back pain are not going to be able to recruit their deep stabilizing muscles with abdominal exercises like trunk curl ups; he suggests abdominal hollowing exercises optimally recruit the transverse abdominis and internal obliques. Abdominal hollowing is very effective for recruiting transverse abdominis and internal obliques in supine laying, four point kneeling or in standing (Norris, 2001b). Rapid movement speeds and increased resistance have been shown to recruit mobilizer muscles (e.g., rectus abdominis, external obliques, erector

spinae) selectively over stabilizer muscles (e.g., transverse abdominis, multifidus, internal obliques). To decrease recruitment of mobilizers and increase stabilizer recruitment, lower resistances and slow movements should be used (Norris, 2001a). It is only after re-education and endurance increases are made with stabilizers that multi-joint exercises are introduced to increase performance of the trunk mobilizers (Norris, 2001b).

Muscle Activity During Exercise.

Blackburn and Portney (1981) measured EMG activity at the cervical, thoracic, lumbar, and sacral levels of the spine during 6 Williams' flexion exercises. Williams' flexion exercises were originally published in 1937 for middle aged men and women who had chronic, low grade pain in the lumbar spine, exaggerated hyperextension of the lumbar spine (lordosis), and X-rays showing a narrowing of intervertebral disc space in the lumbar spine. One of the purposes of the Williams' flexion exercises used in the present study was to provide lower trunk stability in the lumbar spine by actively strengthening spinal flexors and passively stretching the extensors of the lumbar and sacral regions of the spine (Blackburn & Portney, 1981). Blackburn and Portney's EMG analysis of Williams' flexion exercises included important stabilization exercises like the pelvic tilt, the curl-up, and the squat. Performing pelvic tilts with a neutral pelvis as opposed to a posteriorly tilted pelvis caused no change in EMG (Blackburn & Portney, 1981). Neutral spine and neutral pelvis achieve prevent anterior tilt and minimizes risk of injury to the spine and surrounding passive elements while the spine is loaded by muscle contractions (McGill, 1998). Anterior tilt and exercises in standing were not found to minimize EMG activity in the lumbar and sacral spines much as was previously

thought (Blackburn & Portney, 1981). Blackburn and Portney's analysis of William's stabilization exercises with various pelvic positions provides exercise instructors with an idea of what muscles are being used during various stabilization exercises.

Neural Factors of Motor Control

Motor Control Impaired by Pain.

People with pain local to the lumbar spine have impaired motor control of the deep trunk muscles, including most of the local stabilizing muscle system (Hodges & Richardson, 1996; Richardson, Jull, Hodges, & Hides, 1999). The transverse abdominis slows activation time and responds in a direction-specific manner for people with low back pain; this indicates pain around the lumbar spine does not just delay muscle reaction time but fundamentally changes motor control of this muscle (Hodges & Richardson, 1996). It is unknown how severe the lumbar pain must be to impair the feedforward response of the transverse abdominis. It is unknown how the spinal stabilization exercises tested in Arokoski et al. (2001) would affect chronic back pain patients. Hodges and Richardson (1996) and Richardson et al. (1999) recommended avoiding exercises incorporating high levels of spinal loading for people experiencing lumbar spine pain. Richardson et al. (1999) listed procedures for safe spinal stabilization exercises (Appendix A). It is important to realize that participants having lumbar pain will be unable to properly recruit their transverse abdominis, reinforcing the need to study healthy participants prior to studying injured participants.

Instruction of Motor Activity.

Motor control during stabilization exercises is important because it protects the spine from possibly dangerous movements that could cause injury. Motor control also allows people to learn new movements and refine those movements with deliberate practice. Anterior pelvic tilt is a posture of the hips that will increase lordosis of the lumbar spine and weaken abdominal muscles while tightening the hip flexor iliopsoas (Norris, 1993).

Training patients or participants to recruit abdominal muscles in accordance with motor control guidelines can be difficult (Sahrmann, 2001). Robison (1992) suggested emphasizing oblique recruitment when instructing stabilization exercises. Flexibility in the hamstrings, quadriceps, iliopsoas, gluteals, piriformis, iliotibial band, calves, and nerves are highly recommended (Saal, 1992). Robison recommended progressing exercises on a continuum of simple, non-weightbearing, and supported positions to complex, high-speed, and functional activities. Gentile's taxonomy (1987, 2000) for progression of motor learning for novices of a given activity also recommends beginning with simple, stationary, consistent movements and progressing to complex, variable, movements where the person is manipulating their limbs while they are on an unstable surface. Miller and Medeiros (1987) used tactile and verbal cues to measure awareness and recruitment of combined transverse abdominis and internal obliques. The methodology is somewhat difficult to follow, but it appears that statistically significant differences were found between 20 experimental participants and 20 control participants in only one day of training (Miller & Medeiros, 1987). Miller & Medeiros (1987) used

EMG to measure muscle activity during eccentric movements. Feedback is important to give novices during abdominal exercise training.

The goal of core stabilization should be conscientious movements resulting in an “engram” of motor control to accomplish spinal stability (Saal, 1992). Motor learning literature indicates that engram theory is not as accepted as the more recent Generalized Motor Program. Engram theory is based on repetition of a precise activity over and over again producing a constant movement pattern in which speed and force are maximized. In 1980, Kottke made a crude estimate that hundreds of repetitions would begin to create a faint and fragile engram which will fade quickly; tens of thousands of repetitions form a fair engram in which speed and force can begin to increase; one hundred thousand repetitions result in significantly increased skill; and millions of repetitions are required to perfect an engram. Kottke (1980) also made it clear that improper movement patterns take longer to unlearn and establish a proper movement pattern than establishing a correct pattern without interference.

Research published since Kottke’s engram theory (1980) shows that many fewer repetitions are required to establish movement patterns than thought by engram proponents. Anderson and Sidaway (1994) compared novice soccer players’ standard instep kick to expert (intercollegiate players with at least ten years experience) soccer players’ standard instep kick before and after a 10 week session of 15-20 kicks, twice weekly. After 15-20 kicks, twice weekly for 10 weeks, the novice group’s videotaped movements were digitized and the results looked remarkably like the experts’ results with regard to angular velocity as a function of time at the hip and knee. Anderson and

Sidaway (1994) pointed out the novices changed their skill patterns to more expert patterns, but the range of motion and angular velocity of the novices' kicks were statistically significantly less than the experts' kicks. These results seem to support the acquisition of skilled behavior theory that states constraints are placed on the body until a coordinated structure develops, after which the constraints are lifted and joint range of motion and angular velocity at the joints statistically significantly increase. The shortcomings of Anderson and Sidaway's (1994) study are they only had six participants, and only three of the six participants were videotaped for digital analysis. The authors stated practice kicking was done before the participants' soccer class and "no augmented information was given to the subjects [sic] about their performance of the instep drive" (Anderson & Sidaway, 1994). Participants in Anderson and Sidaway's (1994) study were enrolled in a soccer class where they were kicking as well as receiving instruction during class. The impression that as few as 300 repetitions with little feedback over 10 weeks can allow a novice to gain an expert movement pattern is probably not accurate because the participants were enrolled in a soccer class where they were instructed in soccer techniques and had the opportunity to practice those techniques concurrent with the study. Anderson and Sidaway's (1994) study did show vast improvement could be made in motor skills in a relatively short time, and the improvement was related to a change in coordination rather than a simple increase in the speed or force of the movement.

Temprado et al. (1997) replicated Anderson and Sidaway's (1994) study by comparing expert versus novice movements of the shoulder, elbow, and wrist during a

volleyball serve. Temprado et al. (1997) found novices statistically significantly changed their movement patterns and coordination, especially in the important area of shoulder/wrist coupling. The change in coordinated movement from novice to expert suggests the passage from one stable state of movement to another where degrees of freedom in the joints are released, rather than the generation of a completely new pattern of movement (Temprado et al., 1997).

Sanders (1995) studied nine masters' level swimmers, each with at least 10 years experience. In 10 coaching sessions of 45 minutes per session over the course of 12 days, Sanders found all participants statistically significantly changed their swimming technique as measured in the fundamental frequencies of the vertex, shoulder, and hip vertical displacements (1995). Sanders found that it is possible for experts to change their movement patterns in a short time span (1995).

Miller and Medeiros (1987) compared 20 young, healthy controls to 20 young, healthy participants in the training to increase voluntary recruitment of the combined muscle groups of internal obliques and transverse abdominis. The methodology is somewhat difficult to follow, but it appears that the experimental group was able to statistically significantly increase eccentric use of the internal obliques and transverse abdominis during curl-up exercises through the use of auditory, tactile, visual, and kinesthetic cues in only 11 repetitions. This data were recorded by electromyography to measure muscle use during the eccentric phase of the curl-up movement (Miller & Medeiros, 1987). Miller and Medeiros' (1987) results relate to the present study because it shows the internal musculature of the abdomen can be voluntarily recruited during

movement and the internal obliques and the transverse abdominis can be trained within a 6 week time period.

Neural Factors in Strength Gains.

Moritani and de Vries (1979) used electromyography on 15 healthy young participants, mean age 22.0 years old to test the postulate that initial increase in strength is based on neural factors and not on morphological changes. The participants used a strength training program of dumbbell exercises for elbow flexors at two-thirds maximum load for 10 repetitions, twice daily. The program had a frequency of three times a week over a period of 8 weeks. The participants had their maximal strength tested at 2 week intervals throughout the duration of the program. Moritani and de Vries (1979) found statistically significant effects for both hypertrophy of the muscle and strength increases; they also found statistically significant increases in the untrained arm, leading to the conclusion that early changes in strength are from primarily form neural factors and over time, hypertrophy of the muscle accounts for strength changes. Further analysis indicated that the hypertrophy of the muscle became a statistically significantly greater strength factor than the neural aspects between 4 to 6 weeks of training (Moritani & de Vries, 1979). Neural aspects appear to be the major cause of strength gains in the first 4 to 6 weeks of a training program.

Colliander and Tesch (1990) compared 11 males to 11 female participants in eccentric and concentric resistance training of the quadriceps muscles for a frequency of three times a week for 12 weeks. Both males and females statistically significantly increased in eccentric and concentric strength gains, but only the men increased their

torque-velocity relationship, indicating a greater coordination at the maximum slow speed, high force movements. Further analysis ties into the present study because the peak torque gains in the males were sharply increased in the first 4 weeks, indicating that the gains were probably from neural motor learning more than muscle hypertrophy (Colliander & Tesch, 1990).

Sale (1988) used electromyography (EMG) to compare muscle recruitment in trained and untrained participants. Sale (1988) found EMG showed the adaptive changes within the nervous system that more fully activates prime movers, lessens antagonistic activity, and coordinate movements better in those using resistance training than untrained controls. These increases in EMG activity and in voluntary strength gains are made with little or no muscle hypertrophy (Sale, 1988). Sale (1988) inferred that neural adaptation is the cause of the gains because there are no quantifiable adaptations to the muscles after training. It is important to recognize that voluntary strength can be increased without proportional gains in muscle hypertrophy.

Summary of Literature Review

Few published studies reference core stability from the standpoint of improving muscle flexibility in the lower extremity or explore a relationship between the lumbo-pelvic region and the hamstrings. The result is a review of literature divided into hip flexion range of motion, lumbo-pelvic stability, abdominal strength, and neural factors of motor control.

The passive straight leg raising test as a measure of hamstring length is easy to apply, valid, and routinely used in clinical settings (Gajdosik, 1991 & 1997; Gajdosik et

al., 1993). Bandy et al. (1997) found that one static stretch of 30 seconds a day, five times a week for 6 weeks increased hip range of motion and had no statistically significant differences from more bouts or longer durations of stretch. Li et al.'s (1996) doorframe stretch was chosen because it is commonly used and easy to learn. Gains in hip range of motion by hamstring stretches might not always be statistically significant with a small number of participants (Worrell et al., 1994; Doeblner, 2000).

In the "pelvic crossed syndrome" Jull and Janda (1987) theorized joint imbalance occurs as a generalized response pattern to maintain lumbo-pelvic posture with as little effort as possible via tight hip flexors, tight back extensors, weak hip extensors, and weak abdominis. Correlation tests were inconclusive on the relation among many factors including abdominal strength, hip extension, pelvic tilt, and lumbar lordosis (Walker et al., 1987; Heino, et al., 1990; Youdas et al., 1994; Van Wingerden et al., 1997). Gracovetsky et al. (1989) found that pelvic tilting exercises allows the participant to adjust the amount of lordosis of the spine.

The transverse abdominis may be recruited and controlled independently of other abdominal muscles (Hodges & Richardson, 1999; Miller & Medeiros, 1987; Norris, 2001a). The transverse abdominal muscle is the only muscle to fire before any limb movement (Hodges & Richardson, 1997 & 1999). Pelvic stabilization can be achieved with proper cueing of the abdominal muscles (Graves et al., 1994; Elia, et al., 1996; Miller & Medeiros, 1987; Delisle et al., 1997). Weak abdominal muscles cause the hamstrings to become primary movers in a synergistic action of posterior pelvic tilting, but people have been taught to change that movement pattern (Mayhew et al., 1983; Van Wingerden et al., 1997; Sahrmann, 2001). Overused hamstring muscles easily become

strained in running sports as a result of inadequate participation by hip extensors and spine flexors (Sahrmann, 2001). Stabilization exercises designed to teach proper movement patterns and eliminate joint imbalances could significantly reduce the workload of the hamstrings, preventing hamstring strains.

Spinal stability training has been presented as a motor learning exercise protocol (Jull & Richardson, 2000; Robison, 1992; Panjabi, 1992b; Sahrmann, 2001). Motor control theories for spinal rehabilitation can make vast improvements in a relatively short time by a change in coordination rather than a generation of a new movement pattern (Anderson & Sidaway, 1994; Temprado et al., 1997). Studies indicate neural factors are primarily responsible for strength gains in the first 4 to 8 weeks of exercise (Moritani & de Vries 1979; Miller & Medeiros, 1987). Quality of movement is more important than quantity of repetitions for stability exercises because the muscles being trained are used at a small percentage of maximal strength (Saal, 1992; McGill & Cholewicki, 2001).

Despite differences in theories of the cause of joint imbalance, there is agreement in the basic progression of treatment of joint imbalance. It is preferable to stretch the tight muscles before strengthening the weak muscles (Jull & Janda, 1987; Kendall et al., 1993; Norris, 2001a, 2001b; Chaitow, 2001; Sahrmann, 2001) with the goal of normal strength and length in hamstring, abdominal, and spinal muscle groups.

Chapter 3

Methods

Intercollegiate athletes were recruited to test for the effects of various approaches to increase hamstring range of motion over a period of six weeks. Hamstring range of motion changes were attempted by following a program of either static hamstring stretches only, core stability exercises only, a combination of core stability exercises and static hamstring stretches, or a control of neither core stability exercises nor static hamstring stretches. Exercise programs focused on increasing the stamina and control of muscles used during the treatments. The exercises involved all the participants utilizing an exercise mat, and some programs included use of an exercise ball.

After the Institutional Review Board (Appendix B) provided consent for the study and participants read and signed the release, all participants had their hamstring ROM measured pretreatment and every week post treatment by a single large goniometer. This was done in an attempt to measure how specific approaches to improve hamstring flexibility affected the participants' range of motion as measured in the passive straight leg raising test.

Participants

San José State University's Institutional Review Board and the Athletic Department of the Division II University where the study took place approved the present study for human subjects participation. Participants ranged in age from 20 to 27 years old. They were verbally recruited from the baseball team at a Division II university in the west to volunteer for the present study. Participants were randomly assigned to one

of four groups. All participants in the present study were free of back, hip, or leg injuries during the six months prior to the study. Participants signed a consent to participate agreement prior to any participation in the study (Appendix C). The rationale for studying student athletes was the high level of ability, similar workout routines, and their ease of access for the study administrator.

All participants should have gained in range of motion at the hip, but it was unknown at the beginning of the study to what level of statistical significance the gains would be. The risks to participants anticipated from participation involved only minimal risks, as the probability and magnitude of harm or discomfort are no greater than they encounter in daily life. These risks were primarily delayed onset of muscle soreness from exercise. No compensation was awarded to the participants from the present study. Confidentiality was maintained for the participants by coding all data, and only the study administrator had access to the code key and the data (Appendix C). When the data were not being recorded they were kept with the study administrator or locked at all times. Only the study administrator and his committee members had access to the data. Once the data were analyzed, the participant code key was destroyed to maintain participant confidentiality.

Apparatus

The apparatus and instrumentation for the present study included an exercise mat 4 feet by 8 feet with a thickness of 2 inches, an inflatable plastic exercise ball 75 cm in diameter, an inflatable plastic exercise ball 65 cm in diameter, a clear plastic goniometer with arms 12 inches in length and individual degree markers for all 360 degrees, and a

written copy of the exercises based on Kola's (2000) progression of core stability exercises that included instructions for the exercises and the proper progression of the exercises (Appendix D).

Most core exercises and hamstring stretches were performed on the exercise mat. The participants were fitted for either the 75 or 65 cm exercise ball as determined by the length of the participant's arm, which most closely matches the diameter of the ball (Choosing the right size of the ball, 2003). The goniometer used for measuring hip flexion range of motion has been found to have a reliability coefficients of $r = 0.99$ and $r = 0.98$ ($p < .001$) and interobserver reliability of $r = 0.97$ ($p < .001$) when used according to proper goniometry guidelines (Mayerson & Milano, 1984).

The participants were also about daily workout activities on the previous and current day during every treatment (Appendix E). As intercollegiate student athletes, the participants regularly encounter risk in order to participate in competition. The data for exercises completed, stretches completed, and the hamstring ranges of motion were noted on the logs that recorded study data (Appendix F).

Procedures

The procedures began with the participant signing a consent form (Appendix C). Participants were instructed in the treatments for their particular group every session as part of their 20 minute session. Participants performed their exercise treatments three times a week for 6 weeks by scheduled appointment. Three days of exercise per week is within American College of Sports Medicine guidelines for exercise frequency per week (ACSM, 2000). The present study attempted to minimize the time issue for the

participants; participation took place in the university athletic weight room where the participants already exercised. Participants never spent more than 20 minutes participating per session for the present study. Participants were instructed repeatedly to focus on the quality of their movements and not the amount of repetitions or time spent on their treatments. Athletes were tested in groups when multiple participants could make the same appointment time, or were tested alone when necessary. All participants in every treatment were asked about their independent workout activities. The independent workout logs were reviewed for obvious confounding activities, and to verify participants in the control or hamstring groups were not doing similar core exercises. The study administrator retained the completed independent workout logs.

The study administrator was qualified to conduct the specified treatments as he is certified by the National Athletic Trainers Association as an athletic trainer, certified by the National Strength and Conditioning Association as a strength and conditioning specialist. He had worked as a physical therapy aide for more than five years supervising and progressing patients through therapeutic exercises under the supervision of licensed physical therapists in the state of California.

Hamstring Stretch Group.

The hamstring stretch treatment group was taught to stretch by resting their leg against a doorway while supine on an exercise mat on the floor. Participants were instructed to move pelvis closer to doorway to increase the stretch, and to move pelvis further away from the doorway to lessen the stretch. After warm-up to the onset of sweat in order that the stretching program was conducted with warm muscles, participants were

instructed to stretch to a point of a stretching sensation in the hamstring and hold the position for a single set of 30 seconds for each leg, but at no time were they to feel any pain or discomfort in the hamstring. Ideally, the hamstring stretch participants were able to find a position of stretch without pain and did not need to adjust for the duration of the stretch. The participants who performed hamstring stretches were reminded of how to stretch and what type of sensation they should feel in their hamstrings during every session. The hamstring stretch group performed the same static hamstring stretches three times a week for 6 weeks. At the end of each week, each participant was remeasured in the passive straight leg raising position to record hamstring range of motion.

Core Stability Exercise Group.

Participants in the core stabilization exercises were taught core stabilization exercises based on Kola's (2000) progression of core stability exercises. All participants were required to warm up until the onset of sweat in order to warm the muscles. Exercises began with learning to recruit the transverse abdominis initially because the transverse abdominis has been shown in EMG studies to fire before movement and without regard to direction of movement (Hodges & Richardson, 1997). Of special importance to all participants who execute core stabilization exercises was learning to control the transverse abdominis contraction. Maximal joint stiffness can be achieved during contractions as low as 25% of a maximum isometric contraction of the transverse abdominis (McGill et al., 2001).

Stabilization training progressed from the simplest non-weightbearing supported position to the most complex and dynamic functional activities as described in Appendix

D. Exercises were performed in accordance with standard rehabilitation guidelines where proper technique is emphasized; participants progressed to more challenging exercises only after the previous exercise has been completed competently (Richardson et al., 1999; Robison, 1992). The study administrator determined the participants' competency of exercise subjectively based on previous professional experience of working with people on exercise progressions. Sahrman (2001) recommends core stabilization exercise program with transverse abdominis training. In transverse abdominis training, each subsequent exercise begins with the conscious recruitment of the transverse abdominis before movement is initiated. Once participants successfully recruited the transverse abdominis and could control the contraction, progression was made to slow positioning tasks that required precision and control. Low levels of force were used, and slow speeds were maintained to maximize the control aspect of the work. Participants were reminded to focus on joint position rather than the control of force. The program followed in the present study introduced an exercise ball as participants mastered control of their joint movements (Kola, 2000). The participants were given feedback to increase awareness of their surroundings and decrease the risk of injury; for example, the tester more closely monitored neutral spine on ball exercises where participants appeared to work harder to maintain stability. Sahrman's exercises fit appropriately with the clinical procedures for testing and exercise prescription for active joint stabilization (Richardson et al., 1999; Robison, 1992).

A specific schedule of exercises and instructions was followed (Appendix D). Each exercise was instructed to be completed in a 2-count up, hold, and 4-count down

manner (Kola, 2000). The goal for each exercise session was for a participant to complete exercises until the 20 minutes of treatment time, including warm-up, expires. The participants should have been challenged by the exercise but able to control their body while exercising. The core stability exercises were completed at a frequency of three times a week for 6 weeks; during the last treatment of every week, each participant was remeasured in the passive straight leg raising position to record hamstring range of motion.

Combination Group.

The combination hamstring stretch and core stabilization exercise group began each session with a warm-up, attempted to progress through core stability exercises as described for the core stability group, then they stretched for one bout of 30 seconds on each leg as described for the hamstring stretch group until they have exercised for a total of 20 minutes. This group exercised three times a week for 6 weeks. At the end of each week, each participant was remeasured in the passive straight leg raising position to record hamstring range of motion.

Control Group.

The control group participants began each session with a warm-up, then were questioned about independent workouts to record their physical activity or stretching on their own. The principal investigator noted any overlapping work that could corrupt the data gathered by the study in the discussion. Control groups met with the study administrator three times a week for 6 weeks. During the last meeting every week,

control group participants were measured for hamstring range of motion in the straight leg raising position.

Design

The present study used a pretest posttest control group design, 4 (exercise treatment groups) x 7 (test week). The continuous dependent variable, hip flexion range of motion as measured in the passive straight leg raising position, was measured in a pretest and six times following the last session of each week. Each participant was randomly assigned to one of four treatment groups.

Analysis of Data

Data gathered from the continuous dependent variable (hip flexion range of motion) were analyzed by a 2 way ANOVA. A 4 (exercise treatment group) x 7 (test week) ANOVA with repeated measures on the last factor was conducted on hip flexion with knee extension to indirectly measure hamstring range of motion.

Chapter 4

Results

Introduction

The purpose of the study was to examine the effects of core stability exercises, static stretching exercises, a combination of core stability exercises and static stretching exercises in randomized, controlled environment on hamstring range of motion. Core stabilization exercises have not been scientifically tested as an effective means of improving hamstring range of motion as compared to other methods of exercise.

The data collected on the degrees of hip flexion from the four treatment groups across pretest, five weeks of follow-up, and a posttest at the end of the sixth week were analyzed using a two-way, repeated measures ANOVA. An alpha level of .05 was set as the acceptable level of significance for all statistical tests. The null hypothesis that hamstring range of motion and test week would not interact to affect the degrees of hip flexion and the main effects of test week and type of exercise program were tested.

Descriptive Analysis

A Division II intercollegiate baseball team from the West is limited with regard to players to a maximum of 28 players who could be recruited for the present study. Of those 28 players, 5 players were ineligible due to back, hip or leg injuries in the 6 months previous to the start of data collection. The NCAA definition for injury is one that must meet all of the following criteria: occurs as a result of participation in an organized intercollegiate sport practice or contest; requires medical attention by a team physician or athletic trainer; and results in a student athlete's restriction in practices or competitions

for one or more days beyond the day of injury (2002-03 NCAA injury surveillance system). Of the remaining 23 players eligible for participation in the study, 4 athletes were non-responsive to an orientation meeting; the 19 remaining players eligible for participation in the study were oriented, agreed to participate, and signed consent to participate forms. The ages of the participants ranged from 20 to 27 years old with a mean of 22.0 years ($SD=1.8$ years). Of the 19 health participants who began the study, 13 completed the study. The ages of the participants who completed the study ranged from 20 to 28 years old with a mean of 22.2 years ($SD=2.1$ years). The means and standard deviations for each of the four groups' measurements of degrees of hip flexion to assess hamstring range of motion for each participant who completed the entire 6 week study can be found in Table 1.

The small sample size makes statistical interpretation of the measurements difficult. There are more than eight degrees of measurement in the standard deviation from the mean 11 times in 28 opportunities in Table 1. This is a good indication that the participants responded very differently in each group to their treatments. Appendix F also shows a wide variety of changes in range of motion. At least two participants in each of the three treatment groups increase their hip flexion range of motion by 20%, but one participant in the control group increased his hip flexion range of motion by more than 80% which made clear analysis difficult. Appendix F also shows the median pretest measurement to be 60 degrees and the median posttest measurement to be 72 degrees across all participants, indicating most started with fair and ended with normal range of motion in hip flexion.

Table 1

Mean Measurements of Hip Flexion Range of Motion Across a 6-Week Study

	Treatment Group	M (degrees)	SD	N
Pretest measurement	1	57.50	9.71	4
	2	53.67	8.96	3
	3	59.50	.71	2
	4	56.50	11.12	4
Week 1 Measurement	1	65.25	9.22	4
	2	57.33	12.74	3
	3	59.50	6.36	2
	4	65.00	2.94	4
Week 2 Measurement	1	65.00	8.52	4
	2	62.33	3.22	3
	3	61.50	4.95	2
	4	63.25	2.36	4
Week 3 Measurement	1	71.25	5.56	4
	2	64.67	4.62	3
	3	68.00	8.49	2
	4	70.50	4.20	4
Week 4 Measurement	1	71.25	3.30	4
	2	64.67	9.50	3
	3	71.00	11.31	2
	4	70.25	2.63	4
Week 5 Measurement	1	67.75	8.06	4
	2	64.33	8.51	3
	3	71.00	5.66	2
	4	70.00	3.27	4
Posttest Measurement	1	71.50	1.73	4
	2	66.00	5.20	3
	3	75.50	4.95	2
	4	69.25	7.81	4

Note. Treatment Group 1= Core stability exercise, 2= hamstring stretch, 3= Combination of stability exercise and static stretch, 4= control

For the purposes of description, the baseball players who signed the consent to participate in the study forms were described according to position and eligibility in school in Table 2. By position, there were a total of 8 pitchers, 3 catchers, 6 infielders, and 2 outfielders signed consent forms and began the study. There were 6 pitchers, 1 catcher, 4 infielders, and 2 outfielders that completed the study. By eligibility in school, there were 8 seniors, 8 juniors, and 3 sophomores who signed consent forms and began the study. There were 6 seniors, 5 juniors, and 2 sophomores who completed the study.

Table 2

Participant Description by Position and Year in School

Position	Started Study	Completed Study
Pitcher	8	6
Catcher	3	1
Infielder	6	4
Outfielder	2	2
Year	Started Study	Completed Study
Senior	8	6
Junior	8	5
Sophomore	3	2
Freshman	0	0

Of the six players who signed consent forms but did not complete the study, two were injured in baseball practice or games and became ineligible according to NCAA

injury guidelines, two dropped out related to finals week requirements which fell on the sixth and last week of the study, and two dropped out of the study without relation to injury or schoolwork. No one was injured participating in the present study. The raw data for all records of exercises, stretches, and measurements for all 19 participants who started the study can be found in Appendix F.

Inferential Analysis

A 4 (exercise group) x 7 (test week) ANOVA with repeated measures on the last factor was conducted on hamstring range of motion. The ANOVA (see Table 3) failed to reveal a statistically significant interaction of exercise group by test week on the degrees of hip flexion used to measure hamstring range of motion ($F(18, 54) = .270$; $p = .998$). The main effect for exercise group failed to reach statistical significance as well ($F(3) = 1.51$; $p = .998$).

Table 3

Analysis of Variance Summary for the 4(Group) x 7(Time) with Repeated Measures of the Last Factor on Degrees of Hip Flexion

Source	df	Mean Square	F
Group	3	128.53	1.51
Error	9	84.95	
Time	6	306.40	7.28**
Time * Group	18	11.37	.27
Error (Time)	54	42.08	

** $p < .001$.

The repeated measure, test week, had a statistically significant impact on degrees of hip flexion ($F(6, 54) = 7.28; p < .001$). A closer inspection of the means revealed that a large, but not a statistically significant change in the degrees of hip flexion occurred from time point 3 in the second week to time point 4 third week (see Figure 1). Participants maintained the change from the pretest throughout the remainder of the trials.

Figure 1. Estimated marginal means of Range of Motion across all groups as a function of test week.

Note. Where Test week 1= pretest, 2= first week, 3= second week, 4= third week, 5= fourth week, 6= fifth week, and 7= posttest.

Summary of Results

Research was conducted to determine if core stability is an effective means of improving hip flexion range of motion as compared to static hamstring stretches, a combination of stability exercises and static stretching, and a control group. Participants were chosen from an intercollegiate baseball team for their high level of motor skills, similar workout schedule, an ease of access for the study administrator.

The participants were all from the same athletic team; the participants ranged in age from 20 to 27 years, were all male, represented all positions of their sport, and represented all classes except for the freshman class. After signing a consent form, participants were measured before any treatments were conducted, then met with the study administrator three times weekly for 6 weeks. Two participants of the 19 that signed consent forms were injured playing baseball and had to drop out of the study; two other participants had to drop out of the study due to academic workload; two other participants dropped out of the present study with no explanation given.

A 4 (exercise group) x 7 (test week) ANOVA with repeated measures on the test week was conducted. The ANOVA failed to reveal a statistically significant interaction of exercise group by test week, or a main effect for any of the exercise groups. Only the repeated measure, test week, had a statistically significant impact on hip flexion range of motion ($F(6,54) = 7.28; p < .001$).

Chapter 5

Discussion and Recommendations

For the purpose of the present study data were collected and analyzed about possible ways to increase hamstring range of motion over the course of a 6 week study. In this chapter, results will be compared and contrasted to results found in the literature previously reviewed.

Discussion

The present study utilized Sahrman's progression of core stability exercises as recommended by Kola (2000). No changes were made to the order of exercises, nor were any exercises added or deleted from Sahrman's list. Kola (2000) has not published any study findings on Sahrman's list of core stability exercises. Exercise has been used to treat lumbar spine pain and lumbo-pelvic instability for almost a century. Evidence for the effectiveness of exercise has been largely anecdotal, but McGill (1998) described the effectiveness for lumbar spine exercises in an attempt to improve clinicians' proper use of specific types of exercise in lumbar spine rehabilitation. The present study scientifically tested ways to improve hip flexion range of motion through a variety of methods including stabilization exercises for the lumbo-pelvic region.

The exercise group did not result in a statistically significant increase in the range of motion for passive hip flexion. The participants executing the core stability exercises in the core exercise only and combination exercise and stretch group all progressed through the list of core stability exercises. One of the participants finished the list of exercises; all other core stabilization exercisers, even those dividing time between

stretching and exercising, finished their last treatment only four exercises from finishing out of a list of 44 exercises. All participants taking part in core stability exercises finished in the normal range of motion for hip flexion. The only participant who started with a normal amount of hip flexion range of motion was the one who finished the exercise list, supporting Chaitow, Jull and Janda, Kendall et al., Norris, and Sahrmann's idea that strengthening is optimized after normal range of motion is gained. Statistically, the participant who started in the normal range of motion did not gain very much range of motion because there was little left for him to gain.

The hamstring stretches performed in the present study were developed from a combination of the studies reviewed (Bandy et al., 1991; Gajdosik, 1991; Gajdosik et al., 1994; Li et al., 1996), but was not identical to any of these studies in type of stretch, measurement of hamstring flexibility, nor did any of these studies compare stretching to core stabilization flexibility. Participants in the Bandy et al. (1991) study stretched in a different position (standing versus laying supine), and met five times per week instead of three times per week. Bandy et al. (1991) did find statistically significant results in a 6 week duration of study with stretches conducted five times each week, indicating a study of 10-12 weeks was not necessary to find statistically significant changes in hamstring range of motion. The methodology used in the present study was all four groups met three times per week, as opposed to the Bandy et al. study that met five times per week. The participant size of Bandy et al.'s study could not be reached due to study delimitations. This current study delimited participants to a single athletic team to minimize variations in workouts.

Gajdosik (1991) used 24 men between the ages of 18 and 37 years old.

Gajdosik's (1991) participants stretched in a similar manner to Bandy et al.'s (1991) participants. Gajdosik's participants were also required to have tight hamstrings, which he defined as less than or equal to 70 degrees of hip flexion in the straight leg-raising test (all participants in the present study would have qualified for Gajdosik's study).

Gajdosik's participants had a much more strenuous regimen over much shorter duration: stretch to discomfort for 15 seconds followed by 15 seconds of rest for 10 bouts per day for 21 straight days.

Gajdosik et al. (1994) had 30 participants evenly spread over varying degrees of hamstring flexibility. The participants were analyzed for lumbar and pelvic movements while stretching the hamstrings from the standing toe-touching position. The participants appeared to have stretched six times during one day only.

Li et al. (1996) studied 39 participants with a straight leg-raising test less than or equal to 70 degrees. The participants performed the same doorway stretch as was used in the present study, but in frequency and duration similar to Gajdosik's 1991 study (10 bouts of 15 seconds stretch/ 15 seconds rest for 21 straight days). The participants in the Li et al. (1996) study performed the doorway stretch to the point of mild discomfort as opposed to the present study where the participants were instructed not to stretch to the point of pain.

In the present study test week had a statistically significant effect on the passive range of hip flexion; this indicates a 6 week study was long enough to find statistically significant effects. Studies indicate neural factors are primarily responsible for strength

gains in the first 4 to 8 weeks of exercise (Moritani & de Vries 1979; Miller & Medeiros, 1987). The similarity of activity over the course of the study from team activity could be another factor for the test week effect. Similar to Worrell et al. (1994) and Doebler et al. (2000) gains in hip range of motion by hamstring stretches might not have been statistically significant with a small number of participants. Doebler et al.'s (2000) study indicates large numbers of participants are important to statistical power; this is important for future study because larger numbers of participants would allow improved statistical power over the current study. Core stabilization exercise effects may have also been hampered by small sample size. The combination exercise and stretch group had only two participants complete all six weeks of the study; the present study had group sample sizes that hindered finding statistical significant results for much of the data.

The purpose of the present study was to examine the effect of core stability exercises, static stretching exercises, a combination of core stability exercises and static stretching exercises, and a control on hamstring flexibility as measured on hip flexion in the passive straight leg raising test position. The null hypothesis that test week would not affect the passive range of hip flexion was rejected. The null hypothesis that the interaction of type of exercise and test week would affect the passive range of hip flexion was accepted; and the null hypothesis that the type of exercise would affect passive range of hip flexion was accepted. The present study attempted to test various forms of core stabilization exercises and static hamstring stretches that had been previously discussed in the literature.

There were several limitations in the present study. A limitation of the present study testing a progression of core stability exercises on hamstring range of motion too few participants to permit adequate statistical power. The statistical power was too small to allow adequate analysis of hamstring stretches on hamstring range of motion. Part of the small sample size was caused by the delimitation placed on the present study of recruiting participants all from the same team to control for similarity of exercise purposes. Part of low participant numbers was caused by the difficulty in recruiting eligible participants. Adherence was good as the program ran for three days a week over six weeks. This is further reflected in the fact that of all of the eligible team members who signed a consent form and began the study, only two dropped out for reasons other than sport-related injury or end of the term academic requirements. Including those participants were forced to drop out for sport-related injuries or academic requirements shows the overall amount of participants who did not finish the study was near 30% of those participants that began the study. Losing participants probably hurt the statistical power of the present study.

In the present study all participants, including controls, participated in the team's activities, including warm-up, stretching, and conditioning during practices and games. It is possible that all participants had a homogenous workout schedule outside of the present study, and that could have lead to homogenized results as well. Smith, Kane, and Arnold (2001) found that a cycling warm-up produced similar results to brief warm-up and stretching. The present study had all participants warm up every meeting, including the control group; normally warm up was on an exercise bike. Warming up for the study

could have resulted in similar results across all four groups. All participants were involved in jogging, stretching, and participating in baseball activities during the course of the study that may have interfered with the present study. The participants were not evaluated for transverse abdominis activity at the onset of the study; since none of them had lower back injuries as part of the delimitations placed on participants' eligibility, it is possible all participants were already using their transverse abdominis musculature in baseball practice. Recall that Hodges and Richardson (1996) found spinal pain caused the transverse abdominis to recruit differently than in those people without spinal pain. In future studies, using relatively inactive or non-athletic participants could lessen the confounding variable of high amounts of regular exercise in the participants' daily schedule.

An important issue relative to core stability and hamstring range of motion is the close proximity of single joint hip flexor muscles such as the iliopsoas and also the gluteals. The iliopsoas and gluteal muscle groups are reported to be very influential of joint imbalance in the pelvic and lumbar regions (Jull & Janda, 1987; Norris 1993, 2001a, 2001b; Chaitow, 2001). It would be wise in retrospect to study the importance of core stability for gluteal function and iliopsoas flexibility than studying core stability's influence on a more secondary function such as hamstring range of motion.

Recommendations

At this time, further application of this research is unclear. The differences in stretch technique, pain sensation, length of stretch, frequency of stretch, and duration of study need to be compared to further study in hamstring range of motion as measured by

the straight leg raising test. In the future, a study of hamstring stretching should focus on the methodology of one study and not combine multiple methodologies for a single, new methodology. It is recommended that the present study be replicated with enough participants for a high statistical power, as well as conducted with non-athletic participants. Further study of core stability exercises including pretest strength testing should be methodically tested to determine their use in improving proprioception and decreasing muscle imbalances around the joints of the body instead of reliance upon non-scientific advertising and marketing. The present study can be used as a pilot study to guide further research on this topic for participant population size, population activity level, hamstring stretch techniques, and exercise progression of the participant population. It is recommended that the effects of core stability should be studied on the flexibility of the hip flexor iliopsoas muscle group. Future studies might also want to include an initial measurement of core strength to determine improvement with core stability exercises.

It is also recommended for future study that the three dimensional nature of the muscles in the lumbo-pelvic region be taken into consideration. Most texts (Jull & Janda, 1987; Kenall et al., 1993; Norris, 1993, 2001a, 2001b; Chaitow, 2001) address muscle imbalance around the lumbo-pelvic region in the two dimensions of anterior and posterior in the sagittal plane. Both the iliopsoas and gluteal muscle groups have components that facilitate movement outside of the sagittal plane (Kendall et al., 1993; Marieb & Mallat, 1992). Not only should the three dimensional nature of the lumbo-pelvic region be taken into consideration in future study, but the fourth dimension of time should be taken into

consideration as well since most stability movements being studied are to be taught as endurance movements in a motor control progression (Jull & Janda, 1987; Gentile 1987, 2000; Kendall et al., 1993; Norris, 1993, 2001a, 2001b; George & Delitto, 2002).

Summary of Discussion and Recommendations

The present study did not indicate an effect on hip flexion range of motion by core stability exercises, static stretching exercises, a combination of core stability exercises and static stretching exercises, and a control on hip flexion range of motion. Hip flexion range of motion was measured in the passive straight leg raising position as a means of indirectly measuring hamstring flexibility (Gadjosik et al., 1993). Test week, 6 weeks, was statistically significant across all four treatment groups as increasing hip flexion in the passive straight leg raising test position. The null hypothesis that test week would not affect the passive range of hip flexion was rejected. The methodology of this present study had all participants warm up every meeting, even the control group; normally warm up was conducted on an exercise bike. This, as well as the homogeneous workout schedule could have resulted in similar results across all four groups.

Future research needs to examine the relationship of the iliopsoas and gluteal muscles on lumbo-pelvic relationships. These two muscle groups are more important to hip movements than the hamstring muscles; therefore, the iliopsoas and gluteal muscles may be affected by core stabilization exercises more than the hamstrings. As enjoyable as the participant athletes were to work with, future research should be attempted with non-athletic participants to ensure controls are not exercising in ways that can skew the results.

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Appendix A

Clinical Relevance of Co-contraction of Muscle Groups. Richardson et al., (1999).

Therapeutic Exercise for Spinal Stabilization in Low Back Pain.

Testing procedures and exercise for active joint stabilization should:

1. Include co-contraction exercises
2. Avoid unidirectional (open kinetic chain) high strength training
3. Use slow, controlled closed kinetic chain exercises
4. Focus on joint position rather than the control of force
5. Use unstable environments (e.g. a balance board)
6. Use slow positioning tasks which require precision and control
7. Include exercise in neutral joint positions
8. Use only low force levels for training
9. Do not overtrain co-contraction of the large torque producing muscles (otherwise stability may be gained while compromising freedom of movement)

Appendix B

Consent Form

See Agreement to Participate in Research on following pages.

College of Applied
Sciences and Arts
Department of Human
Performance

One Washington Square
San Jose, CA 95182-0054
Voice: 408-924-3010
Fax: 408-924-3033

Agreement to Participate in Research

Responsible Investigator: Paul-Wayne Mahlow, ATC, CSCS

Title of Protocol: Effect of Exercise Programs on Hamstring Range of Motion

I have been asked to participate in a research study investigating the effect of core stability exercises, static stretching exercises, a combination of core stability exercises and static stretching exercises, and an inactive control on hamstring range of motion. Specifically, previous research has not investigated whether core stability is an effective means of improving hamstring range of motion.

I will be asked to attempt exercises as described by the investigator four times a week for six weeks. Exercise sessions will last a maximum of 20 minutes. Materials used in this study include an stationary bike for warm up, an exercise mat, exercise balls of 75 cm and 65 cm in diameter, a large goniometer made of clear plastic to measure hamstring range of motion, and a list of instructions that includes progression of exercises.

Foreseeable risks or discomforts to the participants include delayed onset of muscle soreness from exercise.

Possible benefits to the participants reasonably expected from the research depend on exercise treatments completed. Benefits include better muscle control of the trunk muscles and improved hamstring range of motion.

The results of the study may be published but no information that could identify the participant will be included. There is no monetary compensation for participation in the study.

Questions about the research may be addressed to Paul-Wayne Mahlow at 408-422-6286. Complaints about the research may be presented to the Human Performance Department Chair, Dr. Greg Payne at 408-924-3028. Questions about research, participants' rights, or research-related injury may be presented to Nabil Ibrahim, Ph.D., Associate Vice President for Graduate Studies and Research at 408-924-2480.

No service of any kind, to which a participant is otherwise entitled, will be lost or jeopardized if a person chooses to "not participate" in the study. Consent to participate is given voluntarily. A participant may refuse to participate in the study or in any part of the study. If a participant decides to participate in the study, he or she is free to withdraw at any time without prejudice to the participant's relations with San Jose State University or any other participating institutions.

Participant's initials _____

I, the participant, have received a signed and dated copy of the consent form.

The signature of a participant on this document indicates agreement to participate in the study.

The signature of a researcher on this document indicates agreement to include the above named participant in the research and attestation that the participant has been fully informed of his or her rights.

Participant Signature

Date

Investigator's Signature

Date

Appendix D

Exercise Instruction and Progression List

(From Kola, 2000)

Sahrmann starting position/TVA recruitment (Core 1)

1. Lie on back with hips and knees bent and feet on the floor. Place finger tips between ribs and hips.
2. Pull belly button up and in, flattening stomach and flattening back. Do not flatten back completely.
3. If done correctly, the belly button should feel as if it is pulling towards the spine and the stomach is flattening.
4. The stomach should remain flat and pulled in (it should not pooch out) during the rest of these exercises.

High knees from starting position (Core 2, Level 1A)

1. Assume starting position.
2. Lift one foot up and bring knee toward chest, far enough that it points toward your head. Re-tighten abs and lift other leg in a similar manner.
3. Lower first leg, then second leg back to starting position.
4. If your back arches from the starting position at any time during the exercise, it is being performed improperly.

Marching from starting position (Core 3, Level 1B)

1. Assume starting position.
2. Keeping the knee bent, lift one foot up until the thigh is vertical. Re-tighten abs and lift other leg to same position.
3. Lower first leg, then second leg back to starting position.
4. If your back arches from the starting position at any time during the exercise, it is being performed improperly.

Alternating heel slides, heels touching surface, with knees extended (Core 4, Level 2)

1. Assume starting position.
2. Slide one foot along the table until your hip and knee are bent and your foot is resting on the mat as close to hips as possible. Re-tighten abs and slide foot down to starting position.
3. Repeat movement with other leg.

Alternating heel slides, heels not touching surface, with knees extended (Core 5, Level 3)

1. Assume starting position.
2. Bring both knees to chest until thighs are vertical. Maintain this position with one leg while straightening the other.
3. Touch heel to the mat before returning to starting position.
4. Repeat movement with other leg.
5. If your back arches from the starting position at any time during the exercise, it is being performed improperly.

Bilateral heel slides, heels touching surface (Core 6, Level 4)

1. Assume starting position.
2. Bring both knees to chest until thighs are vertical.
3. Touch both heels lightly to the mat at the same time and straighten legs so the knees and hips are fully extended.
4. Slide back to starting position.
5. If your back arches from the starting position at any time during the exercise, it is being performed improperly.

Bilateral heel slides, heels not touching surface (Core 7, Level 5)

1. Assume starting position.
2. Bring both knees to chest until thighs are vertical.
3. Straighten legs out at the same time but do not let the heels touch the mat.
4. Return to starting position.
5. If your back arches from the starting position at any time during the exercise, it is being performed improperly.

Supine trunk curl ups (Core 8, Level 1)

1. Assume starting position.
2. Lay with legs straight and resting on mat.
3. Point hands towards feet, bring chin to chest, and slowly curl up until your shoulder blades come off of the mat.
4. Return to starting position.

Supine trunk curl with folded arms (Core 9, Level 2)

1. Assume starting position.
2. Lay with legs straight and resting on mat.
3. With arms folded on chest, bring chin to chest, and slowly curl up until your shoulder blades come off of the mat.
4. Return to starting position.

Supine trunk curl with hands on head (Core 10, Level 3)

1. Assume starting position.
2. Lay with legs straight and resting on mat.
3. With hands on top of head, bring chin to chest, and slowly curl up until your shoulder blades come off of the mat.

Supine bridge (Core 11, start position)

1. Lying supine with heels centered on top of ball, bend hips and knees to 90 degrees.
2. Recruit TVA from this position.

Supine bridge (Core 12, Level 1)

1. Assume starting position, with arms out and palms down.
2. Squeezing gluts, extend hips up so that trunk is in a straight line from the ribs to the knees.
3. Relax back down to mat.
4. Do not arch back to extend hips up, but keep gluts and abs contracted.

Supine bridge without elbows out (Core 13, Level 2)

1. Assume starting position, with hands on stomach but keep elbows on ground for support.
2. Squeezing gluts, extend hips up so that trunk is in a straight line from the ribs to the knees.
3. Relax back down to mat.
4. Do not arch back to extend hips up, but keep gluts and abs contracted.

Supine bridge with folded arms (Core 14, Level 3)

1. Assume starting position, with arms folded across chest.
2. Squeezing gluts, extend hips up so that trunk is in a straight line from the ribs to the knees.
3. Relax back down to mat.
4. Do not arch back to extend hips up, but keep gluts and abs contracted.

Supine bridge with leg lift (Core 15)

1. Laying with both heels centered on top of ball, bend hips and knees to 90 degrees.
2. Assume bridge starting position.
3. Squeezing gluts, extend hips up so that body is in a straight line from ribs to feet.
4. While maintaining in the plank position, do a straight leg raise in height of 12-18". Repeat with other leg.
5. Return to laying on mat. To increase difficulty, progress from arms out to elbows out to arms folded across chest.

Seated on exercise ball/TVA recruitment (Core 16)

1. Sit on ball with back straight, knees and hips flexed to 90 degrees.
2. Pull belly button up and in, flattening stomach and flattening back. Do not flatten back completely.
3. If done correctly, the belly button should feel as if it is pulling towards the spine.
4. The stomach should remain flat and pulled in (it should not pooch out) during the rest of these exercises.

Seated on exercise ball with alternating knee extensions (Core 17)

1. Sit on exercise ball and recruit TVA.
2. Lift one foot off of ground and straighten the knee with no weight shift or lateral trunk movement.
3. Return foot to ground and repeat with other leg.

Seated on exercise ball with FABERS (Core 18)

1. Sit on exercise ball and recruit TVA.
2. Lift one foot off of ground and cross it over the other leg so that the ankle rests on the knee of supporting leg. Return to starting position.
3. Repeat movement with other leg.

Shoulder bridges on exercise ball/TVA recruitment (Core 19)

1. Lay on ball, keeping shoulder blades on top of the ball and knees bent at 90 degrees with feet on mat.
2. Squeeze gluts and pull belly button up and in towards ribs. Thighs and trunk should be parallel with mat.

Shoulder bridges on exercise ball with marching (Core 20)

1. Lay on ball, keeping shoulder blades on top of the ball and knees bent at 90 degrees with feet on mat.
2. Squeeze gluts and pull belly button up and in towards ribs. Thighs and trunk should be parallel with mat.
3. Lift one leg by flexing at the hip approximately 45 degrees. Return to starting position and repeat with other leg.

Shoulder bridges on exercise ball with marching (Core 21)

1. Lay on ball, keeping shoulder blades on top of the ball and knees bent at 90 degrees with feet on mat.
2. Squeeze gluts and pull belly button up and in towards ribs. Thighs and trunk should be parallel with mat.
3. Lift one leg by flexing at the hip approximately 90 degrees. Return to starting position and repeat with other leg.

Shoulder bridges on exercise ball with knee extensions (Core 22)

1. Lay on ball, keeping shoulder blades on top of the ball and knees bent at 90 degrees with feet on mat.
2. Squeeze gluts and pull belly button up and in towards ribs. Thighs and trunk should be parallel with mat.
3. Lift one foot off of ground and straighten the knee while keeping both thighs parallel to mat. Return to starting position and repeat with other leg.

Shoulder bridge on exercise ball with FABERS (Core 23, Level 1)

1. Lay on ball, keeping shoulder blades on top of the ball and knees bent at 90 degrees with feet on mat.
2. Squeeze gluts and pull belly button up and in towards ribs. Thighs and trunk should be parallel with mat.
3. Lift one foot off of ground and touch heel to the opposite knee.
4. Return to starting position and repeat with other leg.

Shoulder bridge on exercise ball with FABERS (Core 23, Level 2)

1. Lay on ball, keeping shoulder blades on top of the ball and knees bent at 90 degrees with feet on mat.
2. Squeeze gluts and pull belly button up and in towards ribs. Thighs and trunk should be parallel with mat.
3. Lift one foot off of ground touching heel to the opposite knee. Drop the raised knee out in abduction.
4. Return to starting position and repeat with other leg.

Shoulder bridge on exercise ball with FABERS (Core 23, Level 3)

1. Lay on ball, keeping shoulder blades on top of the ball and knees bent at 90 degrees with feet on mat.
2. Squeeze gluts and pull belly button up and in towards ribs. Thighs and trunk should be parallel with mat.
3. Lift one foot off of ground touching heel to outside of the opposite knee.
4. Return to starting position and repeat with other leg.

Shoulder bridge walk out (Core 26)

1. Assume seated ball starting position. Tuck chin in and cross arms on chest.
2. Walk feet out until body is in a perfect shoulder bridge position.
3. Walk feet in until returned to seated starting position.

Shoulder bridge walk with 45 step (Core 27)

1. Assume seated ball starting position. Tuck chin in and cross arms on chest.
2. Walk feet out until body is in a perfect shoulder bridge position.
3. While in shoulder bridge position, pick one foot up off mat by flexing the hip approximately 45 degrees. Lower leg and repeat with other foot.
4. Walk feet in until returned to seated starting position.

Shoulder bridge walk with 90 step (Core 28)

1. Assume seated ball starting position. Tuck chin in and cross arms on chest.
2. Walk feet out until body is in a perfect shoulder bridge position.
3. While in shoulder bridge position, pick one foot up off mat by flexing the hip approximately 90 degrees. Lower leg and repeat with other foot.
4. Walk feet in until returned to seated starting position.

Prone on exercise ball/ TVA recruitment (Core 29)

1. Lay with belly button on ball. Toes should be on the ground with knees slightly bent.
2. Pull belly button up and in, flattening stomach and flattening back. Do not flatten back completely.
3. If done correctly, the belly button should feel as if it is pulling towards the spine.
4. The stomach should remain flat and pulled in (it should not pooch out) during the rest of these exercises.

Prone on exercise ball with alternating diagonal limb lifts (Core 30)

1. Lay with belly button on ball. Toes should be on the ground with knees slightly bent. Extend arms out in front of ball on mat.
2. Pull belly button up and in, flattening stomach and flattening back. Do not flatten back completely.
3. While maintaining flattened stomach and back, straighten one arm and the opposite leg at the same time until aligned with the trunk. Relax to starting position. Repeat with other arm and leg.
4. Do not arch back.

Prone on exercise ball with bilateral arm lifts/ superman (Core 31, Level 1)

1. Lay with belly button on ball. Toes should be on the ground with knees slightly bent. Cross arms to touch fingers on shoulders.
2. Pull belly button up and in, flattening stomach and flattening back. Do not flatten back completely.
3. Cross arms on the chest with fingers on shoulders. Extend the trunk until the back is straight. Relax into starting position.
4. Do not arch back.

Prone on exercise ball with bilateral arm lifts/ superman (Core 32, Level 2)

1. Lay with belly button on ball. Toes should be on the ground with knees slightly bent. Cross arms to touch fingers on shoulders.
2. Pull belly button up and in, flattening stomach and flattening back. Do not flatten back completely.
3. Cross forearms. Extend the trunk until the back is straight. Relax into starting position.
4. Do not arch back.

Prone on exercise ball with bilateral arm lifts/ superman (Core 33, Level 3)

1. Lay with belly button on ball. Toes should be on the ground with knees slightly bent. Cross arms to touch fingers on shoulders.
2. Pull belly button up and in, flattening stomach and flattening back. Do not flatten back completely.
3. Extend arms straight out in front. Extend the trunk until the back is straight. Relax into starting position.
4. Do not arch back.

Sidelying bridge on exercise ball starting position (Core 34)

1. Lay on your side with feet centered on top of ball. Extend bottom arm out and under head. Place top hand in front of your body for support.
2. Recruit TVA in this position. Relax.
3. Repeat exercise on other side of the body.

Sidelying bridge on exercise ball (Core 35, Level 1)

1. Lay on your side with feet centered on top of ball. Extend bottom arm out and under head. Place top hand in front of your body for support.
2. Lift hips off floor, creating a straight line from ribs to feet.
3. Relax down onto mat.
4. Repeat exercise on other side of the body.

Sidelying bridge on exercise ball (Core 36, Level 2)

1. Lay on your side with feet centered on top of ball. Extend bottom arm out and under head. Place top hand on hip.
2. Lift hips off floor, creating a straight line from ribs to feet.
3. Relax down onto mat.
4. Repeat exercise on other side of the body.

Sidelying planks on exercise ball with leg abductions (Core 37, Level 1)

1. Lay on your side with feet centered on top of ball. Extend bottom arm out and under head. Place top hand in front of your body for support.
2. Lift hips off floor, creating a straight line from ribs to feet.
3. While maintaining position, abduct top leg 12-18". Do not rotate foot/leg outward.
4. Lower leg down into bridge position, then relax down onto mat.
5. Repeat exercise on other side of the body.

Sidelying planks on exercise ball with leg abductions (Core 38, Level 2)

1. Lay on your side with feet centered on top of ball. Extend bottom arm out and under head. Place top hand on hip.
2. Lift hips off floor, creating a straight line from ribs to feet.
3. While maintaining position, abduct top leg 12-18". Do not rotate foot/leg outward.
4. Lower leg down into bridge position, then relax down onto mat.
5. Repeat exercise on other side of the body.

(Core 39 not in Kola's exercise list)

Prone push up position with exercise ball at feet (Core 40)

1. Start in push up position with exercise ball under tops of feet.
2. Pull belly button up and in, flattening stomach and flattening back.
3. If done correctly, belly button should feel as if it is pulling towards the spine.
4. Straighten arms into position of body parallel to mat.
5. Relax back down to starting position.

Prone push up position with exercise ball at feet, alternating leg lifts (Core 41)

1. Start in push up position with exercise ball under tops of feet.
2. Pull belly button up and in, flattening stomach and flattening back.
3. Straighten arms into position of body parallel to mat.
4. Without tilting trunk or arching spine, raise one leg 6-12" off of ball. Lower leg back onto ball and repeat with opposite leg.
5. Relax back down to starting position.

Prone push up position with exercise ball at feet, one arm stance (Core 42)

1. Start in push up position with exercise ball under tops of feet and body on the mat.
2. Straighten arms and push into position of body parallel to mat.
3. Without rotating trunk or arching back, raise one hand off of mat. Lower hand back down to push up position. Repeat with other hand.
4. Relax back down to starting position.

Prone on exercise ball with alternating salute and hand behind back (Core 43)

1. Lay with belly button on ball. Toes should be on the ground with knees slightly bent.
2. Pull belly button up and in, flattening stomach and flattening back.
3. Place one hand behind back and the other hand saluting on the face. Extend the trunk until the back is straight. Do not arch back.
4. Relax into starting position. Switch hands and repeat.

Prone on exercise ball with alternating salute and leg lifts (Core 44)

1. Lay with belly button on ball. Toes should be on the ground with knees slightly bent.
2. Pull belly button up and in, flattening stomach and flattening back..
3. Place one hand behind back and the other hand saluting on the face. Extend the trunk until the back is straight. Without moving the pelvis, rotate the trunk as far as possible in the direction of your saluting arm. Do not arch back.
4. Lift the opposite leg of saluting arm until aligned with trunk.
5. Relax into starting position. Switch limbs and repeat.

Appendix E

Daily Log of Exercises

I.D. # _____

Exercise Type	set 1	set 2	set 3	set 4	set 5
Strengthening	weight/reps	weight/reps	weight/reps	weight/reps	weight/reps
chest					
shoulders					
triceps					
biceps					
forearms/wrists					
back					
abdominals					
gluts					
thighs					
hamstrings					
calves					
plyos					
Stretching	duration	duration	duration	duration	duration
chest					
shoulders					
triceps					
biceps					
forearms/wrists					
back					
abdominals					
gluts					
thighs					
hamstrings					
calves					
Running	distance/time	distance/time	distance/time	distance/time	distance/time
flat					
hills					
inclines					
declines					
trails					
stairs					

Appendix F

Data Entry Record for Treatments and ROM Scores for All Weeks

Note. C= core stability exercise (see Appendix D for individual descriptions); S= hamstring stretch; E= independent exercise; N/S= no show; tx= treatment; wk= week. For example, the first entry of the first week of records reads:

I.D. #	tx 1 (pretest ROM)	tx 2, wk 1	tx 3, wk 1	wk 1 posttest ROM
3-2	59	S; C1-C2; no E	S; C2-C4	64

This entry indicates participant 3-2 was measured with 59 degrees pretest range of motion during the first treatment of the first week. Participant 3-2 performed hamstring stretch (S), core stability exercise #1 and #2 as described in Appendix D (C1-C2), and did not perform any independent exercise that day previous to testing or the day before (no E) for the second treatment of the first week. Hamstring stretch (S), core stability exercises #2 through #4 (C2-C4) were performed for the third and final treatment of the first week, and participant 3-2 ended his third treatment of the first week with 64 degrees of motion when measured is the passive straight leg raising test. Please refer to this example as a guide for reading the data entry logs for the study.

Table F1

First Week Data Entry Record for Treatments and ROM Scores

I.D. #	tx 1 (pretest ROM)	tx 2, wk 1	tx 3, wk 1	wk 1posttest ROM
3-2	59	S; C1-C2; no E	S; C2-C4	64
1-5	48	C1-C4; no E	C4-C5; no E	60
3-8	66	Injury	Injury	Injury
2-12	40	S; no E	S; no E	78
4-14	40	No E	No E	68
3-16	60	S; C1-C3	S; C3-C5	55
1-18	52	C1-C3	C3	62
3-22	62	S; C1-C3	S; C3-C4; no E	68
3-23	60	S; C1-C2; no E	S; C2-C4	72
1-27	70	C1-C2; no E	C3-C6; no E	79
4-28	60	No E	No E	67
1-24	60	C1-C3; no E	C3-C6; no E	60
2-3	48	S; no E	S; no E	49
1-4	65	C1-C2; no E	C2-C4; no E	62
2-17	49	S; no E	S; no E	72
2-30	55	N/S	N/S	N/S
4-11	62	No E	No E	63
2-x3	64	S	S	51
4-34	64	No E	No E	62

Table F2

Second Week Data Entry Record for Treatments and ROM Scores

I.D. #	tx 1, wk 2	tx 2, wk 2	tx 3, wk 2	wk 2 posttest ROM
3-2	S; C4-C6	S; C6-C9; no E	S; C9-C12; no E	58
1-5	C5-C7; no E	C7-C11	C11-C17; no E	58
2-12	S; no E	S; no E	S; no E	55
4-14	No E	No E	No E	60
3-16	S; C5; no E	S; C5-C8; no E	S; C8-C12; no E	65
1-18	C4-C7; no E	C7-C9; no E	C9-C14	77
3-22	S; C4-C9; no E	Injury	Injury	Injury
3-23	S; C4-C7; no E	S; C8-C14; no E	C14-C17; S; no E	68
1-27	C6-C9; no E	C9-C13; no E	C13-C16	60
4-28	No E	No E	No E	65
1-24	C6-C11; no E	C11-C14; no E	C14-C17; no E	65
2-3	S; no E	S; no E	S; no E	61
1-4	C4-C7; no E	C7-C14; no E	N/S	N/S
2-17	S; no E	S; no E	S; no E	66
4-11	No E	No E	No E	63
2-x3	S; no E	S	S	60
4-34	No E	No E	No E	65

Table F3

Third Week Data Entry Record for Treatments and ROM Scores

I.D. #	tx 1, wk 3	tx 2, wk 3	tx 3, wk 3	wk 3 posttest ROM
2-12	S	S; no E	S; no E	66
4-34	No E	No E	No E	68
2-17	S; no E	S; no E	S; no E	62
1-27	C16-C19; no E	C19-C23; no E	C20-C23; no E	73
1-18	C14-C20	C20-C22	C22-C25; no E	75
1-24	C17-C19; no E	C19-C23; no E	C22-C25; no E	63
3-16	S; C12-C14	S; C14-C17; no E	S; C17-C19; no E	62
1-5	C17-C20; no E	C19-C22; no E	C22-C25; no E	74
3-2	S; C12-C15	S; C16-C19; no E	S; C19-C22	74
4-14	No E	No E	No E	66
4-28	No E	No E	No E	73
3-23	S; C16-C20; no E	S; C19-C23; no E	S; C24-C25; no E	82
2-3	S; no E	S; no E	S; no E	70
4-11	No E	No E	No E	75
2-x3	S; no E	S	S; no E	62

Table F4

Fourth Week Data Entry Record for Treatments and ROM Scores

I.D. #	tx 1, wk 4	tx 2, wk 4	tx 3, wk 4	wk 4 posttest ROM
4-28	Independent E	No E	No E	74
2-17	S; no E	S; no E	S; no E	65
1-18	C25-C28	C28-C29	C30-C32	73
3-16	C20-C23; S; no E	S; C24-C26	S; C27-C28	63
1-5	C25-C27; no E	C27-C28	C28-C30	69
1-27	C23-C26; no E	C27-C29	C29-C33; no E	68
4-34	No E	See E	See E	68
3-2	C22-C24; S	C25-C26; S; no E	S; C27-C28	79
4-14	Independent E	No E	Independent E	69
3-23	Sick	C25-C29; S; no E	C30-C34; S	68
4-11	No E	No E	No E	70
2-12	S	S; no E	S; no E	71
1-24	C25-C27; no E	Sick	C28-C30; no E	75
2-3	S; no E	S; no E	S; no E	55
2-x3	S; no E	S	S	74

Table F5

Fifth Week Data Entry Record for Treatments and ROM Scores

I.D. #	tx 1, wk 5	tx 2, wk 5	tx 3, wk 5	wk 5 posttest ROM
4-28	No E	No E	No E	74
1-5	C30-C33; no E	C33-C35	C35-C36	57
2-x3	S; no E	S; no E	S; no E	74
1-24	C30-C34; no E	C34-C36	C36; no E	67
4-34	No E	Independent E	Independent E	70
2-17	S; no E	S; no E	S; no E	61
1-18	C33-C35; no E	C35-C37	C37	76
3-16	S; C29-C32	C32-C34; S; no E	C35-C36; S	67
1-27	C33-C35; no E	C35-C37; no E	C37-C38	71
3-2	C29-C32; S; no E	S; C33-C35; no E	C36; S	75
4-14	Independent E	No E	No E	66
4-11	No E	No E	No E	70
2-12	S	S; no E	S; no E	76
2-3	S	S	S; no E	58
3-23	N/S	N/S	N/S	N/S

Table F6

Sixth Week Data Entry Record for Treatments and Final ROM Scores

I.D. #	tx 1, wk 6	tx 2, wk 6	tx 3, wk 6	wk 6 posttest ROM
2-12	N/S	N/S	N/S	N/S
1-5	C37-C38	C38-C40	C41-C42	72
1-24	C37; no E	C38	C40; no E	69
1-18	C38	C40-C41	C41-C42; no E	73
1-27	C40-C41; no E	C41-C43	C43-C44	72
2-x3	S; no E	S; no E	S; no E	72
2-17	S; no E	S; no E	S; no E	63
2-3	S; no E	S; no E	S; no E	63
3-2	S; C37-C38; no E	S; C38-C40	S; C40-C42; no E	79
3-16	S; C37-C38; no E	S; C38-C40; no E	S; C41-C43; no E	72
4-28	Independent E	No E	Independent E	74
4-14	Independent E	Independent E	Independent E	75
4-11	No E	No E	No E	58
4-34	No E	No E	No E	70

Appendix G

Consent from Participating Institutions

San José State
UNIVERSITY

**Office of the Academic
Vice President**

**Academic Vice President
Graduate Studies and Research**

One Washington Square
San Jose, CA 95192-0025
Voice: 408-285-7500
Fax: 408-924-2477
E-mail: gradstudies@sjsu.edu
<http://www.sjsu.edu>

To: Paul-Wayne Mahlow
5406 Colony Park Circle
San Jose, CA 95123

From: Nabil Ibrahim,
AVP, Graduate Studies & Research

Date: March 28, 2003

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

“Core Stability and Flexibility Effects on Hamstring Range
of Motion.”

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Nabil Ibrahim, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subjects portion of your project is in effect for one year, and data collection beyond March 28, 2004 requires an extension request.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services that the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

San Francisco
State University

Department of Athletics

1600 Holloway Avenue
San Francisco, California 94132-4041

Tel: 415/338-2218 ¹⁰³
Fax: 415/338-1967

March 20, 2003

To Whom It May Concern:

Paul-Wayne Mahlow, ATC, CSCS, is a graduate assistant athletic trainer at San Francisco State University. He is also a graduate student in the Human Performance department at San Jose State University. He would like to investigate improving hamstring range of motion; he has asked permission to recruit student athletes in the athletic department for participants in his study. This study will be conducted in accordance to all guidelines set forth by the Human Subjects Institutional Review Board at San Jose State University.

As this study will help our athletes improve aspects of their athletic performance at no risk beyond what they normally encounter in their activities, San Francisco State University athletic department clears Paul-Wayne Mahlow, ATC, CSCS, to recruit and conduct his study using participants who are student athletes at this university.

Doug Hupke, Director of Facilities, SFSU