A MOTOR LEARNING STUDY COMPARING CONSTANT TO VARIABLE FEEDBACK USING DYNAMIC ULTRASOUND IMAGING FOR RECRUITMENT OF THE LUMBAR MULTIFIDUS

A Thesis

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By

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ABSTRACT

Background: Evidence suggests that the lumbar multifidus, an important stabilizer of the spine, may be inhibited in patients with acute low back pain (LBP). Clinical research suggests that patients with LBP require weeks of exercise therapy to learn to recruit the lumbar multifidus. It is not known whether the extensive training required for acquisition and retention of the motor skill (multifidus recruitment) is a factor of the therapist’s approach to motor learning versus a function of motor recovery. Objectives: Two training methods for recruitment of the lumbar multifidus were compared. Based on motor learning theory, we hypothesized that during the training phase, the group who received constant feedback would demonstrate greater success than the group who received feedback according to a variable schedule. However, during the retention phase, the variable group would show greater success on retention tests. Methods: The 28 subjects (age 19-47 years) without a history of LBP were randomly assigned to the constant and variable groups. Subjects attended 8 training sessions over 4 weeks. Subjects practiced with 12 repetitions of multifidus isometric recruitment at the L5-S1 level. Visual feedback of activation of the multifidus was provided via real-time ultrasound imaging. The constant group received feedback with every repetition. The variable group received feedback with 33 percent of the repetitions. Subjects returned at 1 week and ≥ 4 weeks post training for retention testing. A two-way (group x trial) repeated
measures ANOVA compared percent success on the training and a two-way (group x trial) repeated measures ANCOVA, with time as a covariate, compared percent success on the retention phase of the study. Results: During training, the overall success in the constant group of 90.8 ± 20.4 percent was somewhat higher (P = .055) than the 78.9 ± 27.5 percent success of the variable group. There was a significant interaction (P < .05) between the group and trial factors. This was a result of the early, rapid increase in the constant group's percent success over the first four visits. The performance of the variable group was less consistent over this same period. However, by the final session, the variable group's percent success (90.4 ± 20.2%) was no different (P > .05) from the constant group (94.7 ± 15.4%). On retention tests at 1 week there was no difference between the constant (91.3 ± 19.2%) and variable (87.8 ± 25.3%) groups. But, there was a significant interaction (P < .05) in performance success between short-term and long-term retention testing between groups, indicating that the variable group outperformed the constant group on long-term retention testing. Conclusions: As expected, the variable group did not perform as well as the constant group during training, especially in the early phase. However, subjects in the variable group were better able to retain the ability to recruit the multifidus in the long-term follow-up tests, which is evidence of learning. Future studies will need to determine if these findings hold true for individuals with LBP.
I would like to dedicate this work to the memory of my beloved husband, Daniel Barry Sanchez. He was always supportive of my pursuit of this degree. Although he did not live to see me achieve this milestone in my career I know he would be proud.
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CHAPTER 1

INTRODUCTION

Background to the Problem

Low back pain (LBP) is a major health problem afflicting millions and is a leading reason why people seek out medical interventions and miss work each year.\textsuperscript{1-6} The rising costs of treating LBP are largely attributed to the allocation of resources for those experiencing recurrent episodes and those suffering from persistent, chronic LBP.\textsuperscript{4,7,8} Most initial, acute cases of LBP resolve within 2-4 weeks. However, the recurrence rate within the first year after the initial, acute episode has been shown to be extremely high, ranging from 60 to 86\%.\textsuperscript{4-8} It is with recurrent as well as chronic LBP disorders that medical professionals are in disagreement as to the exact causes and best approaches to treating these conditions.

Neuromuscular Control of Stability

Muscles are thought to play an important role in maintaining the stability of the spinal column and in the etiology and presentation of LBP.\textsuperscript{9,12} However, there is much controversy in the choice of appropriate treatment programs for treating recurrent or chronic LBP. This controversy is largely the result of the many theories
regarding the specific causes of LBP.\textsuperscript{13} One proposed source of LBP relates to poor neuromuscular control of the motion segment which may result in the loss of stability and pain.\textsuperscript{13-15} The muscular system responsible for providing this spinal stability consists of several different muscle groups, known as the global and local muscle systems.\textsuperscript{11} Each group of muscles is thought to influence the spine differently based upon the muscle attachments and their primary functions.\textsuperscript{16,17}

The global muscle system of the trunk consists of the large, superficial muscles spanning the pelvis to the ribcage with the primary function of balancing the external loads through transfer of the load between the pelvis and ribcage thereby minimizing the forces transferred directly to the lumbar spine.\textsuperscript{11,16} The global muscles, though they do exert greater forces and have larger lever arms, may not be suitable for counteracting the displacement forces at the intersegmental levels.\textsuperscript{9,10,18}

The local muscle system of the trunk consists of the deep muscles all having their origin or insertion or both at the vertebral level, spanning one or a few segments.\textsuperscript{11,16} Muscles falling into this deep, local system category include the multifidus, transversus abdominis, intertransversarii, interspinalis, and more. Biomechanical measurements by Wilke\textsuperscript{17} indicate the intervertebral muscles including the multifidus are the primary stabilizers while the global muscles (iliocostalis, rectus abdominis, external and internal obliques) control trunk posture. The multifidus is considered by many as a primary spine stabilizer because it can directly control (or fine tune) the inter-segmental movements.\textsuperscript{7,17,19,20} An injury to the multifidus is thought to have a direct effect on poor functional outcomes and resultant recurrence of LBP because of this muscle's primary role of stabilization.\textsuperscript{7,21,22}
In exploring the relationships of the local versus the global muscle control systems and their roles in spinal stabilization, studies suggest that it is the intersegmental muscle control that is of greatest importance, especially the functioning of the lumbar multifidus.\textsuperscript{10-12,17,20} It is thought that in the cases of recurrent and chronic LBP populations that the global muscle system may dominate over the local muscle system. Research into lumbar instability and chronic LBP suggests that it is this local motor control system that is most vulnerable to dysfunction.\textsuperscript{20,23} Therefore, improving neuromuscular control at the intersegmental level through isometric activation of the multifidus should be an effective intervention for preventing LBP recurrence in individuals who repeatedly injure and reinjure the tissues of the spine.

\textbf{Multifidus Dysfunction in Cases of LBP}

There is a significant body of evidence indicating that morphological changes occur in the muscles associated with the presence of LBP. Internal structural changes to the multifidus fibers have been found in as little as three weeks following the acute onset of LBP.\textsuperscript{7,24-26} However, it is unknown whether the changes were a precursor to the LBP rather than a result. Researchers have found that the cross-sectional area (CSA) of the paraspinals and multifidus are smaller in patients who suffer from chronic LBP.\textsuperscript{1,19,26} Kadar, et al.\textsuperscript{27} examined the relationship of multifidus muscle atrophy and LBP using magnetic resonance imaging (MRI) and identified that multifidus muscle atrophy was present in 80 percent of the patients with LBP. However, this evidence of muscle wasting is rarely used to evaluate treatment programs.\textsuperscript{1} A relationship has been shown between muscle dysfunction of the multifidus and recurrence rate of LBP.\textsuperscript{7,21,22}
Motor Learning and Stabilization Exercise Training

Researchers are beginning to give attention to the motor control mechanisms of spinal stability in exploring more effective treatment approaches for LBP. Recruitment of the lumbar multifidus in the rehabilitation of LBP is gaining attention by researchers for the important role the muscle plays in providing spinal stability. Experts in this area of research indicate that it can take up to ten weeks for individuals with LBP to learn to recruit the lumbar multifidus. A question being raised is whether there is a relationship between the length of time required for subjects to learn to recruit the multifidus and the motor learning strategies implemented in these studies. One theory why individuals continue to suffer from recurrent and chronic episodes of LBP suggests that they may not be taking advantage of the best motor learning principles and techniques during training. Motor learning is defined as an internal process that is associated with practice or experiences and leads to long-lasting changes in motor behavior that can be applied to novel situations.

Richardson led a group of Australian clinicians and researchers who developed specific motor control exercise techniques for retraining the deep trunk muscles after LBP. Hides et al applied this exercise approach in an intervention directed towards multifidus recovery in subjects with initial, acute episodes of LBP. The findings of the Hides et al study suggested that subjects required a minimum of four weeks of specific exercise techniques, to begin to show signs of muscle recovery. Another group of Australians, O’Sullivan et al, also applied the exercise approach of Richardson and Jull to subjects with chronic LBP. The findings of O’Sullivan et al suggest that it takes a
minimum of four to five weeks for subjects to begin to demonstrate accuracy in the performance of motor recruitment, and at least ten weeks to detect multifidus recruitment. Neither Hides nor O’Sullivan indicated whether recruitment of the lumbar multifidus was verified through palpation or dynamic ultrasound (DUS) imaging of the activated multifidus.

It is never clearly stated in the literature by the Australians that they use any training methods other than verbal feedback on every exercise repetition (constant feedback) in their studies. Therefore, the developers and promoters of the multifidus training regimen may not have used the best techniques for motor learning and this could be the reason why their subjects required the extensive length of time to achieve recovery of the multifidus. This raises the question of whether the time frame for motor learning can be reduced if a more effective training technique was implemented.

The motor learning literature shows that during the practice or acquisition phase of training greater amounts and frequency of feedback benefits performance of the motor task and the rate of improvement increases over trials. However, studies have shown that although frequent feedback enhances performance during practice, it is less effective and possibly detrimental to performance on retention tests due to the individual’s dependence on the feedback and the limited cognitive processing required during training. What is necessary for motor learning to occur is not only repeated practice, but the ability to retain the motor skill and ultimately to transfer the skill into novel functional activities. Variability in the frequency or schedule of feedback during practice is thought to be superior to constant feedback when measuring individuals’ retention and ability to transfer skills to novel conditions. Lessening the amount of
feedback allows the individual greater opportunity to cognitively analyze the task, demonstrate self correction of errors, and generate accurate responses in novel situations.\textsuperscript{34} No other studies to date have examined motor learning strategies for recruitment of the lumbar multifidus. Before investigating these strategies in the LBP population, it is wise to investigate a group of healthy controls. Pilot work with healthy controls has shown that learning to isolate the multifidus is a challenging task, especially in the absence of external feedback. This may be related to the limited amount of sensory feedback perceived during correct performance of the exercise.\textsuperscript{36}

**Real-time Ultrasound Imaging**

Real-time DUS imaging is a safe, non-invasive method of testing deep muscle function, and can give both researchers and clinicians objective measurements of lumbar multifidus activation.\textsuperscript{40} Studies have shown the reliability and validity of the use of real-time DUS imaging in rehabilitation of muscle activation by being able to observe and monitor muscle contractions as they occur.\textsuperscript{27,27,41-43} Information gained from real-time DUS imaging gives researchers the ability to visually analyze motor control problems of the deep back muscles as they occur and can provide clinicians with a new assessment tool to drive evidence based practice.

**Summary**

In summary, research into the neuromuscular control of spinal stability has purposed that the local muscle system is the vital link that should be given greater attention in the rehabilitation of those with LBP. The lumbar multifidus muscle is
important in providing the segmental stabilization of the lumbar spine. Dysfunction of
the multifidus has been shown to occur within a few weeks of the initial acute episode,
and has a direct effect on recurrence and chronic LBP. Emerging evidence suggests that
the recruitment of the multifidus in rehabilitation is important in producing successful
outcomes, but that it takes a long time to create a change in the motor behavior. The
focuses of the current study are to compare constant to variable feedback in a group of
healthy controls to determine if variability in the feedback schedule is more effective for
training multifidus recruitment, and to explore the possibility of reducing the time frame
required for new motor learning to occur given the cognitive processes associated with
variable feedback.

Problem Statement

Current research suggests that the focus of rehabilitation should be directed at
recruitment of the multifidus during stabilization exercise training because of its role as
primary stabilizer of the lumbar spine. Clinicians may not be utilizing the best motor
learning techniques to retraining the multifidus after low back injury. Currently, most
researchers and clinicians provide constant verbal and/or tactile feedback during training
of the multifidus. However, motor learning theory suggests the cognitive processes that
occur during training with variable feedback may be more effective for motor learning.
No study to date has compared the effectiveness of constant feedback to variable
feedback using real-time DUS imaging for learning to recruit the lumbar multifidus. By
using a group of healthy controls, this study is a first step in investigating the feasibility
and application of motor learning principles in a muscle group that is difficult to preferentially isolate during exercise.

Significance of the Study

With reimbursement dictating practice and third party payers shortening the number of allowable visits for interventions, therapists are being challenged to explore more efficient and effective methods for accomplishing successful outcomes in the rehabilitation of LBP. This study provides physical therapists with evidence to support the choice of one feedback method over another when training the multifidus muscle as part of a rehabilitation program for LBP. The utilization of real-time DUS as a method of biofeedback may be an effective and expeditious intervention in the treatment of musculoskeletal back injuries in clinical practice.

Purpose of the Study

1) This study compared constant (CON) to variable (VAR) feedback, provided from real-time DUS imaging, in the ability to learn to successfully recruit the lumbar multifidus muscle in healthy adults. At rest the multifidus is an elliptical shape, whereas when activated the multifidus becomes more rounded in shape. (Appendix A) Success was defined as the observation of any movement (muscle thickening) of the lumbar multifidus in the DUS images. Visualizing movement of any part of the muscle was considered a success. Furthermore, to be considered a success, the exercise must be performed without substitution of extraneous
movements such as pelvic tilt, arching the back, valsalva, lifting the upper trunk, or lifting the lower extremity.

2) This study compared percent success of CON and VAR feedback during both the training phase and retention tests. Percent success was defined as the number of successful attempts out of the twelve repetitions of exercise specific multifidus recruitment.

Hypotheses

1. The CON group would demonstrate greater percent success than the VAR group during performance in the training phase (CON > VAR).

2. The VAR group would demonstrate greater percent success than the CON group on the retention tests, which is considered an indicator of motor learning (VAR > CON).

3. Both groups would show increased percent success over the eight training sessions.

Research Approach

This study examined the effectiveness of CON and VAR feedback provided through the use of real-time DUS imaging in training and retention of learning the specific motor skill of isolated, isometric recruitment of the lumbar multifidus. This research was categorized as a true experimental design with two factors, treatment group and time, and used a sample of convenience.
Limitations

1. All subjects for the study were from a small sample, ages 18-49 without LBP or with LBP not significant enough to seek out medical treatment. Therefore, it is difficult to generalize the results to subjects experiencing any significant amount of LBP.

2. The study required subjects to participate in 10 sessions, and study design did not account for drop outs.

3. The small sample size has implications for the power to detect statistically significant differences, particularly in the retention phase.

4. Learning was assessed with retention tests only. The ability to transfer the motor skill to novel situations was not assessed.

5. Training and assessment was performed by the same researcher which could be a source of bias. Video graphic images were used to check the objectivity and reliability of the judgments made by the researcher. However, the quality of the videos was not as good as the original real-time images, which may be a source of error in the reliability.

Assumptions

1. Subjects had not received any formal muscle re-education training for the lumbar multifidus.

2. Subjects would demonstrate a new motor learned behavior from the feedback methods selected from the researcher.

3. The motor task would be difficult to learn, taking several visits to master.
Definitions of Terms

1. Low back pain (LBP): The occurrence/presence of one or more of the following symptoms: (1) pain in the area of the lumbosacral spine; (2) referred pain to the buttock or lower extremity thought to be of spinal origin; (3) paresthesias and/or other changes in cutaneous sensation to the lower extremity or foot believed to be of spinal origin; (4) altered reflexes and/or loss of motor function in the lower extremity believed to be of spinal origin.44,45

2. Local muscle system: The local system is made up of the deep, intersegmental muscles having their origin or insertion or both at the vertebral level. The local system controls the forces transferred to the lumbar spine, maintaining the mechanical stability by controlling the posture of the lumbar lordosis.11

3. Global muscle system: The global system consists of the large paraspinal muscles, spanning the pelvis to the thoracic ribcage. The role of the global system is to balance the external loads and respond to sudden load producing forces, therefore minimizing the force transferred directly to the lumbar spine.11

4. Cross sectional area: A function on the real-time DUS imaging unit that creates an elliptical measurement which is used to trace over the image of the lumbar multifidus in order to capture graphic representation of the whole muscle size.

5. Motor learning: The internal, cognitive process associated with practice or experiences that lead to long lasting motor behavior changes that can be applied to novel situations.30,31

6. Motor control: The process of the central nervous system (CNS) of organizing the commands to the muscles after the perceptual information (neural, physical, and
behavioral) from the environment has been received and processed and the motor plan has been developed.\textsuperscript{31,46}

7. Constant feedback: Subjects viewed the isometric activation of the right lumbar multifidus at the first sacral spinal level (S1) using real-time DUS imaging projected to a TV screen during each repetition.

8. Variable feedback: Subjects viewed the isometric activation of the right lumbar multifidus at S1 recorded from the real-time DUS imaging unit to video tape 33\% of the time. Feedback was provided early on in the practice session then the feedback was provided at a random frequency.

9. Retention test: Subjects were retested both one week and again at least one month after completion of the training sessions and asked to isometrically recruit the right lumbar multifidus at S1 following the protocol during training without real-time DUS feedback. These performance tests were administered to assess if motor learning has occurred.

10. Performance success: The researcher rated performance success by visualizing movement (muscle thickening) of the lumbar multifidus on the SonoSite screen. Visualizing movement of any part of the muscle was considered a success.

11. Performance failure: If no movement of the lumbar multifidus was visualized by the researcher on the SonoSite screen or if the subjects performed extraneous movements of the spine, pelvis, or lower extremities during the trial the movement was considered unsuccessful.
CHAPTER 2

LITERATURE REVIEW

Anatomy of Low Back Pain

The treatment of LBP is a major challenge for health care providers today. It is one of the leading causes of individuals to seek medical interventions, and one of the costliest reasons for missing work. Although there is little agreement on specific diagnoses for most LBP occurrences, much research has been done looking into the specific anatomy and functional roles of the different muscle groups that directly impact the spine.

The spinal column is known to be incapable of carrying the physiologic loads imposed on it without the muscular support systems. Studies have shown that the human lumbar spine buckles in vitro under the compressive load of 90 N, and that the muscles act as ‘guy wires’ to stiffen the intersegmental levels that they cross.\textsuperscript{9,10} The passive joint structures and the short, intrinsic muscles such as the multifidus have been shown to provide intervertebral joint stiffness that is necessary to support the neutral zone. The neutral zone is defined as the mid position of the spinal segments in which the passive joint structures offer the least passive resistance.\textsuperscript{10,16} Biomechanical models have indicated that there are low levels of muscular activity at the lumbar spine giving
rise to supporting the stable neutral zone, and that this creates a vulnerability of the lumbar spine to injury.⁹ Coactivation of the trunk muscles surrounding the spine is necessary to provide the lumbar spine with a stable mechanical equilibrium, and this requires the appropriate timing and muscle recruitment.⁹ Studies have repeatedly shown the importance of the musculature in maintaining spinal stability under various conditions.⁹⁻¹¹,¹⁶ It has been suggested that muscular dysfunctions are possible causes of recurrent and chronic low back pain disorders.⁹ Cholewicki and McGill’s study in 1996 showed that spinal stability seemed to decrease during light activities requiring low muscle activity, contradicting the hypothesis that the human spine can maintain constant stability regardless of the movement or activity demands. They further showed that the motor control to coordinate the recruitment pattern between the large, global muscles and the small, local intrinsic muscles during all functional activities is of great importance in order to ensure spinal stability is maintained.¹²,²⁰

Postural control and intersegmental stability are requirements for all activity levels and are important factors in the prevention of musculoskeletal injuries. Studies have shown that limb movements challenge the stability of the trunk, and muscle recruitment is necessary to minimize the effects on spinal stability. Hodges and Richardson¹⁵ suggest that the muscular recruitment is a preprogrammed postural response by the central nervous system. Muscle recruitment reaction times of the trunk muscles have been shown to be reduced in individuals with LBP.¹⁵ This feed-forward type of motor response is thought to be due to the interconnection of voluntary movements with the associated postural adjustments to restore equilibrium, stiffen the spine, and therefore ensure spinal stability.
The spine muscular system is made up of several different muscle groups, and each group is thought to influence the spine differently.\textsuperscript{11,17} The long, multi-segmental erector spinae muscle groups serve to provide global spinal stability and activate to balance external loads. The global system is made up of large, torque-producing muscle that can act on the spine without being directly attached to it, therefore provided generalized stabilization.\textsuperscript{11,20} Although these large, global muscle groups spanning the pelvis to the ribcage play an important role in the postural control of the spinal column, it is the activation of the deep intrinsic muscles such as the multifidus that has been shown to have a critical role in fine tuning the control of stabilizing the lumbar spine.\textsuperscript{11}

The deep intervertebral muscles, known as the local system serve an internal stabilization role between adjoining vertebrae, controlling their movement during motions of the whole vertebral column, and therefore functioning primarily as postural muscles.\textsuperscript{11,16,20} The local system’s primary function is to handle the loads transferred to the lumbar spine, and respond to changes in the posture of the lumbar spine.\textsuperscript{11} The local muscle system has been shown to be tonically active during upright postures and during active spinal movements, despite trunk position, or direction of the movement.\textsuperscript{11} Research looking at changes in the neuromuscular system in the presence of chronic LBP has indicated that it is this local muscle system that is particularly vulnerable to dysfunction.\textsuperscript{20} Therefore, dysfunction in local motor control could lead to segmental instability leaving the spine vulnerable to injury.\textsuperscript{20} In cases of chronic LBP perhaps the intrinsic musculature becomes deficient in providing sufficient stability to the spine due to injury, nerve damage, or fatigue. The small intrinsic muscles such as the multifidus may be subject to greater risks of tissue injuries and muscle fatigue because of this
deficiency. Studies have shown that even when the large muscles produce significant force buckling of the spine occurs if the activity level of the multifidus is zero. Multifidus

The multifidus is classified as the largest intrinsic muscle and lies deep and most medially in the groove formed between the transverse and spinous processes. It consists of five separate bands of fibers running obliquely from the spinous process of one vertebra down to the transverse process of the vertebra below, the iliac crest, and the sacrum. The multifidus is believed to be the only paraspinal muscle to receive its innervation primarily from a single nerve root. The other paraspinal muscles show longitudinal overlap in innervation which provides a protective mechanism that may explain why the EMG abnormalities may not correspond with the level of the lesion. A typical response of a muscle to loss of innervation such as with a radiculopathy is atrophy. Studies have shown that in approximately 80 percent of individuals with LBP there is isolated muscle atrophy of the multifidus which corresponds with the clinical and diagnostic level of injury.

When compared with other muscles having their influence at the L4-L5 vertebral level, the multifidus contributes the strongest influence, making it a vital link in the local muscle system. The multifidus plays an important role in the transfer of forces acting directly on the lumbar spine, and therefore controls lumbar lordosis. Studies have shown that the multifidus contains both fast and slow twitch fibers. The slow twitch fibers give the multifidus its postural role; whereas the fast twitch fibers allow the multifidus to adapt quickly to protect the intersegmental stability of the spine. Recent
research supports that the lumbar multifidus muscle has an important influence on the stability of the spine.\textsuperscript{17} It is able to provide segmental stiffness and control motion in the neutral zone. The multifidus has been shown to provide two thirds of the spinal stiffness at the L4-L5 vertebral level.\textsuperscript{17,19,20} Therefore, studies suggest that injury or dysfunction of the multifidus muscle will directly affect lumbar segmental stability.\textsuperscript{7,16} Segmental instability of the lumbar spine is a suggested cause of functional disorders associated with LBP.\textsuperscript{12,47} Repeated loading of the spine with prolonged anterior flexion forces has been shown experimentally to induce an increase in strain of the passive tissues of the spine.\textsuperscript{12} This in turn increases the laxity of the intervertebral joints. The increased joint laxity in animal models has been shown to desensitize the mechanoreceptors within the tissue and as a result significantly decrease or inhibit the reflexive stabilizing forces of the multifidus muscle.\textsuperscript{16} It is theorized that this deficit in muscular stabilization may be an important factor contributing to the high recurrence of symptoms, and has been proposed that poor functional outcomes could be secondary to this loss of functional muscle support of the multifidus.

There is a large body of research emerging which shows that the multifidus muscle undergoes both morphological and neurophysiologic changes following low back injury.\textsuperscript{21,24,25,40,48} In cases of LBP the muscle wasting of the multifidus has been shown to be unilateral, and based upon the arrangement of the innervation pattern, the site of greatest atrophy would be at the vertebral level of pathology and/or symptoms.\textsuperscript{13,19} Ultrasound studies have shown that in individuals with acute LBP there was rapid muscle atrophy of the multifidus ipsilateral to the painful side within the first 24 hours.\textsuperscript{16,19} There are many theories into why such a rapid response within the muscle occurs. One
thought is that there is muscle wasting due to the disuse associated with the LBP. This is unlikely since disuse would be associated with an overall reduction of muscle size throughout the lumbar spine. Reflex inhibition might be the major contributing factor, since this can occur in the absence of pain and presents in a more specific pattern of muscle wasting. Reflex inhibition decreases alpha motor neuron activity, and has been shown to persist twelve weeks after surgical interventions for LBP, even when the individuals had returned to normal function and full weight bearing status. A study using a porcine model explored the neuromuscular interaction between the paraspinal muscles, the facet joint, and the intervertebral discs. The findings of this study demonstrated that stimulation of nerve fibers in the annulus portion of the disc elicited reflexes in the lumbar multifidus muscle. These reflexes were decreased when saline was injected into the facet joint suggesting that neural pathways from the joint capsule had an inhibitory effect on the motor neurons which in turn resulted inhibited the muscle. Therefore, it is postulated that even though individuals with LBP appear to fully recover from acute pain and other symptoms, the muscle system has not recovered.

Hides et al showed that multifidus recovery from inhibition after first episode LBP is not spontaneous even when the individual had returned to functional activity levels. These changes in the multifidus have also been shown to persist at least five years after surgical interventions for intervertebral disc herniation. This lack of multifidus recovery is suggestive of a neurological deficit rather than simply weakness or disuse. Studies have shown that the median time from recovery of an acute first episode to the first recurrence of LBP is about two months. The question being asked is what creates this vulnerability to recurrences? A relationship is theorized to exist between

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multifidus dysfunction and poor functional outcomes resulting in recurrence of LBP after disc surgery. There is an optimal functional level of the muscular system required to control and protect the spinal segments following injury. Despite the resolution of the initial symptoms associated with the LBP, the muscle dysfunction may continue and this failure to protect the spinal segments could increase the risk of recurrence.

Skeletal muscles show enormous inter-individual variability in their fiber composition, and studies have reported histological changes within the internal structure of the muscle fibers. These internal structural changes can occur in individuals without surgical interventions. A study exploring normal changes in the fiber types with aging showed that as individual’s age the multifidus takes on a more postural role as the slow twitch fibers predominate. Rantanen, et al examined biopsies of the multifidus in individuals five years after surgical intervention for herniated disc repair and found histological changes within the muscle fibers. In a study by Weber et al, biopsies were harvested from patients’ multifidus muscle pre and post first time surgical intervention to evaluate the pathologic changes of the muscle fibers. At the time of first operation, 60 percent showed pathologic signs. In those with lumbar disc herniation, 50-89 percent of the biopsies showed alterations in either the type 2 or the type 1 fibers, or both. Interestingly, Weber’s study concluded that lumbar multifidus pathologic changes in the muscle fibers are poorly paralleled with clinical signs and symptoms. These studies suggest that the multifidus muscle undergoes not only morphological changes but also neurophysiologic changes following low back injury, which is theorized to represent impairment in the motor control system, not simply weakness or disuse atrophy. Therefore, improving this neuromuscular control at the intersegmental
level through exercise specific training of the lumbar multifidus muscle is theorized to be an effective intervention in the treatment of individuals with recurrent LBP.

Training

The question is how to effectively rehabilitate individuals with LBP. A major challenge in health care research today is providing the evidence of which treatment is the optimal intervention for those suffering from recurrent and chronic LBP.\textsuperscript{1,54} The literature supports the need for active reconditioning exercises, and that the type of muscle work is proposed to be important in the rehabilitation of LBP.\textsuperscript{55} Physical therapists have trained individuals using various approaches of dynamic stabilization theories, yet the recurrence rate after the initial episode of LBP remains high. When looking at outcome data on recurrence rates after initial, acute onset of LBP, researchers began investigating methods of treatment approaches and possible links with recurrence of symptoms.\textsuperscript{1} It is purported that individuals with chronic LBP exhibit altered patterns of motor control, substituting the global muscle system over the impaired function of the local muscle system.\textsuperscript{20} Knowing that the multifidus contains a greater percentage of slow twitch fibers and has an important stabilization function, more attention should be given to how to recruit this local muscle more effectively. The slow recovery of the multifidus following resolution of initial, acute symptoms suggests that a more specific exercise approach may be advantageous to the more general, conventional exercise approaches commonly being used in the treatment of chronic LBP.\textsuperscript{54} Many of the conventional therapy approaches focus their attention on strength and endurance training in the later stages of recovery after LBP.\textsuperscript{37,56}
There is a recent focus in physical therapy management of the individual with acute and recurrent LBP to train more specifically the muscles surrounding the lumbar spine whose primary role is providing dynamic stability and segmental control to the spine.\textsuperscript{7,16} Hides posed the theory that specific multifidus strength training would decrease the recurrence of LBP.\textsuperscript{23} Several studies have shown that localized isometric co-activation of the transversus abdominis and multifidus muscles facilitated recovery of muscle wasting in individuals suffering from LBP.\textsuperscript{7,16,20} O'Sullivan’s study\textsuperscript{20} aimed to specifically train the isometric co-contraction of the deep abdominals and the multifidus muscle proximal to the level of the reported injury, while minimally activating the global muscle system. O’Sullivan’s approach demonstrated the difficulty of isolating patterns of activation of the intrinsic muscles without the global muscles overriding. The muscle activity of the internal oblique and upper rectus abdominis muscles was measured while the subjects performed specific exercise programs consisting of the double leg raise exercise and the abdominal drawing in maneuver. The researchers indicated that it took as long as five weeks of specific exercise training before the subjects were able to accurately achieve the motor pattern of recruitment of the multifidus. The findings showed that subjects with LBP required ten weeks of daily specific exercises of isolated activation of the deep abdominal muscles without muscle substitution.\textsuperscript{20} This supports the contention that motor learning and motor control during recovery from low back injury are not simply a process of strength training, but depend on a change in the motor programming. This change in the motor program suggests an automatic pattern of recruitment to stabilize the spine dynamically during functional activities.
Rehabilitation of the local stabilizers at the intersegmental levels is gaining evidence in the effectiveness of having a direct effect on increasing the CSA of the multifidus muscle. Danneels et al.\textsuperscript{1} found that as the CSA of the multifidus returned to symmetrical size with the uninjured side the individual’s reported LBP decreased, and directly influenced the percentage of recurrence of LBP. The results by Danneels et al.\textsuperscript{1} also showed that generalized stabilization training was not sufficient to increase the CSA of the multifidus, suggesting that the generalized approach is not specific enough to alter recruitment patterns of the internal stabilizer muscles. Regular training with specific localized activation of the multifidus muscle has been shown to facilitate recovery of the multifidus. Hides et al.\textsuperscript{7} focused on non-resisted, isometric activation of the multifidus and deep abdominal muscles. The results showed that the individuals who received the specific exercise training had CSA changes of the multifidus within the four week study as compared to the control group. The control group, even though they had returned to prior activity levels, at the ten week follow up continued to have decreased CSA. This demonstrates that multifidus recovery is not spontaneous with the absence of painful symptoms. The persistence of the asymmetry in multifidus CSA between the painful and painless side is the proposed result of insufficient or ineffective muscle retraining. Structural multifidus changes are thought to be reversible with adequate physical therapy intervention, and specific, localized training has been proposed to be a more appropriate first stage of rehabilitation of LBP.\textsuperscript{7} It appears that specific exercise programming aimed at targeting the local muscle system, especially the multifidus, may supply the missing link in conventional exercise programs, improving successful outcomes in the treatment of recurrent and chronic LBP.\textsuperscript{37} Clinicians need to explore the role of local motor control
training as an adjunct to traditional muscle strengthening, and its effectiveness in the improvement of treatment outcomes in LBP populations.\textsuperscript{12}

**Motor Control**

A theory gaining interest in LBP research is that a key impairment in the musculoskeletal system is not solely one of strength but one of motor control.\textsuperscript{37} Normal motor control is defined as the CNS’s ability to use previous and current information to coordinate effective, efficient movement patterns.\textsuperscript{57} Motor control can be viewed as the mechanism which organizes the commands to the muscles after the perceptual information received from the environment has been processed and the action plan has been developed.\textsuperscript{46} This process enables the learner to execute the movement strategy necessary to carry out the action plan and achieve successful attainment of the goal.\textsuperscript{58}

Researchers studying the differences between the global and local muscle systems in spinal stability propose that there is an important link between LBP and motor control deficits of the local muscle system, specifically the multifidus.\textsuperscript{7,19,20,37,59} It has been shown that when the spine is subjected to high loads or unexpected loads the large trunk musculature is activated to counteract the displacement.\textsuperscript{9,11,12} With the current research it is hypothesized that there is a necessary overlap of muscle activity of both the large and the intersegmental muscle groups required as the spine is moved through the neutral zone, and that there needs to be a coordinated response between the two groups when the spine is under stress. However, it is due to this very complexity that makes the spine vulnerable to injury. Motor control is necessary to coordinate the muscle recruitment when the spine is subjected to large and small loads.\textsuperscript{9} It has been shown that the risk of
spine injuries is greatest when there is a decreased demand on muscular activity such as in standing. The intact motor control system is able to recognize the forces on the spine and can compensate with the addition of muscular support from the intrinsic (local) muscles that cross the unstable joint to counteract the displacement forces. The questions being raised suggest that the motor control system may become impaired with LBP. There is much debate in the literature regarding the motor control properties of the local stabilizers, specifically the lumbar multifidus and how to most effectively promote the recovery of motor control in these muscles to prevent future recurrence of LBP.  

**Motor Learning**

Motor learning can be defined as the development of permanent, long-lasting changes in motor behavior as the result of practice or experiences, and implies that the changes persist well beyond the practice sessions. Permanent changes in learned motor behaviors are the desired outcomes, therefore, the focus of research has been to look at the practice as well as the feedback conditions and how these conditions affect skill acquisition and retention of the new motor behavior. Motor learning is viewed as the process of refining motor strategies in the performance of a motor skill in order to be able to apply this new skill at a later time or transfer to a new task. The learning that takes place to permanently change a person’s motor performance has been shown to require repeated practice, and attention is being directed towards the underlying cognitive processes necessary for long term retention of the newly acquired motor behavior.
The researchers in the field of motor learning have explored the types, quantities, and frequencies of feedback during practice, and compared the effectiveness of different combinations of feedback situations in the successful acquisition and retention of learned motor behaviors. There is consensus that feedback is necessary for motor learning, however, there is much debate in the literature regarding the amount, frequency, and schedule of feedback that is most effective for motor learning to occur.\textsuperscript{1,29,36,46,62,67,69,70} Earlier studies concluded that frequent feedback was necessary in the acquisition of new motor skills, however, these studies only looked at skill acquisition during practice.\textsuperscript{62,66} The only assumption that can be drawn from these early findings is that frequent feedback enhanced performance during practice. The question of long term retention of the motor behavior remains the focus of research today.

The challenge in developing effective treatment approaches is being able to understand motor learning strategies and choose interventions that assist the individual to function in a variety of situations. If the individual can not transfer what they have learned to novel situations then they are more likely to repeat the same errors, and in the cases of the LBP population suffer from recurrent or chronic injuries.\textsuperscript{46,71}

Few would argue that practice and, more specifically, movement repetition is a key factor in learning a new motor skill, but, there is more to learning than just repetition. Repetition during practice is viewed as an attempt to reach the goal of the movement and is based upon previous experiences, therefore cognitive processing has a vital role in skill acquisition.\textsuperscript{29} The process of practice requires repeated problem solving through error detection and error correction, and therefore the cognitive activities are of considerable importance to this investigative process.\textsuperscript{29} Learning theories suggest that presenting
motor tasks in difficult learning context, such as unpredictable environmental conditions, or variable order of practice or feedback forces the individual to overcome the difficulty of practice and create stronger cognitive processes for skill acquisition and create long term retention of motor patterns.¹³⁰,³⁵,⁶⁵,⁷¹-⁷³

Physical therapists act as facilitators in the motor learning process through guidance, encouragement, and feedback about the errors in performance during practice of functional skills, and try to assist patients in mastering efficient and successful performance of their everyday activities.⁵⁷,⁷³ In order to be effective in helping patients learn new motor behaviors, therapists need to have a working understanding of the different levels of functional behaviors, clarify at which functional level the goal of intervention is targeting, and assist the patient through the processes of skill acquisition.⁷³ According to Gentile,⁶⁵,⁷³ functional behaviors can be analyzed on three levels: (1) actions; (2) movements; and (3) neuromotor processes. Actions can be defined as the motor performance outcomes that are motivated by the goals and influenced by the environmental conditions. At this level the individual may have acted but not necessarily been accurate or consistent in attaining the goal.⁶⁵,⁷³ Movements are the approaches, patterns, or strategies utilized during the individual’s attempts to achieve the goal.⁷³ Neuromotor processes refer to the organizational mechanisms within the CNS that controls or sequences movement.⁷³ Skill acquisition is a dynamic process as the individual utilizes multiple movement strategies requiring the CNS to generate variable neuromotor processes to consistently attain the goal.
Phases of Motor Learning

The process of motor learning and skill acquisition is theorized to progress through three stages: the cognitive phase, the associative phase, and the autonomous phase. The most important step in skill acquisition is the cognitive phase. During this phase the individual is experimenting with movement strategies, trying to get the idea of the movement. It is during this time that there is marked variability in practice as the individual is pulling together information from the environment, the movement itself, and also from past experiences. Emphasis is placed on the amount and type of instruction or environmental cues as the individual struggles to identify and process the information about the environmental conditions that control the movement in order to develop the most effective movement strategy to achieve the desired goal. Next, the individual moves into what Gentile refers to as the associative phase. As the individual evaluates the outcomes produced by the movement strategies they begin to show signs of refining the characteristics of practice, lessening the amount of variability within trials, and developing consistency in their movement performance. The individual may choose to repeat the movement as planned, revise the motor plan, or reevaluate the environmental conditions before attempting the movement again. The final phase of motor learning is known as the autonomous phase. At this time the individual is efficient in performance of the motor skill, requires very little cognitive processing, and is able to apply the learned behavior to new situations or tasks. It is unknown how much time it takes to progress from the cognitive to the autonomous phase, and is thought to be
attributed to the type of motor skill and the environmental conditions surrounding performance.

**Taxonomy of Task or Skill Acquisition**

If motor strategies are refined or revised dependent upon the environmental conditions, then understanding the context in which the action will take place can assist in the processes involved in skill acquisition.\(^{58,65,67,73}\) The motor learning literature describes two types of skills: (1) open skills; and (2) closed skills.\(^{58,65,67,69,73}\) An open skill is defined as a movement that is performed under environmental conditions that are variable and unpredictive from one attempt to the next.\(^{57,58,65,73}\) The emphasis is on providing variable practice opportunities for the learner. Through the variability of the conditions the individual is required to modify the movement strategy to match the demands of the new conditions.\(^{58,65,67}\) Closed skills, in contrast, are movements performed in environmental conditions that are stable and predictive.\(^{58,65,67,73}\) By the conditions remaining unchanged from one attempt to the next, the learner should be able to predict in advance what the conditions will be like during the execution of the movement. The emphasis is on developing consistency of movement that increases the probability of goal attainment on each trial.\(^{58,69}\) In closed skills the task should be easier for the learner to achieve than when the environmental changes are ongoing. The stable environmental conditions require that the replication of movements be based upon proprioceptive feedback, and places greater demands on the learner's ability to use these internal cues from the movement.\(^{58,65,67,73}\)
Schmidt’s schema theory examined classes of movements and that accuracy and consistency of the newly learned motor program is gained through variability of practice leading to the ability of the individual to execute motor skills in novel situations. Schmidt predicted that there was a relationship between variability in practice of different tasks within the motor program versus practice of a single movement and the individual’s ability to transfer this motor skill to novel situations. The environment can become an influential factor in motor learning. Therapists must keep in mind that the goal of the action determines the conditions required, and different environmental factors will elicit different motor responses.

To accurately assess if learning has occurred, the motor skill needs to be applied to a new situation and/or reevaluated after a period of time elapses. The depth of learning can be measured by how efficiently the motor pattern is transferred to the novel situation or activity. When working with individual’s with LBP, the goal is to have the patient retain the skills taught during a session and be able to perform the new motor skills in familiar functional activities and varying environmental conditions. It is important to train the patient’s cognitive development instead of focusing on solely the physical problems to make an impact on successful acquisition of new motor skills. True skill acquisition is a long process but the use of motor learning strategies may significantly accelerate the learning process.

Feedback

Feedback is a means by which the learner is able to evaluate the success of each aspect of the performance. The role of feedback is to provide error information, and
can be selected to motivate the individual, reinforce the behavior, or stabilize performance. Acquisition of motor skills have been shown to be strongly influenced by the type, amount, and variability of feedback provided during the practice phase of learning. Integrating the motor learning principles is highly relevant and invaluable to the practice of physical therapy. The principles form the very guidelines that answer commonly asked questions with regards to how often to provide feedback, how much, and what kind is most effective.

Feedback is defined as either intrinsic or extrinsic. Intrinsically, the proprioceptive and kinesthetic sensory systems provide information associated with the performance of the movement itself. This sensory information can either be available prior to moving, known as feed forward, or received either during or after the movement known as feedback. Extrinsically, feedback is given to the individual about the consequences or results of the movement and is termed either knowledge of results (KR) or knowledge of performance (KP). KP is augmented feedback about the patterns of actions that led to the achievement of the goal, providing the learner with important information for error detection to assist in developing consistent movement patterns. The movement is analyzed regarding the outcome and the intended goal achievement. KR is augmented feedback about the success or failure of the movement itself and is thought to serve as a reference for error correction. Early research suggested that KR fostered faster development of motor patterns leading to facilitation of skill acquisition, however not all movement provide the same amount of KR. Under conditions where KR is not as readily available or limited, the individual must rely upon KP to improve performance. KP has not been studied as extensively as
KR, but is theorized to behave similarly to KR in motor learning, and KP is thought to be a vital component to the cognitive processes required for skill acquisition. Both KP and KR can be utilized during practice and skill acquisition, and have been shown to contribute to learning and retention of the new motor behavior. When training individuals in learning or relearning a motor task such as lumbar stabilization, physical therapists need to remember that acquisition of a motor skill is not the same as becoming independent with exercising. Clinicians need to recognize that the research is supporting that the atrophy of the multifidus muscle in those suffering from LBP is suggestive of a form of motor control impairment and not simply disuse weakness. Therefore, this may explain why traditional strengthening exercise protocols for treating LBP fail to correct the dysfunction. Typically, physical therapists provide constant KR as the mode of feedback, and do not always encourage the patients to assess their own performance to facilitate the utilization of KP. By not having the patient utilize KP and work through the cognitive phase of skill acquisition the therapists may be impeding learning, and could explain the extremely long time required to learn lumbar stabilization in some studies. Successful use of the feedback will depend on the learner, the type of skill being performed, as well as the type of feedback provided. Motor learning research looks at the types of feedback that are thought to effect permanent changes in motor behaviors.

Feedback Schedule during Practice and Learning

During practice the learner is being asked to master a motor skill. Successful performance of the movement can be manipulated by varying the type and/or schedule of
feedback. Early studies suggested that providing constant or frequent feedback was superior in the acquisition of the skill, however these studies did not look at retention of learning after removed from practice.\textsuperscript{62,66} Though conditions where the feedback is provided more frequently produces positive effects during practice, the literature supports that providing feedback less often during practice is more beneficial for long term learning and retention.\textsuperscript{29,30,71} One reason is thought to be that frequent feedback attracts attention away from the individual’s own intrinsic feedback system, and therefore does not require the cognitive processing necessary to develop the ability to internally detect errors and self correct.\textsuperscript{30,34-36,72}

Manipulating the feedback schedule creates higher levels of cognitive processing of the motor function, and therefore has been shown to be beneficial in learning the motor pattern.\textsuperscript{46,71} Retention of learning occurs when the individual is able to perform the motor skill without the use of external feedback.\textsuperscript{30,39,46} Therefore, when the therapy goal is to enhance motor skill retention, increasing the level of difficulty of the learning context through variability of feedback schedules during the practice phase is very beneficial for learning to occur. The literature describes several methods of providing the variability of feedback during practice.\textsuperscript{65,66,68,73,74} The intended movement outcome, degree of difficulty of the task, and amount of intrinsic feedback provided through the action itself can assist in the decision-making process of structuring the feedback schedule.\textsuperscript{65,68,73,74}

The majority of the research studies investigating the variability of feedback schedules are looking at KR and the impact on skill acquisition and retention. There is very minimal research regarding variability of KP and motor skill learning. Young and
Schmidt$^{79}$ manipulated the KP schedule in a study looking at the performance of an upper extremity target task. They compared two groups. One received 100 percent KP and the other received 20 percent KP. The results demonstrated that skill acquisition is not equal between groups, and more specifically that the 20 percent KP group was more successful in skill acquisition and retention of the motor behavior.$^{79}$ Weeks$^{80}$ investigated the effects of reducing the frequency of KP in the learning of a soccer skill in young teens. The study compared two groups, one received 100 percent KP and the other received 33 percent KP. The results of this study demonstrated that 33 percent KP was superior to the 100 percent KP in developing the soccer skill.$^{80}$ The findings of these research studies exploring variability of KP feedback parallel the results of the KR feedback literature, supporting that variability of feedback, both KP and KR, enhances learning.$^{79,80}$

**Real-time Ultrasound Imaging**

It is not possible to perform isolated strength testing of the individual global or local back muscles, especially the deep intrinsic muscle groups such as the lumbar multifidus. Therefore, imaging techniques have been used to assess muscle size and structural changes within the muscles as a result of pathology and/or dysfunctions. The imaging capabilities of magnetic resonance imaging (MRI) and computed tomography (CT) Scans are well documented. They produce excellent image resolution of the soft tissue anatomy. The benefit of using CT Scanning or MRI in measurements of musculoskeletal structures is thought to be because it is less dependent upon operator expertise in comparison with DUS imaging.$^{55,81}$
There is emerging interest in the role of real-time DUS imaging in the physical therapy profession clinically and in research of musculoskeletal conditions. Until recently DUS imaging has been used extensively in medicine, allowing for more rapid diagnoses of conditions. The disadvantage of real-time DUS imaging for clinical use and research is that the accuracy is dependent upon the expertise of the operator. The advantages are its availability within hospitals and radiology practices, no exposure to ionizing radiation, non-invasive, and much lower costs.\textsuperscript{41,42,55} The possible benefits to clinical practice and research are the ability to measure muscle size and dynamically study soft tissue structures of the musculoskeletal system as they contract. Real-time DUS could be a beneficial adjunct to physical therapy practice, assisting the therapists in assessing the efficacy of their treatment interventions. It could also be used as a visual feedback tool for muscle re-education activities. The DUS images of the lumbar multifidus could provide the learner with valuable KP by displaying the movement on the screen and therefore increase error detection during practice.

Several studies have compared MRI and CT Scanning with DUS imaging to evaluate the validity and reliability of the tool in measuring muscle CSA. A study by Sipila and Suominen in 1993\textsuperscript{82} demonstrated the validity of DUS imaging for CSA measurements in comparison with CT Scan, giving a Pearson’s correlation coefficient of 0.911. Hides et al\textsuperscript{55} compared MRI and real-time DUS imaging in measuring the lumbar multifidus muscle in normal subjects and in subjects with acute LBP, and concluded that there was no significant differences between multifidus CSA measures between the two tools at any vertebral level. Critchley and Coutts\textsuperscript{83} were able to show muscle thickness changes during muscle activation using real-time DUS. Young et al,\textsuperscript{79} using imaging
techniques, found that the muscle’s CSA is closely related to the maximal voluntary contraction (MVC) that can be generated. In the presence of pain, conventional strength testing may not produce an accurate representation due to inhibition, and fear of provoking more pain. Therefore, being able to measure the size of the muscle would be beneficial to therapists in assessing the effects of inhibition and muscle atrophy. A study by Hodges et al showed that low levels of muscle activity (less than 20 or 30 percent MVC) are associated with relatively large changes in the muscle CSA, and that DUS imaging can be used to detect low levels of muscle activity.

Hides et al, compared DUS and MRI when subjects were placed in the same spine position and 35 degree hip flexion angle. The results of the study demonstrated repeatability between day and between operator measurements with a coefficient of variation of 3.58 percent. The results of inter-tester reliability indicated that the repeatability for both testers was not markedly different as demonstrated by the coefficient of variation ranges from 4.25 to 11.3 percent for the measurements taken at lumbar segment level L2 through S1.

Electromyography (EMG) studies are used clinically and in research to document muscle activity by either use of fine wire or surface electrode techniques. Surface EMG can provide objective, measurable data regarding estimation of the degree of muscle activation. The controversy arises in the use of surface EMG in recording the potentials of the deep back muscles, specifically the lumbar multifidus. The problem that arises with recording action potentials of the lumbar multifidus using surface EMG is the possibility of picking up activity of surrounding muscles which overlay the multifidus. Therefore, surface EMG may not be the most accurate method of measuring activation of
the lumbar multifidus. A more accurate measurement of deep muscle activity can be recorded using fine wire EMG.\textsuperscript{84} The disadvantage of EMG in comparison with DUS imaging is that EMG does not give the operator muscle size measurements.

The use of real-time DUS imaging in clinical physical therapy practice and research is an exciting new tool giving therapists and patients the opportunity to visualize muscle activity as it happens and could be used to assess the effects of muscle rehabilitation techniques. The operator must demonstrate skill in operating the DUS unit, and possess a thorough knowledge of the musculoskeletal anatomy being evaluated. Using a structured protocol will ensure repeatability and reliability of results, and reduce the amount of error.
CHAPTER 3

METHODOLOGY

Introduction

The following chapter outlines the details for the study. This chapter presents the specifics of the study including the research design, hypotheses, sample selection, instrumentation, procedures, and data analysis.

Research Design

This research study was categorized as a true experimental design with two factors, treatment group and time. Treatment group was the independent factor and time was the repeated factor. The objective of the study was to explore the more effective feedback schedule for learning isometric recruitment of the lumbar multifidus muscle. The two types of feedback being tested were CON feedback where the subjects received visual feedback during each trial, and VAR feedback in which the subjects received both verbal and visual feedback during 33 percent of the trials.

Three threats to internal validity were identified and controlled. The first was the subject characteristic of gender. There is the possibility that males and females learn
psychomotor skills differently. This was controlled through randomization of subject assignment to each treatment group, and with the repeated measures design. The second threat was the concern for the consistency of the initial instruction and the subsequent verbal feedback given to each subject. To control for this threat, a script was developed and read to each subject at the beginning of the study and at each training session (Appendix B). The third threat was rater bias. This was assessed by performing intrarater reliability testing of results with the evaluator blinded to subject and session.

Research Hypotheses

1) **Training Hypothesis**: The CON group will demonstrate a greater percent success than the VAR group during the training phase of isometric recruitment of the lumbar multifidus muscle. Hence, a two way repeated measures ANOVA should show a significant main effect of group when comparing the percent success between the two groups during the training phase of the study (CON > VAR).

2) **Time Hypothesis**: Both groups will show increased percent success over the eight training sessions in their ability to isometrically recruit the lumbar multifidus. The repeated measures ANOVA should show a main effect of time (percent success in later sessions > percent success in earlier sessions).

3) **Retention Hypothesis**: The VAR group will demonstrate a greater percent success than the CON group on the retention tests both one week (short term) and at ≥ 4 weeks (long term) after completion of the training sessions. Therefore the two way repeated measures ANCOVA should show a main effect...
of group (VAR > CON) and that there would be a significant interaction (group x time) on long term retention testing.

Research Variables Defined

For Ho 1 and Ho 2

Dependent variable: percent of performance success (out of 12 repetitions) of isometric recruitment of the lumbar multifidus within each training session.

Independent variables:

1) the type of group feedback given during each session

2) number of the treatment session: subjects received eight sessions, twice a week for four weeks.

For Ho 3

Dependent variable: percentage of performance success on two retention sessions

Independent variable: the type of group feedback given during each training session

Success in this study was defined as isolated isometric recruitment of the lumbar multifidus without substitution of extraneous movements such as pelvic tilt, arching the back, valsalva, lifting the upper trunk, or lifting the lower extremity.

Sample Selection

Approval from the Human Subjects Institutional Review Board (IRB) of The Ohio State University was received prior to initiation of this study. The first 30 people who consented to participate in accordance to the procedures accepted by the IRB, passed the lower quarter screening examination, and met the inclusion and exclusion criteria
were accepted and randomly assigned to treatment groups. Subjects were taken from a sample of convenience through The Ohio State University faculty and employees. Recruitment for subjects was conducted through flyers posted throughout the university.

The criteria for inclusion were as follows:

1) healthy adults between the ages of 18-49
2) body mass index \( \leq 30 \)
3) a lower quarter screening examination that was within normal limits
4) have not met any of the exclusion criteria

The criteria for exclusion were as follows:

1) history of back pain within the past year significant enough to receive medical care
2) history of back or abdominal surgery that would alter the structure or function of the lumbar muscles
3) neuromuscular disease
4) observable spinal deformity
5) received physical therapy training for the multifidus muscle in the past

Instrumentation

Detecto Medic Balance Scale

The Detecto Medic Balance Scale (Physician Scale; Quick Medical, Snoqualmie, WA) in the Human Movement Performance Lab at The Ohio State University was used to quantify the weight of each subject.
Ross Stadiometer

A Ross Stadiometer (accu-hite mechanical Stadiometer; Health Products Incorporated, Cleveland, OH) in the Human Performance Lab at The Ohio State University was utilized to measure the head-to-floor height of each subject. The wall-mounted Stadiometer has a measurement range of 24 to 83 inches and a graduation of 1/16 inch.

Adjustable Treatment Table

A standard adjustable treatment table was used to position subjects for imaging the multifidus muscle.

SonoSite 180/L38 Ultrasound Unit

A hand-held SonoSite 180/L38 unit (SonoSite 180/L38; SonoSite, Inc., Bothell, WA) was used to capture real-time images of the subject’s lumbar multifidus muscles, determine cross sectional area (CSA) and record each trial. The SonoSite unit was designed to take two-dimensional images of superficial, small body parts such as small muscles.

Once this researcher gained basic knowledge of the SonoSite 180/L38 unit students from the physical therapy program at The Ohio State University were recruited to pilot the techniques for capturing the images and measuring the CSA of the L5-S1 multifidus. The images were compared to that of the senior researcher with expertise in using the SonoSite for imaging the multifidus muscle. Competency was achieved when
the first researcher 100 percent of the time could: 1) image and identify the boney landmarks of the posterior superior iliac spine (PSIS) and the S1 spinous process, the lumbosacral fascial boundary, and the multifidus; and 2) replicate the senior researcher’s measurement of the multifidus CSA within one standard error of the measurement (SEM) which was 0.37cm$^2$. 85

TV/VCR Components

A Panasonic TV and Samsung VHS HQ video recording system was used to record the images from the SonoSite unit to tape. Images were visualized by the subjects as part of the visual feedback during the training sessions. The TV was placed on an adjustable table in order to place the image at an appropriate height for the subject to be able to view without lifting their head off the table.

Modified Habitual Physical Activity Questionnaire

A modified Habitual Physical Activity Questionnaire (MHPAQ) was administered in order to characterize the sample’s level of habitual physical activity levels.85-88 The MHPAQ Questionnaire was chosen because it is short, easy to fill out, and its validity and repeatability have been studied in various populations. The HPAQ has a high reliability ($r = 0.93$).87,89 A modified version of the HPAQ was developed using minor modifications of the terminology to make it more typical for subjects in the United States.85 (Appendix C) The MHPAQ showed acceptable validity in the study by Pressler et al.85
Feedback Script

A written script was read to each of the participants at the beginning of the study and at the beginning of each training session, giving the subjects consistent instruction on how to isometrically recruit the multifidus, how long to hold the contraction, and the number and frequency of contractions.

Procedures

Subjects interested in participating in the study were scheduled for an initial session of thirty minutes in the Human Movement Performance Laboratory. Verification was made that subjects were eligible for the study by reviewing the inclusion and exclusion criteria. Subjects reviewed and signed the consent and HIPAA authorization forms. The MHAPQ was completed and the subject’s height and weight were measured and recorded (Appendix D). A standardized lower quarter screening examination was performed by this researcher (with sixteen years of clinical practice) on each subject to ensure that he/she had adequate flexibility, strength, reflexes, as well as no visible spinal deformities before being accepted into the study. After all baseline data were collected this researcher opened the envelope, assigned the subject to group, and followed the feedback schedule (Appendix E). These envelopes containing the randomized group assignment and feedback schedule were created by the second researcher a priori to ensure an equal number of subjects per treatment group.
Ultrasound Imaging of the Lumbar Multifidus

Baseline CSA measurements of both lumbar multifidus muscles were imaged and recorded by the primary researcher in order to characterize the study sample for comparison to the literature. Each subject was positioned prone on the adjustable treatment table. The table surface under the feet was released from a horizontal position creating approximately a 25 degree hip flexion angle. Pillows were used as needed under the trunk of the subject to create a hip flexion angle of 35 degrees, according to the protocol established by Hides et al. The 35 degree hip flexion angle was verified using a standard goniometer.

The PSIS and S1 landmarks were palpated, identified, and marked using a permanent marker. These landmarks were used for proper placement of the ultrasound transducer for accurate imaging of the right lumbar multifidus. Gel was liberally applied to the transducer head and to the subject at the level of S1. Both the left and right multifidus muscles at the level of S1 were imaged, captured, and measured for CSA. Once a real-time image was obtained, a static image was captured for the baseline measurement of the subject’s CSA. Two sets of distance calipers and an ellipse built into the software of the SonoSite unit were adjusted manually to measure the CSA of the muscle. CSA measurements were recorded at the initial training session, the final training session, and then again at each retention test session.

The adjustable treatment table surface was then repositioned so that it was horizontal, creating a 0 degree hip flexion angle, in accordance with the protocol established by Hides et al for the training sessions. The script for isometric recruitment of the multifidus was read to the subject. Real-time images of the right lumbar multifidus
Training Based upon Group Assignment

The right lumbar multifidus muscle was studied on all subjects. Subjects were seen in the lab for fifteen minute sessions twice a week for eight training sessions. Subjects in both training groups were given initial instruction that the training would consist of twelve repetitions of isometric recruitment of the right lumbar multifidus muscle. Subjects were asked to hold each contraction for 3 seconds. The CON group received visual feedback of the real-time ultrasound image on the TV monitor during each repetition. The TV monitor was positioned so that the subject could view the real-time ultrasound image as they activated the muscle.

The VAR group received both visual and verbal feedback after 33 percent of the repetitions of isometric multifidus recruitment. The DUS real-time images were recorded to VHS tape with each repetition labeled. The subjects received visual feedback of the real-time ultrasound images recorded to video tape and verbal feedback by the researcher according to the feedback randomization table created by the researcher. Feedback was provided early on in the training session; then there was no consecutive feedback, only random frequency throughout the rest of the session.
Retention Test

Each subject returned to the lab one week after completion of the training sessions for the short term retention test (R1) and repeated the procedures established for the training sessions with the exception that no visual feedback was provided during the exercises. Each subject performed two sets of twelve repetitions of isometric recruitment of their right lumbar multifidus with a short rest period between sets. The real-time DUS images were recorded to VHS tape with each repetition labeled. According to findings from earlier motor learning studies, there were flaws in the conclusions drawn regarding true retention after practice due to the lack of time break between practice and retention testing.\textsuperscript{68,91}

The subjects for this multifidus study attended training sessions on either Monday/Wednesday or Tuesday/Thursday leaving on average five days between training weeks. The time between the training phase and retention testing averaged seven days. Preliminary data analysis of subjects at one week post multifidus training suggested that the time frame from completion of training to retention was not a long enough break to be able to accurately assess retention. It was theorized that asking subjects to return seven to ten days after completion of the four weeks of training was approximately the same length of time as between training weeks, and therefore did not accurately represent true retention of the motor skill.

Therefore, each subject was brought back to the lab at least four weeks after completion of the training phase for the long term retention test (R2) and the procedure for R1 was repeated to further explore the retention hypothesis. The real-time DUS images were recorded to VHS tape with each repetition labeled. Expanding the length of
time for long term retention was theorized to provide better predictability of transference of the learned motor skill to other tasks.

Data Collection

Each subject was assigned a numerical value for identification during the study. A data collection form generated using Excel (Microsoft, WA) provided a place to indicate the success or non-success of each repetition during each practice session. A “1” or “0” was marked for each repetition to indicate success or failure to isometrically recruit the multifidus within each session (Appendix F). Each training session (1 through 8) and each retention test (R1, R2) was labeled and recorded on VHS tape.

Data Analysis

The BMI was calculated using the non-metric formula: [weight (pounds)/height (inches)^2] x 704.5. Scores on the MHPAQ were manually calculated. Percent success of each training session and on the retention tests were calculated and recorded for each subject in Excel. The SPSS statistical software for Windows (SPSS Inc.; Chicago, IL) was used for calculating ANOVA for hypotheses testing, between group comparisons of subject characteristics, and Kappa statistics for intra-rater reliability testing.

Accepting or Rejecting the Research Hypotheses

1. A two-way repeated measures ANOVA (group and session number) with α=.05 was used to analyze hypotheses 1 and 2.
A. Null Hypothesis: no relationship exists between the type of group feedback and percent success during training. Ho: CON = VAR

Alternative Hypothesis: percent success is directly related to the type of group feedback during training sessions. H1: CON > VAR

The Ho will be rejected if \( p < 0.05 \). Table 3.1 summarizes the *a priori* power analysis using a moderate effect size to estimate the sample size needed assuming inter subject correlation.

<table>
<thead>
<tr>
<th>f=0.25 (Estimating moderate effect size)</th>
<th>Measurable units=80 (10 subjects X 8 trials)</th>
<th>Measurable units=120 (15 subjects X 8 trials)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>0.89</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>( r^* = 0.7 )</td>
<td>( r^* = 0.7 )</td>
</tr>
</tbody>
</table>

* estimated within group correlation

Table 3.1: *A priori* power analysis estimating sample size for group main effect

B. Null Hypothesis: no relationship exists between the amount of training and success over time Ho: Time 1 = Time 2 = Time 3, etc…

The Ho will be rejected if \( p < .05 \).

Alternative Hypothesis: direct relationship between amount of training and success. Greater training over time leads to increased success. H1:
Table 3.2 summarizes *a priori* analysis using a moderate effect size to estimate the sample size needed per group, assuming inter subject correlation.

<table>
<thead>
<tr>
<th>f = 0.25 (estimating moderate effect size)</th>
<th>Measurable units = 20 (10 subjects X 2 groups)</th>
<th>Measurable units = 30 (15 subjects X 2 groups)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>0.60</td>
<td>0.80</td>
</tr>
<tr>
<td>r * = 0.7</td>
<td>r * = 0.7</td>
<td></td>
</tr>
</tbody>
</table>

* estimated within group correlation

Table 3.2: *A priori* analysis estimating sample size for trial main effect

Post Hoc Analysis: Student-Newman-Keuls with pair wise comparisons between groups at each training session was used to control for type I error.

**Measuring Rate of Success**

A single factor ANOVA (α = .05) and slope of linear regression was used to compare the two groups for their rate of success over all training sessions.

2. A two way repeated measures ANOVA (group and retention test number) with α = .05 was used to analyze hypothesis 3.
Null Hypothesis: no relationship exists between the type of group feedback and the percent success on retention testing. Ho: CON = VAR

The Ho will be rejected if p < .05.

Alternative Hypothesis: a direct relationship exists between the type of group feedback and the percent success on the retention test. H1: VAR > CON

Table 3.3 represents the *a priori* analysis assuming inter subject correlation to estimate the statistical power of the study comparing sample sizes needed with moderate to large effect sizes.

<table>
<thead>
<tr>
<th></th>
<th>N=20 (Moderate effect size)</th>
<th>N=20 (large effect size)</th>
<th>N=30 (moderate effect size)</th>
<th>N=30 (large effect size)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>0.52</td>
<td>0.89</td>
<td>0.70</td>
<td>0.98</td>
</tr>
<tr>
<td>r *</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

* estimated within group correlation

Table 3.3: *A priori* analysis to estimate statistical power comparing moderate to large effect size

Two trials of 12 repetitions of the exercise given within the same day were analyzed using two way repeated measures ANOVA. If the results of the ANOVA demonstrated no difference between the two trials, the two trials would
be collapsed into a mean percent success score for each group and repeated measures ANOVA would be used to analyze the data.

**Variability of performance**

To test motor learning, the standard deviation of the percent success scores for each subject at each session was calculated to test the variability of performance both within and between groups.

**Testing for Intra-Rater Reliability**

To test for intra-rater reliability one training session for each subject was randomly selected by the research assistant. This researcher was blinded to subject and session and rated percent success. Cohen’s Kappa statistic ($\alpha = .05$) was calculated to evaluate consistency of rating success/failure at each session (twelve reps/session) for each subject (N=28) during training.
CHAPTER 4

RESULTS

This chapter provides a summary of the results from 28 subjects who participated in exercise specific training of the lumbar multifidus under constant and variable feedback schedules using real-time DUS imaging.

Characteristics of Subjects

Thirty subjects were recruited and randomized into the two treatment groups. Two subjects dropped out for reasons unrelated to the treatment. One subject completed five training sessions but had to drop out for unrelated health problems. The second subject dropped out before beginning the training due to schedule conflicts. The 28 subjects were on average 28 years old (SD = 8.03 year) with an average BMI of 24 kg/m² (SD = 0.70 kg/m²). Sixty-eight percent were female. They averaged a score of 8.75 out of 15 (SD = 0.45) for the total MHPAQ and 3.085 out of 5 (SD = 0.177) for overall sport MHPAQ. The higher score on the MHPAQ indicates greater physical activity of the participants. The CSA measurements for all subjects averaged 5.53 cm² (SD = 0.30 cm²) for the right lumbar multifidus and 5.3 cm² (SD = 0.17 cm²) for the left. The two groups
were similar (P>.05) at the outset of the study on the basis of these characteristics; gender, age, BMI, MHPAQ scores, and CSA measurements (Table 4.4).

<table>
<thead>
<tr>
<th></th>
<th>CON*</th>
<th>VAR*</th>
<th>Tests (2-tail)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>5</td>
<td>4</td>
<td>X² = .164</td>
<td>1.0</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>26.71 ± 7.8 (18 – 24)</td>
<td>29.36 ± 8.34 (19 – 47)</td>
<td>t = .8663</td>
<td>0.394</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.74 ± 3.06 (20.0 – 26.9)</td>
<td>23.75 ± 1.96 (20.9 – 30.0)</td>
<td>t = 1.022</td>
<td>0.316</td>
</tr>
<tr>
<td>MHPAQ (total)</td>
<td>9.07 ± 1.08 (7.63 – 10.76)</td>
<td>8.43 ± 1.36 (6.25 – 11.25)</td>
<td>t = 1.385</td>
<td>0.178</td>
</tr>
<tr>
<td>MHPAQ (sport)</td>
<td>3.21 ± 0.41 (2.75 – 3.75)</td>
<td>2.96 ± 0.61 (1.75 – 3.75)</td>
<td>t = 1.267</td>
<td>0.217</td>
</tr>
<tr>
<td>Left Multifidus (cm²)</td>
<td>5.32 ± 1.26 (3.57 – 7.41)</td>
<td>5.73 ± 0.96 (4.27 – 7.79)</td>
<td>t = .987</td>
<td>0.33</td>
</tr>
<tr>
<td>Right Multifidus (cm²)</td>
<td>5.18 ± 1.06 (3.64 – 6.94)</td>
<td>5.42 ± 1.12 (3.91 – 7.63)</td>
<td>t = .567</td>
<td>0.58</td>
</tr>
</tbody>
</table>

*mean ± SD and range

Table 4.4: Subject Characteristics at the Outset of the Study

Training Phase

The first hypothesis was that during the training phase the CON group would demonstrate a greater percent success than the VAR group.
Fourteen subjects per group completed all eight training sessions. Figure 4.1 shows the results of the two groups during both the training and retention phases of the study. During training, the overall mean success in the CON group of 90.8 ± 6.518% was somewhat higher (P=0.055) than the 78.9 ± 12.545% mean success of the VAR group.

Figure 4.1: Mean percent success over time in multifidus recruitment during the training phase (session 1-8) and retention testing phase (R1 and R2). Error bars represent the magnitude of the standard error.
There was a significant interaction ($P = 0.044$) between the group and training session independent variables. Post hoc analyses (Student-Newman-Keuls) indicated that CON group showed greater percent success at training session 1 ($CON = 79.8 \pm 26.2\%$; $VAR = 61.3 \pm 33.9\%$), session 3 ($CON = 88.1 \pm 21.4\%$; $VAR = 66.6 \pm 28.5\%$), and session 4 ($CON = 97.1 \pm 8.91\%$; $VAR = 70.7 \pm 35.2\%$).

Table 4.5 summarizes the power analysis and effect size for the between group training data. Power analysis calculations with $\eta^2 = 0.134$ (equivalent to a large effect size) revealed that for a power = 0.8 each treatment group should contain seventeen subjects, assuming that these subjects performed the same as the subjects in the current study.

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>P value</th>
<th>Power</th>
<th>Partial Eta squared (effect size)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>0.055</td>
<td>0.489</td>
<td>0.134</td>
</tr>
</tbody>
</table>

Table 4.5: Power Analysis for Between Group Training Data ($\alpha = 0.05$)
The second hypothesis was that both groups would show greater percent success over the 8 training sessions in their ability to isometrically recruit the lumbar multifidus.

Both groups increased their percent success over the eight sessions (P < .001). A single factor ANOVA was used to compare the two groups for their rate of success over training. The rate of success over all training sessions (slope of linear regression) was greater for VAR (4.73) compared to CON (1.53) with P = .04. The two lines converged as they approached the final training session such that the CON group’s percent success (90.4 ± 20.2%) was no different (P > .05) from the VAR group (94.7 ± 15.4%) (Figure 4.1).

Variability, an indication of motor learning, was defined as the standard deviation of the percent success scores for each subject at each training session. Variability decreased (P = .02) over the training sessions for both groups over time (Figure 4.2). There was no group by session interaction, indicating that the decrease in variability was parallel in both groups. Post hoc analysis (Student-Newman-Keuls) showed the greatest differences between groups in variability at sessions 3 (CON .153 ± .219; VAR .349 ± .204), 4 (CON .056 ± .147; VAR .236 ± .219), and 5 (CON .028 ± .104; VAR .185 ± .227) of the training phase, and R2 (CON .225 ± .064; VAR .128 ± .052).
Retention Testing Phase

The original third hypothesis was that the VAR group would demonstrate greater percent success than the CON group on the retention test at one week (R1) after completion of training. However, as this time frame was approximately the same time frame between training weeks, concern was raised that this was an inadequate representation of long term retention. Hence, a second retention test was added at least four weeks (R2) after completion of the training sessions. The hypothesis was that the VAR group would show greater success at the long-term retention test.
Thirteen subjects from the CON group and fourteen subjects from the VAR group completed the short term retention test (R1). The one subject from the CON group did not complete R1 due to being out of town and could not be contacted. At the first (R1) retention testing session, subjects performed two sets of 12 repetitions. The average time (days) between completion of the eighth training session and R1 was 7.3 ± 1.24. The results of the two way (group x trial set) ANOVA demonstrated that there was no difference (P = .974) between the first and second set of tests; therefore, the percent success on R1 for each subject was based on the 24 repetitions.

Eleven subjects from the CON group and twelve subjects from the VAR group completed the long term retention test (R2). Four subjects could not be contacted to return for final testing. Subjects also performed two sets of 12 repetitions at the second (R2) retention testing session and there was no difference (P = .293) between the first and second set of tests; therefore, the percent success on R2 for each subject was based on the 24 repetitions. The overall length of time (weeks) from completion of the eight training sessions and R2 ranged from four to twenty-five weeks (mean = 13.17 ± 6.6 weeks). The average amount of time (weeks) from completion of the training phase to R2 for CON was 10.64 ± 5.32 and VAR was 15.5 ± 7.0.

A repeated measure ANCOVA (group x retention test) using time (weeks) from completion of training phase as a covariate compared the overall mean percent success for R1 with R2 tests. The results showed a significant interaction (P = .047) between group and retention tests. CON success declined (-7.49 ± 13.27%) as VAR (7.99 ± 17.38%) improved (Figure 4.1).
The results for variability in performance were similar. The repeated measures ANCOVA (group x retention test), using time from completion of training (weeks) as a covariate, showed a significant interaction ($P = .02$) (Figure 4.2). The VAR group showed no difference in variability at R1, but lower variability at R2 compared to the CON group.

One out of ten in the CON group (10%) and 3 out of 12 in the VAR group (25%) demonstrated improvement in performance success from R1 to R2. Five out of ten in the CON group (50%) and two out of 12 in the VAR group (17%) showed a decline in performance success from R1 to R2.

**Relationship between Performance and Subject Characteristics**

The effect of gender was explored in the data. There were no differences between males and females in percent success during training ($P=.94$) and retention tests (R1 $P=.82$; R2 $P=.136$).

The data was analyzed for correlations within each group comparing the subject characteristics with percent success over the eight training sessions and on each retention test. There were no significant correlations ($P > .05$) between subject characteristics and percent success for either group during the training phase or retention tests.
**Agreement**

**Intra-rater Reliability**

To examine the issue of bias of the primary researcher not being blinded to group assignment in judgment of multifidus recruitment, an intra-rater reliability study was performed. One training session for each of the 28 subjects was randomly selected by the research assistant. The primary researcher, blinded to subject and training session, rated performance success. Cohen’s Kappa statistic testing for percent agreement on the success/failure scores for all subjects (N=28) at each training session (twelve reps/subject) for initial rating compared to blinded rating showed good strength of agreement with Kappa value = .643 (P = .04) with a 95% confidence interval from .542 to .744 (Table 4.6).

<table>
<thead>
<tr>
<th>Initial Rating</th>
<th>SUCCESS</th>
<th>NO SUCCESS</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUCCESS</td>
<td>239</td>
<td>20</td>
<td>259</td>
</tr>
<tr>
<td>NO SUCCESS</td>
<td>22</td>
<td>55</td>
<td>77</td>
</tr>
<tr>
<td>TOTAL</td>
<td>261</td>
<td>75</td>
<td>336</td>
</tr>
</tbody>
</table>

**Blinded Rating**

TABLE 4.6: Actual Agreement/Disagreement between Original and Blinded Ratings
CHAPTER 5

DISCUSSION AND CONCLUSIONS

Interpretation of Findings

The most important finding of this study is that the real-time DUS imaging feedback appears to have enhanced motor learning of exercise specific multifidus recruitment in both the CON and VAR groups. As expected, constant feedback enhanced performance during training but this did not result in superior retention of the motor skill. The CON group had greater percent success and less variability during training, especially early in the phase, compared to the VAR group. The CON group’s rate of change in percent success leveled off over the eight sessions compared to the VAR group’s gradual improvement. However, by the eighth training session there were no significant differences in mean percent success between the two groups. With the removal of the augmented feedback the CON group showed a steady decline in performance from completion of training to long term retention. The CON group demonstrated increased variability during performance at long term retention testing compared to the VAR group’s steady improvement in refining the motor strategy. These findings were consistent with our predictions based on the motor learning literature.
These findings are supported by Gentile’s taxonomy of tasks and skill acquisition. The motor task of multifidus recruitment is a closed, body stability task with no inter-trial variability. The individual’s ability to successfully produce the motor skill was directly impacted by being a closed skill where environmental characteristics related to the action goal remain constant. Within the training phase, subjects were able to utilize KP more effectively and become consistent in their performance because the environment and the conditions of the task remained stationary. The CON group’s rapid skill acquisition demonstrated how the augmented feedback of real-time DUS enhanced the cognitive stage of learning multifidus recruitment. Practice of this motor skill structured as a closed task enabled subjects in the CON group to progress to the associative stage of learning in less time than the VAR group as illustrated in Figure 4.2.

Variability decreased over time for both groups during training indicating that both groups were able to learn the motor skill over the four week training phase. There were clear between group differences at the long-term retention test as the VAR group continued to refine performance strategies after the removal of augmented feedback. The rate of improvement and variability during the training phases for both groups is supported by Fitts and Posner’s three stage model of learning. The CON group can be theorized to have progressed from the cognitive to the associative stage more rapidly during training than the VAR group as demonstrated by performance success and significantly smaller variability of practice strategies by sessions three and four. The findings suggest that the augmented feedback allowed the CON group to select the best motor strategy for the task and refine their performance in less time than the VAR group.
during training. However, once the augmented feedback was removed the CON group’s decline in performance reflected less reliance on cognitive processes for self correction of errors. These findings supported our hypothesis that VAR feedback would be superior to CON in enhancing the ability to refine motor strategies, and therefore lessening variability, as described in the motor learning literature. It is unknown whether these finding will hold true in individuals with LBP or if pain, atrophy, or other problems would create confounding factors.

Both groups were able to sustain the level of success mastered towards the end of the training phase, which was reflected on the short-term retention test interval. However, there were clear between group differences at the long-term retention test, largely because of the decline in the CON group performance. The VAR group’s greater ability to retain the motor skill on long-term retention tests is consistent with motor learning principles that VAR feedback enhances cognitive processes allowing the individual to more consistently utilize internal feedback of the movement itself in the successful acquisition of the motor skill. These findings supported the hypothesis that with the removal of feedback the CON group would show a decline in performance success of learning to isometrically recruit the lumbar multifidus, and that VAR feedback was superior to CON feedback in enhancing the ability to refine motor strategies and performance success of the newly learned motor skill, as supported by the motor learning literature.

The agreement was good for intra-rater reliability (Table 4.6) suggesting that rater bias was not a factor in the outcomes of the study. However, there were some technical issues in judging performance success that likely impacted the reliability. One factor
may have been related to the ability to detect muscle thickness changes with recruitment in subjects with higher BMI scores (greater than 28). A second factor was that the quality of the video recorded DUS images compared to those observed in real-time which made it more difficult to judge success on the second rating. Digitally recording the real-time DUS images would improve the quality of the images, thereby strengthening the confidence in assessment and possibly increasing the strength of reliability between ratings. Another way to control for rater bias would be to have an expert in DUS imaging of the multifidus serve as a blinded reviewer. However, on a few occasions artifact was produced when the US transducer was inadvertently moved on the skin during a trial. This artifact may affect the reliability of the blinded reviewer and should be evaluated in future studies.

Clinical Significance

In clinical practice physical therapists have a limited number of treatment sessions to impact learning new motor skills, therefore, finding treatment methods that enhance motor learning and possibly decrease the number of sessions required is very beneficial in best practice models. Recruitment of the lumbar multifidus in the rehabilitation of LBP is gaining support by researchers for the important role this muscle plays in providing spinal stabilization. A vital role of physical therapy is the assessment of muscle function and motor control in the determination of musculoskeletal impairments and the resultant impact on function. Many physical therapy assessment methods lack reliability when used to test the truncal musculature in patients with LBP, especially in testing of the deeper back muscles such as the lumbar multifidus. Learning to recruit
the lumbar multifidus is difficult given that there is limited intrinsic feedback of joint motion to enable the learner to confirm success. Therefore, individuals have little input for detecting correct performance through proprioceptive or kinesthetic feedback, further limiting the ability to self correct errors through cognitive processing. Real-time DUS imaging provides physical therapists with objective, reliable means of documenting muscle CSA, recruitment, and muscle performance during interventions. The use of real-time DUS imaging provides the individual with valuable visual feedback during skill acquisition of multifidus recruitment. That the VAR group demonstrated a continuation of improvement in success on short-term and long-term retention tests suggests that the use of variable real-time DUS feedback during exercise specific training of the lumbar multifidus may be a powerful feedback mechanism for physical therapists to utilize clinically during the acquisition of the motor skill. This study demonstrated that motor learning can be augmented by the biofeedback of real-time DUS imaging and possibly decrease the amount of time required to learn the motor skill.

Importance of the Work

One theory why individuals have such high incidence of recurrent and chronic LBP is that training has not included the best motor learning principles to enable the person to learn the motor skill and more importantly transfer the learned motor behavior to novel situations and postures. Determining the most beneficial treatment technique in motor skill acquisition of multifidus recruitment would significantly impact physical therapists treatment approach for LBP. Research has shown that individuals with LBP have difficulty isolating the local stabilizer muscles, which may increase the
risk of recurrent injuries. The use of real-time DUS biofeedback can impact the individual’s efficiency and efficacy of learning the motor skill of isometric multifidus recruitment in a shorter time period than traditional back exercises and transfer the learned skill to other postures and functions with greater success. The findings of this study showed that healthy subjects learned to recruit the lumbar multifidus much faster with the augmented feedback of DUS than previous studies utilizing tactile and verbal feedback methods.\textsuperscript{7,20,28} Helping individuals achieve success in lumbar stabilization in shorter time frames is a viable method for examining this motor learning method in patients with LBP and if successful, could potentially lessen the high percentage of recurrent and chronic LBP.

Comparison of Results with Works of Others

Perhaps for the motor skill of multifidus recruitment where the learner does not have sufficient intrinsic feedback to enable them to self correct performance, the ability to evaluate their performance through the augmented feedback of both the real-time and recorded images provided both groups with a superior way to detect and minimize errors over the eight training sessions. The KP provided through this form of augmented feedback appears to help individuals analyze performance strategies in the absence of kinesthetic awareness and refine the motor skill more successfully and in less time than previously reported.\textsuperscript{23,61} Studies comparing video augmented feedback to no feedback during acquisition of a motor skill demonstrated that participants who received video augmented feedback showed a faster rate of improvement during practice, better error detection, and maintained their success on retention testing when the feedback was
removed. To date, there are no studies exploring variability of feedback schedules using real-time DUS in the acquisition of isolated lumbar multifidus recruitment in healthy adults.

Documentation can be found to support that perception of an action elicits cognitive processes necessary to generate future actions. Hecht et al. compared visual practice to motor practice of a timed arm movement to determine whether subjects could transfer what they learned during practice when tested utilizing the other method of performance. This study investigated whether motor learning of the action, comparing visual-motor learning to motor-visual learning, could most effectively improve the ability to detect and interpret the kinesthetic feedback arising through practice of the motor skill. Since there is limited sensory feedback during isometric activation of the lumbar multifidus, our findings suggest visual-motor learning enhanced our subjects’ ability to perceive the motor plan, refine the motor strategies, and execute the motor skill.

How Results Support or Conflict with Theory

According to the previous research, isolated multifidus recruitment was thought to be a difficult task and took as long as ten weeks for LBP subjects to learn. Our study hypothesized that the task was going to be highly demanding, difficult to learn, and require subjects to focus on the cognitive processes in skill acquisition. Therefore, it was predicted that the VAR group would be superior to the CON group on retention. Based on the findings of this study healthy individuals did not appear to have a high level of difficulty with learning to perform the motor skill as expected. There was little variability in the context of the task performance, so once the skill was acquired, it was easily
replicated by both groups. The healthy subjects in this study were able to acquire the motor skill in as little as four weeks.

Limitations of the Study

First, the small sample size and drop outs decreased the power of the study, increased the risk of a Type II error, and also makes it difficult to generalize to a larger population. Based on the large effect size found, increasing the number of subjects per group to seventeen would have been sufficient to strengthen the power of the study ($\beta = .20$), assuming that these subjects performed the same as current subjects.

Secondly, without a control group who received no augmented feedback or who received only tactile feedback, this study cannot generalize the findings to clinical situations where tactile feedback is used in lieu of real-time DUS imaging. Future studies should verify the belief that visual feedback is superior to no feedback or tactile feedback.

Third, further studies having the variable group only receive feedback at the randomly selected sessions, not providing them with summary of performance between feedback sessions, would strengthen the generalizability that variable feedback is superior to constant when learning to isometrically activate the lumbar multifidus.

Fourth, only one retention test was initially planned and the long-term retention test was added later because of the limited time between training and retention. As a result of adding the second retention test late in the study, the times for the subjects to return were inconsistent and a few subjects were lost to follow-up. Future studies should investigate whether the VAR group performance success would continue to surpass the
CON group over time. This would be important for understanding the long-term effectiveness of this training approach in clinical populations.

Fifth, by not having the subjects perform the motor skill in different exercise postures or activities, the ability to transfer the learned skill to novel situations was not assessed. According to the literature, VAR feedback should result better retention and transfer of the motor skill.

Finally, intra-rater reliability was weakened due to the quality of the video recording of real-time DUS images, making it difficult to accurately assess success/failure. Having an expert in DUS imaging the multifidus as a second blinded evaluator independently rate performance success in real-time could also reduce the potential for bias.

Future Studies

This study has lead to new awareness of motor learning principles regarding recruitment of the lumbar multifidus during exercise specific training and raises additional questions for future studies. First, will individuals with recurrent LBP perform similarly to healthy subjects? Second, will subjects trained to recruit the lumbar multifidus in prone transfer this ability to new exercise postures and activities? Further research needs to explore the development of a scale to quantify the magnitude of lumbar multifidus contraction during isolated isometric recruitment, coordinating the DUS images with EMG signal changes. This scale would be a valuable tool for further analysis of multifidus muscle recovery and recurrent LBP.
Conclusions

The plausible clinical interpretation of these findings suggest that the visual image from the real-time DUS imaging was a powerful biofeedback mechanism during training of isometric recruitment of the lumbar multifidus. The VAR timing of feedback was superior to CON feedback in performance success in long-term retention of the motor skill. Subjects acquired the skill in much less time than expected. The VAR group’s decrease in variability at long-term retention suggests that the timing of feedback promoted the cognitive processes necessary for self correction of errors and performance success in retention and possibly greater success in transferring the motor skill to novel situations. Future research should determine whether these findings hold true in individuals with LBP or if pain, atrophy, or other problems create a confounding factor when patients are trained and tested under similar conditions. Further research should be done comparing tactile feedback as provided in the clinic, visual feedback of real-time DUS with those who receive no feedback to explore best method of lumbar multifidus training for clinical practice. In addition, whether subjects can learn and transfer the skill under a variety of conditions (i.e. postures or functions) must be studied.
LIST OF REFERENCES


Gentile A. A working model of skill acquisition with application to teaching. Quest. 1972; 17:3-23.


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APPENDIX A

Real-Time Ultrasound Imaging of the L5-S1 Multifidus
The Right L5-S1 Multifidus: A) at Rest and B) Activated

A.

B.
APPENDIX B

Instructional sheet and Feedback Script
INSTRUCTIONAL SHEET

I will be placing the ultrasound head over a deep muscle in your back known as the multifidus muscle. You will be able to see the ultrasound image on the TV screen when I give you feedback. When I say begin I want you to try to swell the muscle like you are trying to push the ultrasound head off your back without moving your spine or your pelvis. Try to hold the contraction for a count of 3 seconds while breathing normally then relax. I will be asking you to repeat trying to contract the muscle 12 times.

FEEDBACK INSTRUCTION

Subjects in the constant group will be instructed to watch the TV monitor during the twelve repetitions. The researcher will explain that when they are successful with the exercise they will see the muscle move on the screen.

Subjects in the variable group will review the ultrasound images recorded on the VCR with the researcher. The researcher will provide feedback of which trials were successful/unsuccessful. The researcher will ask the subject to self analyze their performance.
APPENDIX C

Modified Habitual Physical Activity Questionnaire
MODIFIED HABITUAL PHYSICAL ACTIVITY QUESTIONNAIRE

1. My primary occupation is ____________________________________________.

2. At work I sit …
   never  seldom  sometimes  often  always

3. At work I stand …
   never  seldom  sometimes  often  always

4. At work I walk …
   never  seldom  sometimes  often  always

5. At work I left heavy loads …
   never  seldom  sometimes  often  very often

6. After working I am tired …
   never  seldom  sometimes  often  very often

7. At work I sweat …
   never  seldom  sometimes  often  very often

8. In comparison with others my own age I think my work is physically …
   much heavier  heavier  as heavy  lighter  much lighter

9. Do you exercise or play a sport?
   Yes  No

   If yes:
   What exercise or sport do you do most frequently? ______________________
   How many hours per week? ______________________
   How many months per year? ______________________

   If you have a second exercise or sport, what is it? ______________________
   How many hours per week? ______________________
   How many months per year? ______________________

10. In comparison with others my own age I think my physical activity during leisure time is …
    much more  more  the same  less  much less

11. During leisure time I sweat …
    very often  often  sometimes  seldom  never

12. During leisure time I exercise or play sport …
never  seldom  sometimes  often  very often
13. During leisure time I watch TV …
never  seldom  sometimes  often  very often
14. During leisure time I walk …
never  seldom  sometimes  often  very often
15. During leisure time I cycle …
never  seldom  sometimes  often  very often
16. How many minutes do you walk and/or cycle per day to and from work, school, and shopping?
< 5 minutes  5-15 minutes  15-30 minutes  30-45 minutes  > 45 minutes
APPENDIX D

Intake Sheet
INTAKE SHEET

Name ________________________________

Age _________ Sex _________

Height _____________________________

Weight _____________________________

BMI score: [ pounds/inches\(^2\) X 704.5] = ________________

MHPAQ Score ________________________

Occupation __________________________

History of abdominal or back surgery? ______________

Ever had PT training for the multifidus? ______________

Ever had any episode of low back pain? ______________
   If yes, how many episodes? ______________

________________________________________

Any Significant Medical History:

________________________________________

________________________________________

Lower Quarter Screen:
APPENDIX E

Feedback Schedule
Nine Patterns for Variable Feedback Training. Numbers indicate Exercise Repetition Number. F represents a Repetition which is followed by Feedback and T is a Repetition without Feedback.

Pattern 1: T1, F1, T2, T3, F2, T4, T5, T6, F3, T7, T8, F4
Pattern 2: T1, T2, F1, T3, F2, T4, T5, T6, F3, T7, F4, T8
Pattern 3: F1, T1, T2, F2, T3, T4, F3, T5, F4, T6, T7, T8
Pattern 4: T1, T2, T3, F1, T4, F2, T5, F3, T6, T7, T8, F4
Pattern 5: F1, T1, T2, T3, F2, T4, T5, F3, T6, T7, F4, T8
Pattern 6: T1, F1, T2, T3, T4, F2, T5, T6, F3, T7, F4, T8
Pattern 7: T1, T2, F1, T3, T4, F2, T5, F3, T6, T7, T8, F4
Pattern 8: T1, F1, T2, T3, F2, T4, T5, F3, T6, F4, T7, T8
Pattern 9: F1, T1, T2, F2, T3, T4, F3, T5, T6, F4, T7, T8
APPENDIX F

Data Collection Sheet
DATA COLLECTION SHEET

SUBJECT ____________  VISIT ____________

<table>
<thead>
<tr>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Trial 4</th>
<th>Trial 5</th>
<th>Trial 6</th>
<th>Trial 7</th>
<th>Trial 8</th>
<th>Trial 9</th>
<th>Trial 10</th>
<th>Trial 11</th>
<th>Trial 12</th>
</tr>
</thead>
</table>

% SUCCESS ____________