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Abdominal Muscle Characteristics of Elite Male Golfers With and Without Chronic Low Back Pain

by

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Abstract

Chronic low back pain (CLBP) is the most common musculoskeletal problem affecting amateur and professional golfers. The main purpose of this study was to measure the magnitude and onset time of abdominal muscle activity of elite male golfers with and without CLBP during the golf swing. These parameters were measured before and after a typical practice session. Abdominal muscle fatigue was also measured following the practice session. Significant differences were found in abdominal muscle activity onset time between elite CLBP (17) golfers and elite AC (8) golfers. Differences in onset times between CLBP and AC subjects remained following practice. The practice session led to significant increases of low back pain in CLBP subjects. Abdominal muscle fatigue did not occur following practice in either group. Differences in abdominal muscle activity onset time during the golf swing between elite male golfers with and without CLBP might be related to CLBP.

Preface

This thesis is organized in the following way. A general introduction will first be presented followed by a review of literature. The review of literature presents information concerning low back pain in golfers, muscle function in chronic low back pain individuals, electromyographic studies in golf, assessing muscle fatigue with electromyography, and trunk muscle exercises in rehabilitation of chronic low back pain. Following the review, this thesis presents two separate, but related, studies. Chapters 3 and 4 are stand-alone papers. Consequently, there is some repetition in the introduction and methodology sections of these chapters. A third section representing an incomplete study of the effects of training has been placed in Appendix F. This study is incomplete due to scheduling difficulties and subject drop-out. This information is provided for the benefit of those wishing to pursue similar training intervention studies.

Chapters 3 and 4 of this thesis are based on the following manuscripts:

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CHAPTER 1: INTRODUCTION

Low back pain has been identified as the most common musculoskeletal problem affecting amateur and professional golfers (McCarroll, 1996; Sugaya et al., 1999). The development of such pain in amateur golfers has been attributed to poor swing mechanics, excessive practice, and poor physical conditioning (McCarroll et al., 1990; Hosea & Gatt, 1996; Mallare, 1996). Professional golfers tend to exhibit more consistent swing mechanics than amateurs, however, they too display poor physical conditioning and are especially guilty of excessive practice. Overuse (repetitive swings) is believed to be the most common cause of injuries in professional golfers, particularly to the low back (McCarroll & Gioe, 1982; Brendecke, 1990; Hosea & Gatt, 1996; Mallare, 1996).

Although most professional golfers are well aware of the mechanics involved in swinging the golf club properly, subtle factors may be unknowingly present which might contribute to the onset and continuance of low back pain. It is believed that altered swing mechanics combined with overuse can create repetitive abnormal stresses on the lumbar spine thus leading to injury and pain (Batt, 1993; Mackey, 1995; Sugaya et al., 1999). Recent research suggests a combination of counterclockwise axial rotation and right lateral bending (in right handed golfers) during the golf swing may be damaging to the lumbar spine and therefore causing injury and pain (Sugaya et al., 1999). The highest rotational velocities and lateral bending angles are known to occur just after ball impact (Sugaya et al., 1999). Thus, the *impact phase* of the golf swing is suggested as being potentially damaging to the lumbar spine.

One may not think of golf as a particularly fatiguing activity, however, during a typical game of golf (18 holes) or a practice session, repetitive swings may cause muscular fatigue to develop, particularly in the trunk muscles. The oblique abdominal muscles are known to be active throughout the golf swing especially during the *acceleration phase* and *impact phase* (Pink et al., 1993; Watkins et al., 1996). Parnianpour et al. (1988) found fatigued muscles were slower and took longer to accommodate changes in load. In addition, Suzuki & Endo (1983), found fatigue to develop more easily in the abdominal muscles than in the low back muscles and the fatigability of the abdominal muscles in the patients with low back pain was significantly greater than that in control subjects. The association of fatigued muscles and their inability to handle changes in load therefore becomes an issue, given the repetitive nature of the sport of golf. Compensatory movement patterns as a result of fatigue might cause abnormal loading of joints and muscles thus leading to injury and pain.

Dysfunction of the deep abdominal muscles (transverse abdominis - TrA and internal oblique - IO) is thought to play a role in decreasing protection of the lumbar spine and may be directly related to the incidence of low back pain (Hodges & Richardson. 1996; Hodges et al., 1996; O'Sullivan et al., 1997). Transverse abdominis and IO are believed to provide an important stiffening effect on the lumbar spine, enhancing its dynamic stability (Aspden, 1992). These muscles are known to be primarily active in providing rotational and lateral control to the spine while maintaining levels of intra-abdominal pressure and imparting tension to the thoracolumbar fascia (Cresswell et al., 1992; Cresswell et al., 1994; O'Sullivan et al., 1997). Watkins et al.

(1996) suggest muscle activity patterns during the golf swing in injured golfers might be different from those in the uninjured player. Golfers who lack adequate trunk muscle recruitment or conditioning may be particularly susceptible to low back pain.

Physical therapists have generally prescribed stabilization exercises for the trunk flexors and extensors as a form of rehabilitation for the treatment of low back pain (Casazza et al., 1998). The objective of exercise in the management of low back pain is primarily to gain strength and endurance; with the goal to prevent and reduce pain caused by excessive abnormal loading of the lumbar spine (Mälkiä & Kannus, 1996; McGill, 1998). Such exercises have been shown to improve measured strength and endurance characteristics in individuals suffering from low back pain (Moffroid, 1997). A number of papers have addressed the problem of low back pain in amateur and professional golfers and suggest the importance of proper conditioning of the trunk muscles as a form of prevention and rehabilitation (Hosea & Gatt, 1996; Mallare, 1996; Pink et al., 1993; Watkins et al., 1996). However, the few research studies in the literature investigating conditioning in golfers primarily deal with increasing strength and flexibility for performance (Westcott et al., 1996; Hetu et al., 1998; Lennon, 1999). Considering the role of abdominal muscles during the rotational and lateral movements of the golf swing, the implementation of trunk exercises that specifically target the deep abdominal muscles might be a key component in alleviating low back pain in *elite golfers*

Research studies have been conducted (Jobe et al., 1989; Pink et al., 1990; Pink et al. 1993; Kao et al., 1995; Watkins et al., 1996) to investigate muscle activity patterns during the golf swing. However, none have specifically examined abdominal muscle activity patterns in players with and without low back pain. Furthermore, no research has been conducted to examine the amount of fatigue occurring in the abdominal muscles over a period of repetitive swings. Such a study may give insight into the possible role of these muscles during the *impact phase* of the golf swing. Given the issues presented previously and the lack of low back pain research in the sport of golf, it is appropriate to investigate the relationship between trunk muscle performance and low back pain in *elite* male golfers. There is a certainly a need to provide more conclusive evidence about the relationship between the golf swing and low back pain.

Primary Purposes

The first purpose of this research project was to determine whether there were differences in the magnitude of abdominal muscle activity between *elite* male golfers with and without chronic low back pain (CLBP) during the different phases of the golf swing. In addition, differences in the onset time of abdominal muscle activity during the golf swing between these two populations were investigated. The second purpose of this research project was to determine whether *elite* male golfers with CLBP experience greater fatigue in the abdominal muscles than asymptomatic control golfers (AC) following a typical 50-minute practice session. The final purpose of this research project was to determine whether abdominal endurance exercises performed daily over an 8-week period were effective in alleviating low back pain and amount of abdominal muscle fatigue following a typical *practice session*.

Primary Hypotheses

1. *Elite* male golfers who experience CLBP will exhibit less external oblique and internal oblique muscle activity throughout the golf swing than *elite* male golfers who do not experience chronic low back pain.

2. *Elite* male golfers who experience CLBP will exhibit a delayed onset of internal oblique muscle activity during the golf swing compared to *elite* male golfers who do not experience chronic low back pain.

3. *Elite* male golfers who experience CLBP will exhibit greater fatigue in the external oblique and internal oblique abdominal muscles than *elite* male golfers who do not experience chronic low back pain, after a typical 50-minute practice session.

4. Following 8-weeks of abdominal endurance exercises, *elite* male golfers with CLBP will exhibit less abdominal muscle fatigue and less low back pain following a typical 50-minute practice session.

CHAPTER 2: LITERATURE REVIEW

Low Back Pain in Golfers

As recent as the 1970's it was believed there were no unique golf injuries. At that time, there was no official documentation of golf injuries. However, anecdotal reports by physicians suggested injuries to the elbow and hands were the most common in golf. One physician in particular stated "there was always low back pain too", but he didn't believe it was any more prevalent in golfers than in the general population (Roberts, 1978). Today, it is recognized that injuries and pain to the low back are the most common musculoskeletal problems affecting both amateur and professional golfers (McCarroll, 1996; Sugaya et al., 1999).

Golf injuries could result from a combination of factors including predisposing factors such as age or previous injury, poor or altered technique, and overuse. The golf swing is a very complex movement involving flexion, extension, rotation, and lateral flexion; as well as the activation of a myriad of muscles. Over the years notable changes to the swing have evolved. The evolution of the modern swing has promoted greater shoulder turn while restricting hip turn compared to the classic swing, which involved greater hip and shoulder rotation. The general belief is the modern swing creates more torque in the trunk area resulting in greater clubhead velocity in the downswing, however, it appears this swing might be related to an increase in low back pain (Hosea & Gatt, 1996).

A survey completed by 127 touring professionals in the United States indicated overpractice (repetitive swings) was the most commonly reported cause for injuries (McCarroll & Gioe, 1982). A recent survey completed by professional golfers in Japan regarding the incidence of injuries, location of symptoms, and the symptom-related phase of the swing indicated 63 % of injuries sustained were to the low back area; the most common injury among male professionals (Sugaya et al., 1999). This survey also found that 51% of golfers with low back pain reported right side low back symptoms (28% left side, 21% central or no laterality), and those reporting right side low back pain experienced aggravation of symptoms during the impact phase of the swing. All subjects in this study were right-handed golfers.

A radiographic study performed on 10 elite male amateur golfers and 16 professional golfers (14 male) found golfers with right-sided low back symptoms to have a significantly higher rate of right side osteophyte formation as well as right-sided degenerative changes at the facet joints than control subjects (Sugaya et al., 1999).

Previous research by Sugaya et al. (1996) found trunk motion during the golf swing to be a combination of counterclockwise axial rotation and right lateral bending (in right handed golfers) which they consider a distinctly asymmetric motion. Both axial rotation velocity and right side bending angles reach peak values almost simultaneously just after ball impact (Sugaya et al., 1996). The combination of lateral bending along with the high velocity of axial rotation during the golf swing may be damaging to the lumbar spine particularly during the *impact phase*, resulting in injury and pain (Sugaya et al., 1996).

Other mechanisms of low back pain in golfers may relate to muscle behavior. Several electromyographic studies have been performed to determine which muscles are active during different phases of the golf swing. Pink et al. (1993) and Watkins et al. (1996) found high levels of abdominal muscle activity during the *acceleration phase* of the swing. Based on these muscle activity patterns, Mallare (1996) suggests muscular fatigue might occur as a result of overpractice, particularly in unconditioned individuals, therefore increasing the likelihood of injury. The underlying assumption of this suggestion is that unconditioned or fatigued muscles of the trunk may not offer the needed muscular coordination to protect the lumbar spine during repetitive swings.

Muscle Function in Chronic Low Back Pain Individuals

The relationship between muscle insufficiency and CLBP is not clearly understood, however, it is believed that the passive tissues (ligaments, bones, discs etc.) of the spine may suffer increasing abnormal loads with inappropriate muscle recruitment (Roy et al., 1989; Gracovetsky et al., 1985). Deficient muscular support of the abdominal muscles may play a critical role in decreasing support of the lumbar spine and may be directly related to CLBP.

Panjabi (1992) has proposed there are three subsystems that all contribute to the stability of the spine: the passive (ligaments, bones, discs, etc.), the active (muscles and tendons), and the central nervous system. Others suggest the spinal column may have both intrinsic and extrinsic stability (Morris et al., 1961). Intrinsic stability is provided by the alternating rigid and elastic components of the spine which are bound together by the systems of ligaments, whereas extrinsic stability is provided by the paraspinal and other trunk muscles.

The key stabilizer abdominal muscles of the lumbar spine are the external obliques (EO), internal obliques (IO), and transverse abdominis (TrA) (Cresswell et al., 1992; O'Sullivan et al., 1998; McGill, 1998). Internal oblique and TrA are believed to provide an important stiffening effect on the lumbar spine, therefore enhancing its dynamic stability (Aspden, 1992). These muscles are known to be primarily active in providing rotational and lateral control to the spine while maintaining levels of intra-abdominal pressure and imparting tension to the thoracolumbar fascia (Cresswell et al., 1992: Cresswell et al., 1994; O'Sullivan et al., 1997). In both trunk control and pressure regulation there appear to be differences between the individual abdominal muscles. The rectus abdominis (RA), EO and IO perform ventro-flexion whereas the EO and IO are mainly responsible for lateral flexion and rotation (Häggmark & Thorstensson, 1979). These trunk muscles are physiologically postural muscles that are suited to provide low levels of activity for long periods of time (Moffroid, 1997).

P. W. Hodges and C. A. Richardson are the leading researchers investigating abdominal muscle activity onset times in subjects with and without low back pain in the general population. Hodges and Richardson (1999a) found subjects with low back pain failed to recruit TrA or IO in advance of fast limb movement. The contraction of muscles associated with movement of a limb, other than those producing the movement, are believed to contribute to the maintenance of both the position of the center of mass over the base of support and the stability of the affected joints (Hodges & Richardson, 1997). This muscle activity occurring prior to the activity of the prime mover of the limb, is referred to as "feedforward" because it cannot be initiated by feedback from the limb movement (Hodges & Richardson, 1997).

People with CLBP often have reduced trunk muscle strength and endurance (Roy et al., 1997). Trunk muscle strength has generally been assessed by measuring the maximal force that can be exerted using isokinetic dynamometers (Thorstensson & Arvidson, 1982), while endurance tests such as the Sorensen test measure how long a person can sustain a suspended prone position (Moffroid et al., 1994). This muscle insufficiency may compromise the capability of the spine to withstand perturbation and repetitive loads, and thereby increase the likelihood of injury (Campello et al., 1996; Roy et al., 1997).

Roy et al. (1989), stated the practical importance of assessing back muscle fatigue through electromyography (EMG) to associate possible muscle deficits with low back pain. In addition, Hides et al. (1994), have stated that objective direct measurement of muscle, through the use of EMG, might help in the assessment of low back pain and aid in the choice of appropriate treatment.

Considering the importance of the abdominal muscles as stabilizers of the lumbar spine and the importance of appropriate coordination of these muscles in avoiding damage to the lumbar spine, it would appear valuable to investigate abdominal muscle function of golfers during the golf swing. After conducting a study to investigate trunk muscle activity in professional golfers, Watkins et al. (1996) speculated the muscle activity patterns in injured players might be different from those in the uninjured player. Individuals with CLBP may therefore be lacking adequate abdominal muscle recruitment during the golf swing.

Electromyographic Studies in Golf

Electromyography is the study of muscle function through recorded information gained from the electrical signals emitted from muscles during membrane activation processes. Electromyography provides information, within certain limitations, about the neural drive to various components of the musculature (McGill, 1991), and is used to obtain various types of answers such as: 1) whether the muscle in question is active or inactive during a given task; 2) when does the muscle turn on and off?; 3) what is the phasic relationship between the muscles of interest?; 4) is the evaluation of the electromyographic activity based on quantitative measures such as a root mean square?; and 5) is the muscle fatigued?

Previous golf research using EMG was conducted primarily to describe muscle activation patterns during the golf swing among male and female amateur and professional golfers. Researchers have measured activity in the shoulder muscles, scapula muscles, trunk muscles, hip muscles and knee muscles. Jobe et al. (1989) compared muscle activity patterns of normal shoulder musculature in male and female professional golfers. The supraspinatus, infraspinatus, subscapularis, pectoralis major, latissimus dorsi, and anterior, middle, and posterior deltoids were monitored using fine wire EMG. Male and female professional golfers in this study exhibited similar magnitudes and timing of shoulder muscle activity during the golf swing. Since no differences in shoulder muscle activity were found between genders in the study by Jobe et al. (1989), Pink et al. (1990) combined the EMG data from these male and female professional golfers for further analysis. These authors concluded that golf was not a strenuous arm activity but did require high synchronous activity of the rotator cuff muscles in order to protect the glenohumeral complex. The authors noted that all of the right handed golfers seen at their clinic for shoulder problems had left sided rotator cuff problems. Findings indicated that there is a relatively small contribution from the three deltoid muscles during the golf swing, while a greater contribution was found from the rotator cuff muscles.

Kao et al. (1995) examined the role of the scapular muscles (levator scapulae, rhomboid, trapezius, serratus anterior) during the golf swing. They concluded the upper, middle, and lower trapezius all work together to help retract the scapula during different parts of the swing. Activity in the trailing arm primarily occurred during takeaway whereas activity in the leading arm occurred during acceleration. The lead side levator scapulae and rhomboid muscles also helped elevate and retract the scapula on the downswing. Results from this study indicated no single scapular muscle predominates during the golf swing, but rather a balance of these muscles contributes to a normal golf swing. It is suggested that levator scapulae and rhomboid muscles contribute a stabilizing role during the forward swing to control scapular rotation and protraction in the trailing arm, possibly in an eccentric contraction behavior. The authors of this study concluded that the scapular muscles are important during the golf swing and specific strengthening exercises are needed to prevent injuries in this area.

The muscle activity patterns of the trunk muscles in amateur golfers has been investigated by Pink et al. (1993). These researchers found there was high and constant oblique abdominal muscle activity during the *acceleration*, *impact*, and follow-through phases of the golf swing, however they did not distinguish between EO or IO muscles. They stressed the importance of the trunk muscles during the golf swing and the need for an effective preventive and rehabilitative exercise program for golfers. In a similar study using professional golfers, Watkins et al. (1996) established that all the trunk muscles measured in the study were relatively active during the *acceleration phase* of the golf swing, especially the right abdominal oblique muscles. Watkins et al. (1996) did not distinguish between EO and IO muscles. Their conclusions were similar to Pink et al. (1993) with the addition that the trunk muscles were believed to be important stabilizers of the lumbar spine.

Belcher et al. (1995) studied the activity patterns of the gluteus maximus, gluteus medius, adductor magnus, biceps femoris, semimembranosus, and vastus lateralis muscles in competitive golfers. The authors concluded the extensors and abductors of the trail hip, in conjunction with the lead adductor magnus, contract powerfully to initiate pelvic rotation during the down swing. The lead vastus lateralis and the hamstrings acted to stabilize the knee joints during this pelvic rotation.

These EMG studies have all made contributions to the understanding of muscular activity patterns during the golf swing and suggest the need for specific exercise programs for golfers to prevent injuries. Watkins et al. (1996) state the current literature does not fully address the importance of trunk muscle testing in golfers and stress its importance given the significant prevalence of back pain among golfers at all levels of ability. The authors of the trunk muscle EMG studies have indicated the importance of the abdominal muscles for generating maximum power to drive the ball and as stabilizers of the lumbar spine during the golf swing. No study to date, however, has investigated the relationship between abdominal muscle activity during the golf swing and low back pain. Nor has any study specifically investigated the role of the abdominal muscles during the *impact phase* of the golf swing.

Assessing Muscular Fatigue with EMG

One method of directly assessing muscle deficiency is to measure fatigability in particular muscles. Electromyography is commonly used to obtain a detailed measure of muscle activation in individuals suffering from low back pain (Soderberg & Barr, 1983; Roy et al., 1989; Hodges & Richardson, 1995; O'Sullivan et al., 1997; O'Sullivan et al., 1998). Muscular fatigue can be thought of as a time dependent process related to biochemical events rather than as the more popular method of identifying a single point in time wherein contractile failure occurs (Roy et al., 1990).

A popular method of investigating the manifestations of muscular fatigue is to monitor the frequency domain properties of the EMG signal. Several researchers have used the median frequency (MF) as an outcome measure to assess presence of muscular fatigue (Roy et al., 1990; Moffroid et al., 1993; Mannion & Dolan, 1994; Peach & McGill, 1998). Median frequency shifts to lower frequencies from low back muscles are commonly reported representations of surface EMG recordings in muscular fatigue studies of persons with CLBP. The technique of monitoring the frequency shift of the surface EMG signal for the purpose of measuring localized muscular fatigue has several advantages. (1) It is noninvasive, (2) it may be performed on muscle in vivo, (3) it provides information relating to events which occur inside the muscle, and (4) the fatigue measure of the decline of the MF is independent of the subject's effort level because a person can neither perceive nor regulate the frequency content of the EMG signal (Moffroid et al., 1994).

Parnianpour et al. (1988) found fatigued muscles to be slower and take longer to accommodate to changes in load. They also found trunk rotation and lateral bending motions to increase as fatigue developed during repeated sagittal trunk movements against a fixed load. Suzuki & Endo (1983) found fatigue to develop faster in the abdominal muscles than in the back muscles and the fatigability of the abdominal muscles in the patients with low back pain was significantly greater than in control subjects without low back pain.

Laboratory and clinical studies have documented that muscular fatigue measurements based on the MF of the EMG signal is very effective in monitoring changes in muscle function following CLBP rehabilitation and exercise (Roy et al., 1986; Roy et al., 1990; Biedermann et al., 1990). Therefore, the effectiveness of a prescribed treatment program could be determined by changes in the behavior of the characteristic frequency content. While the MF of the EMG signal is known to decrease over time during a fatiguing contraction, the root mean square (RMS) of the EMG signal is known to increase throughout a fatiguing contraction (Asmussen, 1979). Using the RMS of the EMG signal is another reliable method of assessing muscular fatigue during fatiguing contractions.

Trunk Muscle Exercises in Rehabilitation of CLBP

Physicians and physical therapists have frequently prescribed exercise programs to individuals suffering from CLBP as a form of rehabilitation because they are relatively inexpensive, noninvasive, and provide the patient with an active role in their rehabilitation (Campello et al., 1996; Kuukkanen & Mälkiä, 1996). The objective of exercise in the management of low back pain is primarily to gain strength, endurance, and improve proprioception and movement awareness. The goal of such programs is to prevent and reduce pain, which is assumed to be caused by excessive loading of the lumbar spine (Mälkiä & Kannus, 1996; McGill, 1998).

Training of the trunk flexors and extensors has generally been prescribed and has been shown to improve measured strength and endurance characteristics (Moffroid, 1997). In the sub-acute and chronic phases of low back pain, tailored exercise programs have been shown to have a beneficial effect on reducing physical impairments and limitations. A study by Kuukkanen & Mälkiä, (1996) showed strength and endurance in low back pain subjects could be increased, as well as back pain decreased, during a 3-month progressive exercise program. The progression of the program was based on performance tests, which were conducted on a weekly basis. The load of each exercise movement was individually increased relative to the test results. Other studies have also given promising results for graded activities as a tool for effective and economic rehabilitation in CLBP (Kuukkanen & Mälkiä, 1996). Richardson and Jull (1995) believe that control of back pain and prevention of its recurrence can be assisted by enhancing the function of the trunk muscles acting on the lumbar spine.

The strength of muscle contraction has been the function most often assessed in research investigating low back pain. Strength is defined as the maximum force a muscle can produce during a single effort (McGill, 1998). Patients are often told that increased trunk strength will help in the treatment of their low back pain because it is believed to be important in protecting the spine (Thorstensson & Arvidson, 1982). Watkins et al. (1996) and Mallare (1996) advise that trunk muscle strength is important to both the recreational and professional golfer. They point out the need for a trunk-strengthening program for golfers that is oriented toward balance, coordination, and postural control to reduce the risk of injury and as a form of rehabilitation. Golfers who lack adequate trunk strength and endurance, or demonstrate inappropriate motor coordination, may be particularly susceptible to low-back pain.

McGill (1998) believes that endurance exercises have a greater prophylactic value than strength exercises and suggests the emphasis should be placed on endurance, which should precede strengthening exercise in a gradual, progressive exercise program. It is commonly stated that weakness and lack of endurance of the trunk muscles seem to be significant risk factors in the development and occurrence of CLBP (Hodges & Richardson, 1995; Ito et al., 1996; Moffroid, 1997). Endurance is most commonly measured as either (1) the number of times that a repetitive submaximal contraction or task can be properly performed at a constant rate, or (2) the ability of muscle to delay the onset or to minimize the manifestations of fatigue (a decrease in force, work, or power output over time) (Sapega, 1990).

In rehabilitation programs for patients with low back pain it is suggested that therapeutic exercise should be designed to strengthen both the flexor and extensor muscles of the trunk and to minimize fatigability of the trunk flexors (Suzuki & Endo, 1983). Current programs consist of a variety of general trunk exercises, and for the most part they seem to have some success. However, within these general programs it is difficult to ascertain which particular features of the exercise tasks are more responsible for successful outcomes in some patients compared to others.

Specific exercises that isolate some of the muscles acting directly on the spine appear to be a beneficial way of training for stabilization in rehabilitation programs (Richardson & Jull, 1995). Isometric exercises are believed to be most beneficial for re-educating the role of the deep local muscles of the lumbar spine (Richardson & Jull, 1995). Such an exercise is the horizontal side support. This isometric exercise produces high levels of activity in the abdominal obliques and quadratus lumborum with limited lumbar compressive loading. From surface EMG studies, McGill (1998) suggests there is no single abdominal exercise that challenges all of the abdominal muscles. He adds the most appropriate exercises are those that challenge the muscle and impose minimal joint loads.

Moffroid (1997), however, believes that exercise and motor learning are not synonymous and therefore exercises aimed toward improving strength, endurance, and recruitment strategies should be chosen while considering relevant functions during a particular movement. A study by O'Sullivan et al. (1998), highlights the importance of exercise specificity when prescribing exercises in the rehabilitation of patients with specific chronic low back pain conditions, particularly in situations where the treatment objective is to enhance the dynamic control and stability of the spine. For a conditioning program to be most effective, load, intensity, or duration of exercise should increase over this time period. Training programs should also be specific to the demands of the sport (Hetu & Faigenbaum, 1996). Specificity of training applies to endurance training as much as to strength training. These suggestions can be interpreted as an indication that the most appropriate training program would involve movement, which simulates a golf swing. Research to determine how endurance training of trunk muscles in persons with CLBP affects performance and function is sparse (Moffroid, 1997).

Although there is a common belief among some experts that exercise sessions should be performed at least 3 times per week, there is some evidence that trunk exercises are most beneficial when performed daily (McGill, 1998). Selection of the appropriate number of repetitions and holding times for each exercise is based on the clinician's judgement, because at present there are no data to guide selection for these variables (McGill, 1998). More repetitions of less demanding exercises will assist in the enhancement of endurance (McGill, 1998).

Summary

Low back pain is the most common musculoskeletal problem affecting amateur and professional golfers today (McCarroll, 1996; Sugaya et al., 1999). Surveys have found a high percentage of low back pain to occur on the right side (in right-handed golfers) of professional golfers, especially during the *impact phase*. A high rate of right side osteophyte formation and facet joint degeneration has been seen in professional golfers who experience right side low back symptoms. Although the relationship between muscle insufficiency and CLBP is not clearly understood, it is believed that reduced strength and endurance of the key abdominal stabilizer muscles may contribute to the onset of low back pain. Research studies investigating muscle activity during the golf swing have found the oblique abdominal muscles to be particularly active during the *acceleration* and *impact* phases of the golf swing. High levels of abdominal muscle activity during a single golf swing combined with repetitive swings might lead to muscular fatigue over time. Individuals with CLBP in the general population are known to experience greater abdominal muscle fatigue than pain free individuals after repetitive trunk movements. Exercise programs have often been prescribed to people with CLBP as a form of rehabilitation. Endurance exercises for the abdominal muscles are believed to be more appropriate than strength exercises for rehabilitation of stabilizer muscles of the trunk. Endurance exercises may be particularly beneficial for golfers with CLBP considering the repetitive nature of the game.

CHAPTER 3: ABDOMINAL MUSCLE RECRUITMENT PATTERNS IN ELITE MALE GOLFERS WITH AND WITHOUT CHRONIC LOW BACK PAIN

Introduction

Low back pain is the most common musculoskeletal problem affecting amateur and professional golfers (McCarroll, 1996; Sugaya et al., 1999). A recent survey found 55% of professional golfers had a history of low back pain sufficient enough to cause them to miss at least one tour event or to cause an unsatisfactory level of play (Sugaya et al., 1999). Low back pain in golfers is an important issue identified by epidemiologic studies, but one that has received little scientific investigation. Watkins et al. (1996) suggest the abdominal muscles act as stabilizers of the lumbar spine during the golf swing, and speculate that muscle activity patterns, which can be detected by surface electromyographic (EMG) measurements during the golf swing, might be different in injured golfers than in uninjured golfers.

The relationship between muscle insufficiency and chronic low back pain is not clearly understood. Passive tissues (ligaments, bones, discs etc.) of the spine may suffer increasing abnormal loads leading to low back pain when muscle recruitment is inadequate or inappropriate (Roy et al., 1989; Gracovetsky et al., 1985). The key stabilizer abdominal muscles of the lumbar spine are believed to be the transverse abdominis (TrA), internal oblique (IO), and external oblique (EO) (Cresswell et al., 1992; O'Sullivan et al., 1998; McGill, 1998). Internal oblique and TrA are believed to provide an important stiffening effect on the lumbar spine thereby enhancing its dynamic stability (Aspden, 1992). These muscles are known to be primarily active in providing rotational and lateral control to the spine while maintaining levels of intra-abdominal pressure and imparting tension to the thoracolumbar fascia (Cresswell et al., 1992; Cresswell et al., 1994; O'Sullivan et al., 1997).

Dysfunction of the deep abdominal muscles, particularly TrA and IO may play a critical role in decreasing protection of the lumbar spine and might be related to the development of low back pain (Hodges & Richardson, 1996; Hodges et al., 1996). The contraction of muscles associated with movement of a limb, other than those producing the movement, are believed to contribute to the maintenance of both the position of the center of mass over the base of support and the stability of the affected joints (Hodges & Richardson, 1997). The onset time of TrA and IO muscles in individuals with chronic low back pain (CLBP) occurs after movement of the upper limbs whereas onset time of these muscles in control subjects free of low back pain occurs prior to upper limb movement (Hodges & Richardson, 1996; Hodges et al., 1996). Such studies have offered valuable insight into the function of the abdominal stabilizer muscles in general population individuals with and without low back pain.

Electromyographic and biomechanical studies on the golf swing have made significant contributions to the understanding of muscular activity patterns and forces applied to the spine during the golf swing. Pink et al. (1993) and Watkins et al. (1996) have conducted surface EMG studies of the trunk muscles during the golf swing. The right side abdominal oblique muscle was found to be particularly active during the *acceleration phase* and *impact phase* of the golf swing. The *impact phase* of the golf swing is believed to be potentially damaging to the lumbar spine with the highest rotational velocities and lateral bending angles occurring just after ball impact (Sugaya et al., 1999).

Though the development of low back pain in amateur and professional golfers has been recognized as an important issue, few studies have investigated factors associated with low back pain in these individuals. Golfers who experience CLBP may lack adequate abdominal muscle recruitment during the golf swing.

Purpose

The purpose of this study was to determine whether there were differences in the magnitude of abdominal muscle activity during the different phases of the golf swing between *elite* male golfers with and without chronic low back pain. In addition, differences in the onset time of abdominal muscle activity during the golf swing between these two populations were investigated.

Hypotheses

1. *Elite* male golfers who experience chronic low back pain will exhibit less external oblique and internal oblique muscle activity throughout the golf swing than *elite* male golfers without CLBP.

2. *Elite* male golfers who experience chronic low back pain will exhibit less internal oblique activity during the *impact phase* of the golf swing than *elite* male golfers without CLBP.

3. *Elite* male golfers who experience chronic low back pain will exhibit a delayed onset of internal oblique muscle activity during the golf swing compared to *elite* male golfers who do not experience CLBP.

Subject Inclusion Criteria

Male teaching and/or club professional golfers within the Alberta Professional Golf Association, and low handicap (<5) amateurs within the Alberta Golf Association were given the opportunity to volunteer as subjects for this study. Potential subjects were initially asked to complete a general golf questionnaire (Appendix A) regarding the location, duration, and frequency of back pain, and their playing and practicing habits. Those individuals who had "never" experienced pain in the lumbar region of their back after practicing or playing during the six months prior to completion of the questionnaire were classified as asymptomatic control subjects (AC). Those individuals who had "always" or "often" experienced pain in the lumbar region of their back after practicing or playing for longer than six months prior to completion of the questionnaire were classified as chronic low back pain subjects (CLBP). Individuals were excluded from participating in the study if they were older than 55 years of age. All subjects completed a physical activity readiness form (PAR-Q) (Appendix B) and gave their informed consent (Appendix C) prior to any testing procedures.

Methods

All testing was conducted in the Human Performance Laboratory at the University of Calgary, Calgary, Alberta, Canada. Ethics approval was granted by the Conjoint Faculties Research Ethics Committee at the University of Calgary.

Testing Procedures

The testing period consisted of a series of procedures, which were consistent for all subjects. Anthropometric (height and weight) measurements were first made followed by electrode placement on appropriate muscles. Next, a submaximal isometric contraction (double leg raise) was performed to gather muscle activity data to be used as a normalizing measure. After the double leg raise, subjects were permitted to warm-up for approximately 10 minutes to physically prepare for maximal effort shots with the driver. The warm-up consisted of sub-maximally (1/2 swings) hitting golf balls into a net with an 8 iron. Subjects were asked to warm-up in this manner until they felt ready to hit maximal effort shots with the driver. The warm-up also served as an indication of the adhesiveness of electrodes to the skin. Subjects then hit 5 maximal effort shots with the driver while video and EMG data were collected. Subjects were asked to rate each shot on a scale of 1 – 5 in terms of solid ball contact to determine which of the five shots was the best. This information was later used to select the most appropriate trial for further data analysis.

EMG Data Recording

Each subject's skin was prepared for EMG electrode placement by shaving the appropriate areas, abrading the skin with fine grade emery paper, and then cleaning the area thoroughly with an alcohol swab. Pairs of AgAgCl surface EMG electrodes (10 mm active diameter) (CONMED Corporation, Utica, New York, USA) were attached to the skin approximately 25 mm apart (center to center) along the expected muscle fiber direction of the right and left rectus abdominis (RA) (3 cm lateral to umbilicus), external oblique (EO) (15 cm lateral to umbilicus at transverse level of umbilicus), and internal oblique (IO) (below EO & just superior to the inguinal ligament). A ground electrode was placed over the left anterior superior iliac spine. Inter-electrode distance and electrode placement were consistent with procedures by McGill et al. (1996) and Juker et al. (1998). EMG signals were pre-amplified and conducted through a battery powered unit (Biovision EMG System, Wehrheim, Germany; input impedance, 10^{12} Ohms; bandwidth, 10 to 1000 Hz). Amplifiers were not more than 12 cm from electrode sites and were taped to the body to minimize movement artifact of the EMG signal. Signals were sampled at 2400 Hz per channel and processed with EVa data collection software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA).

EMG Normalizing Procedure (double leg raise)

Prior to the golf swing trials with the driver, EMG data of the three abdominal muscles were collected during a submaximal isometric contraction to normalize the EMG data during the swing. Subjects were asked to raise their feet approximately 1 cm off the floor and hold the position as steady as possible. When the subject achieved a steady isometric contraction, EMG data were collected for 10 seconds. It did not take longer than 2 seconds for any subject to achieve the steady contraction.

EMG signals from maximal voluntary isometric contractions (MVC) are commonly used for normalization procedures (Basmajian & DeLuca, 1985; Allison et al., 1993). Maximal voluntary isometric contractions for muscles of the trunk are not reproducible in either healthy (McGill, 1991) or low back pain populations (Beimborn and Morrissey, 1988). O'Sullivan et al. (1997,1998) has previously used the double leg raise to normalize EMG data in low back pain populations. Compared to MVC, submaximal contractions are believed to be a more consistent indication of muscle activation. Thus, submaximal voluntary muscle contractions may be a more appropriate tool to use as a normalization standard for subjects with back pain (Allison et al., 1993). The double leg raise is known to require activation of all the abdominal musculature to stabilize the pelvis (Basmajian and DeLuca, 1985).

Video Data Recording

Four high-speed video cameras (Falcon, 6.0 mm Computar lens, Motion Analysis Corp., Santa Rosa, CA) were used to collect information regarding club position throughout the golf swing and to determine the instant of ball impact. Video data were collected at 240 frames/sec and used to synchronize EMG data to various phases of the golf swing. Cameras were positioned in a semi-circle arrangement to the side of the subject away from the direction of ball flight to record several views of club movement for future analysis (Figure 1). Reflective markers were placed on two locations along the shaft of the driver to allow determination of specific phases of the golf swing. A 90-compression golf ball was covered with reflective tape to permit detection of the first indication of ball motion. Video data were collected with EVa data collection software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA).

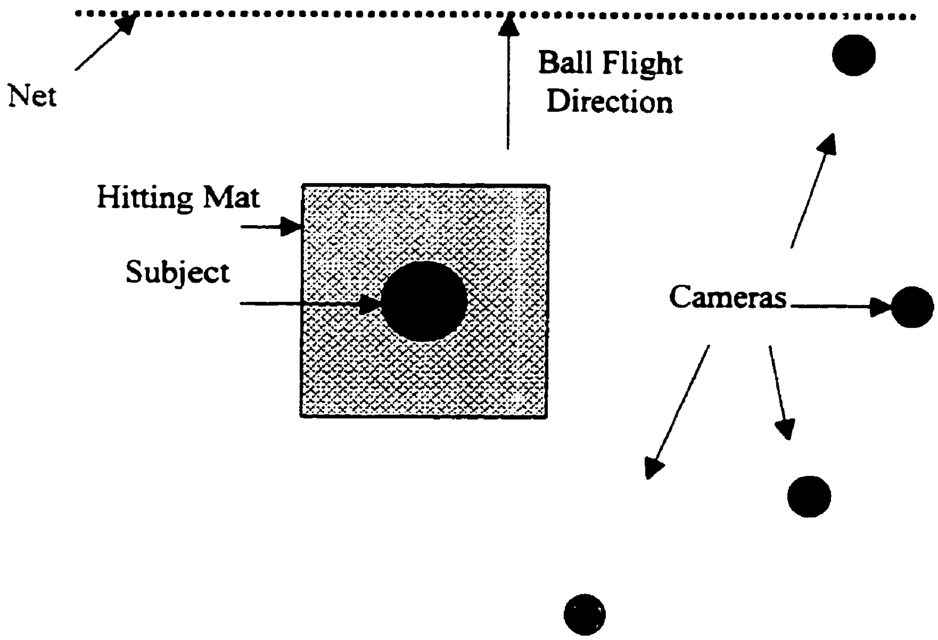

FIGURE 1. VIDEO CAMERA POSITIONING.
Illustration of video camera positioning relative to subject.

Data Analysis

Video Data Analysis

All video data were analyzed using EVa software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA). A straight line was computer generated between the two points represented by the reflective markers placed on the golf club. The video file, which combined data from all four cameras, was advanced one frame at a time to determine the exact time of golf club movement in the backswing direction, which was considered the start of the swing. The same procedure was then used to determine the time at the start of the downswing, club position horizontal to the floor in the forward swing, impact, club position horizontal to the floor on the follow through, and the finish position. The finish position was considered to be the point where the club was above the head and horizontal to the floor (Figure 2). All frame numbers were converted to milliseconds (frame # x 1000/240). This procedure allowed determination of the timing for the sequence of muscle activation and the magnitude of muscle activation for all the EMG signals. The magnitude of these EMG signals was normalized relative to the submaximal signal collected during the double leg raise as previously described.

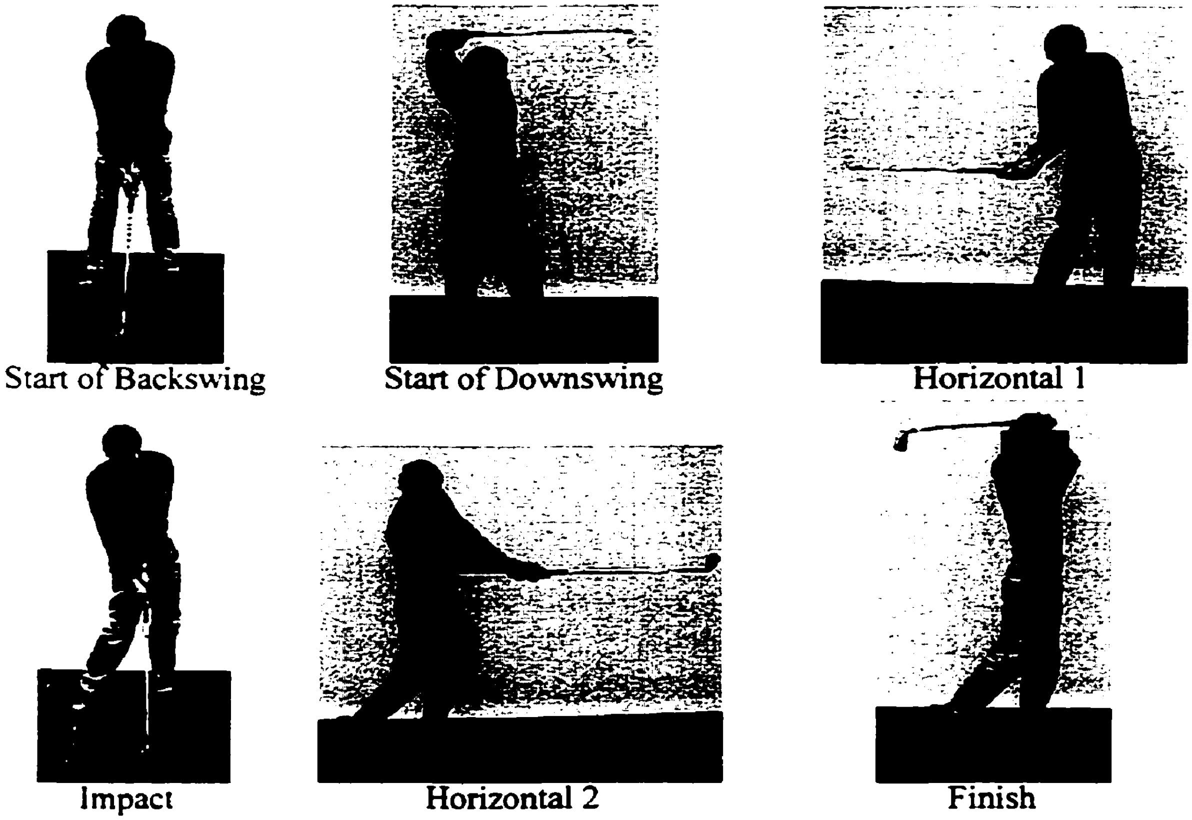

FIGURE 2. CLUB POSITIONS THROUGHOUT GOLF SWING.
Illustrations displaying different club positions throughout the golf swing.

EMG Data Analysis

All EMG data were sampled at 2400 Hz and bandpass filtered between 10 and 240 Hz (fourth order butterworth digital filter). Although EMG and video data were collected during each of the 5 shots with the driver, only one trial was chosen for EMG data analysis. The best rated shot (as indicated by the subject) was used as long as the EMG signals were free of movement artifact. If the EMG signal associated with the best rated shot appeared to be distorted with artifact, then the next best rated shot was used for data analysis.

Root Mean Square Calculation during Submaximal Isometric Contraction

Electromyographic signals of the submaximal isometric contraction (double leg raise) were analyzed in the same manner for all subjects. To avoid artifacts of the filtering process, a 2000 msec selection of each EMG signal was chosen beginning at 1000 msec and ending at 3000 msec (Figure 3). This 2-second selection was chosen because the average total duration of the golf swing for all subjects was 1474.8 ± 20.5 msec (Appendix D). Thus, it was felt that a 2000 msec sample was an adequate duration to calculate a RMS to normalize EMG signals during the swing. EMG Signals were not rectified.

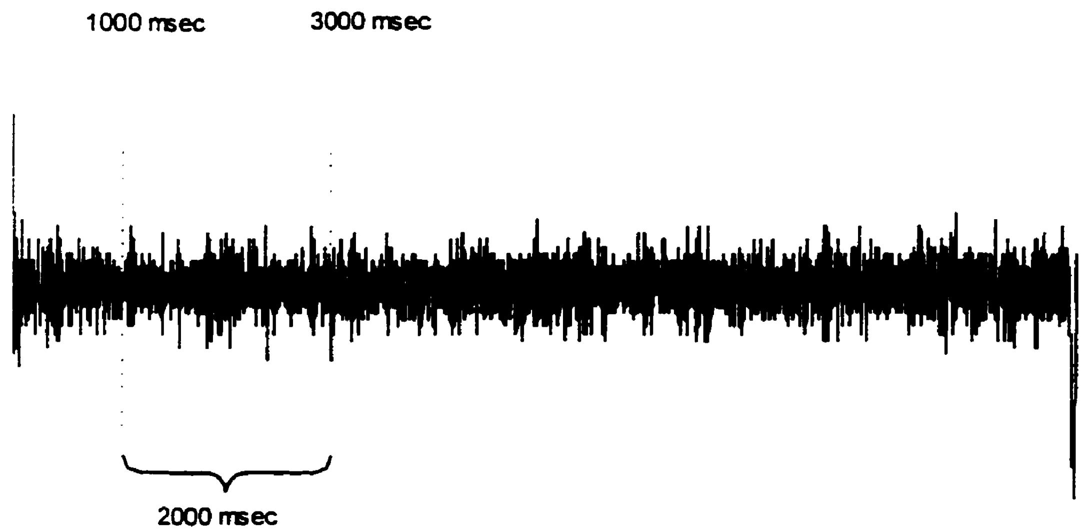

FIGURE 3. EMG NORMALIZING SIGNAL.
EMG signal recorded from a representative abdominal muscle during double leg raise. This illustration shows the time period where the RMS was calculated, which was then used as a normalizing value. The large magnitude signal at the start and end of the EMG signal is due to filtering artifact.

Root Mean Square Calculation during Different Phases of Swing

The magnitude of muscle activity during different phases of the golf swing was calculated in Kintrak (versions 5.2, University of Calgary, Calgary, Alberta, Canada). The RMS for each of the 3 phases (*phase 1*: start of back swing to start of downswing; *phase 2*: start of downswing to impact; *phase 3*: impact to finish) was calculated with results in millivolts. RMS values were also calculated during the *impact phase* (horizontal 1 to horizontal 2). Markers were manually set on EMG signals in milliseconds according to the previously determined video times (Figure 4). RMS values for each phase were averaged within AC and CLBP groups.

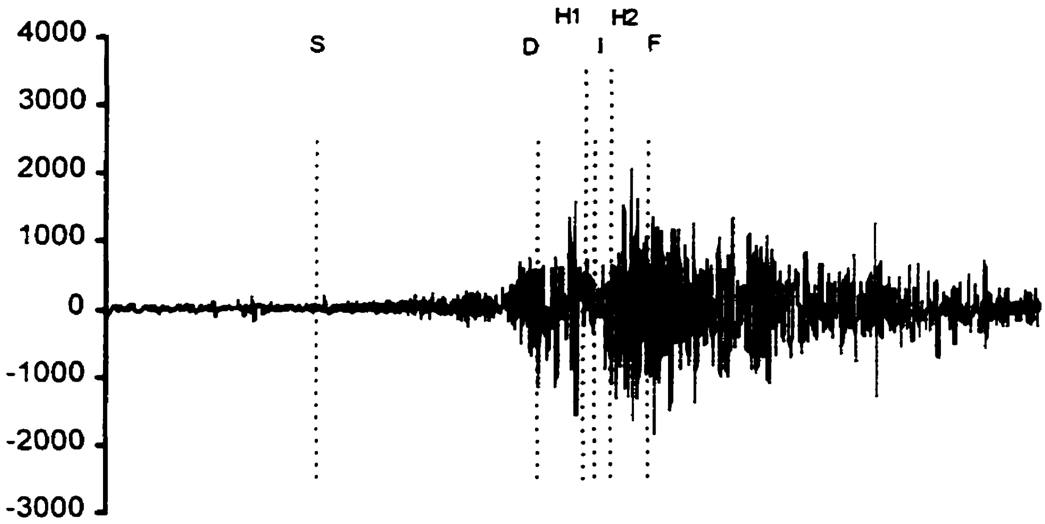

FIGURE 4. MARKER SETTINGS.
Marker settings used to calculate RMS values of various phases of the golf swing. S=start of back swing; D=start of downswing; H1=club horizontal to floor during forward swing; I=ball impact; H2=club horizontal to floor during follow-through; F=finish of swing. Duration of entire EMG signal is 4 seconds. EMG signal was recorded from EO (trail) muscle.

Onset Time of Muscle Activity during the Golf Swing.

Using non-rectified EMG signals, onset times of individual abdominal muscles were determined using Kintrak (version 5.2, 6.0, University of Calgary, Calgary, Alberta, Canada). Hodges & Richardson (1999) have identified EMG onset times as the point where the mean of the 50 subsequent samples exceeded the background level of activity by two standard deviations. This procedure was initially employed for the present data analysis, however, it failed to accurately select an appropriate onset time. This process often selected an onset time, which was apparently unrelated to the golf swing. This was probably because abdominal muscle activity varies considerably during "baseline" conditions. For this reason, the onset times of substantial abdominal muscle activity were calculated as the time when the signal exceeded 7 SD from the mean of the "quietest" muscle activity of the whole signal. Onset time was calculated as 7 SD above the mean of a 200-millisecond segment (1/20th of the whole sample) where the quietest activity in the signal occurred (Figure 5). Use of 7 SD consistently selected times when substantial EMG activity occurred (i.e. related to the golf swing). This procedure was used for all abdominal muscles and subjects.

Computer identified onset times were compared to visually selected onset times and found to accurately identify the major burst(s) of EMG activity. In addition, all identified onset times using Kintrak (version 5.2, 6.0, University of Calgary, Calgary, Alberta, Canada) were checked visually to ensure that they were in fact muscle bursts and not movement artifact or ECG signals. All onset times for each muscle were recorded and then expressed relative to specific times during the golf swing which were determined from the video data analysis.

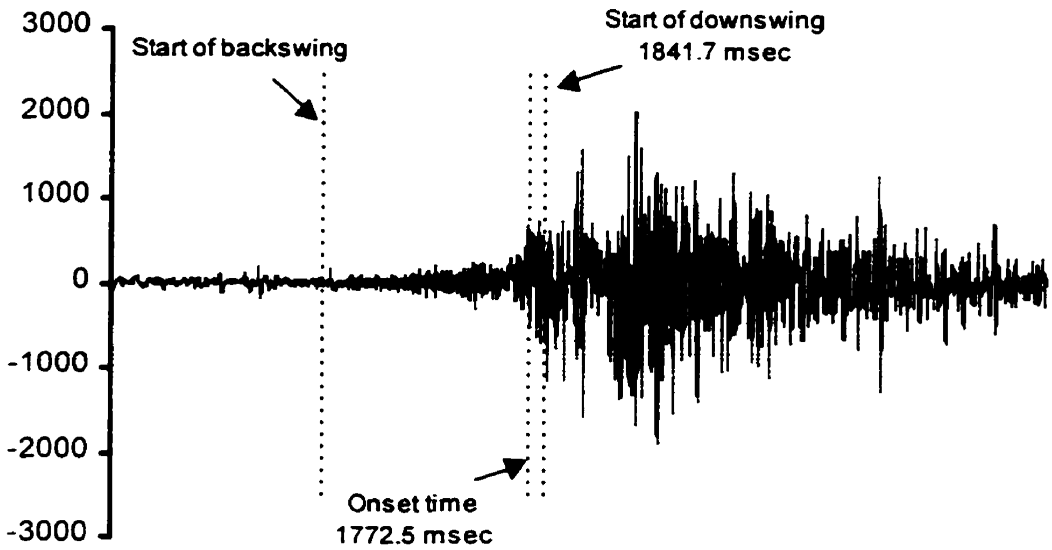

FIGURE 5. ONSET TIME SELECTION.
Example of computer program (Kintrak) calculation of muscle activity onset time. Onset time was calculated as 7 SD above the mean of a 200-msec segment (1/20th of the whole sample) where the quietest activity in the signal occurred. The entire EMG signal was 4 seconds in duration. EMG signal was recorded from EO (trail) muscle.

Statistical Analyses

All data were found to be normally distributed (Kolmogorov-Smirov Test). Statistical differences in the onset time of muscle activity between AC and CLBP subjects were determined with a one-way ANOVA. Statistical differences in magnitude of muscle activity between AC and CLBP subjects during the different phases of the golf swing were determined with a one-way ANOVA. Comparisons of abdominal activity between and within AC and CLBP individuals during the *impact phase* were performed using a two-way ANOVA with repeated measures. Data analyses were performed with the Statistical Package for the Social Sciences.

Results

The results are presented in five sections. The first section presents demographic and descriptive information. The second section presents information regarding the duration of the entire golf swing, each phase of the golf swing, and each phase as a percentage of the total duration of the golf swing. Section three presents information regarding the onset time of the major burst of muscular activity in EO and IO muscles relative to the start of the backswing and relative to the start of the downswing during a maximal effort golf swing with the driver. Section four outlines abdominal muscle activity of AC and CLBP subjects during a maximal effort golf swing with the driver. The final section presents a comparison of abdominal muscle activity between AC and CLBP subjects during the *impact phase* of a maximal effort golf swing with the driver.

Demographic and Descriptive Information

Eight AC subjects (8 professionals) (29.4 ± 2.0 years; 81.7 ± 2.4 kg; 1.8 ± 0.0 m; 25.3 ± 0.6 BMI; Mean ± SEM), and 17 CLBP subjects (10 professionals, 7 amateurs) (36.1 ± 2.7 years; 81.8 ± 2.2 kg; 1.8 ± 0.0 m; 25.4 ± 0.6 BMI) participated in this study. Asymptomatic control subjects ranged from 20 to 39 years of age, while CLBP subjects ranged from 17 to 55 years of age. Three CLBP subjects were older than 50 years of age. Chronic low back pain subjects were individuals who had always experienced low back pain in the lumbar region of their back after playing or practicing for longer than six months prior to completion of the general golf questionnaire (Appendix A). The majority of CLBP subjects experienced low back pain either on the right side of the body or on both sides (Table 1). The CLBP subjects were individuals who had experienced low back pain for some time and continued to play golf regardless of their condition. Chronic low back pain subjects were, therefore, not asked to incur pain they would not have normally imposed on themselves.

TABLE 1. LOCATION OF LOW BACK PAIN OF CLBP SUBJECTS.

	Left	Center	Right	Both sides
# of responses	2	3	6	6
%	12	18	35	35

Duration of Entire Golf Swing and Phase Times

The duration of the entire golf swing for all subjects was determined from video data in milliseconds. Total duration of *phase 1*, *phase 2*, *phase 3* and *impact phase* was also determined for all subjects. Mean values for total duration of the golf swing and each phase are presented in Table 2. Each phase is also presented as a percentage of the total duration of the golf swing (Figure 6).

TABLE 2. DURATION OF GOLF SWING FOR AC AND CLBP SUBJECTS.
Mean duration of entire golf swing and mean duration of each phase of the golf swing for both AC and CLBP subjects.

Total duration	Phase 1	Phase 2	Phase 3	Impact phase
1474.8 ± 20.5	918.2 ± 16.7	279.6 ± 4.2	277.1 ± 6.5	109.4 ± 1.4

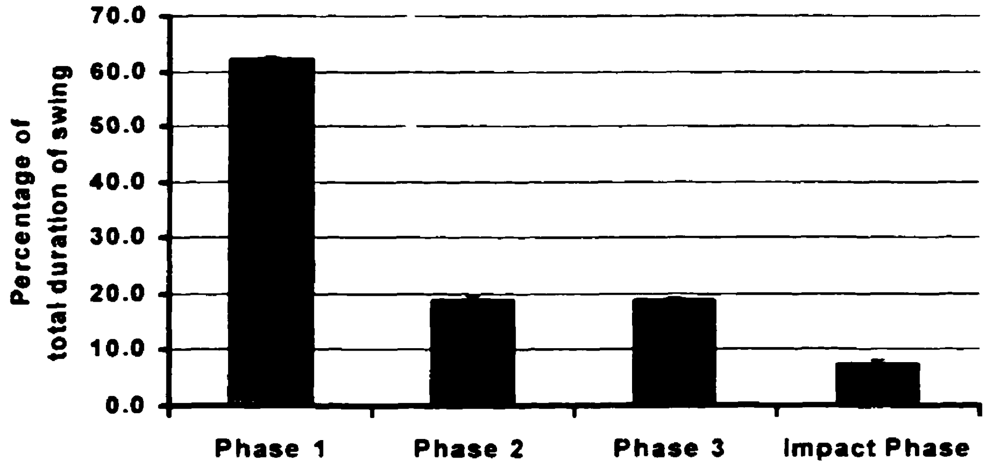

FIGURE 6. PHASES REPRESENTED AS A PERCENTAGE OF TOTAL DURATION OF GOLF SWING. *Phase 1* is the time between the start of the backswing movement and the start of the downswing movement; *phase 2* is the time between the start of the downswing movement and ball impact; *phase 3* is the time between ball impact and finish of the golf swing; and *impact phase* is the time between *horizontal 1* and *horizontal 2* club positions, and overlaps *phase 2* and *phase 3*.

Abdominal Muscle Activity Onset Times during the Swing

Only the EO and IO muscles were chosen to illustrate onset times during the golf swing, as they are the muscles considered most important as prime mover and stabilizer abdominal muscles during the golf swing. Significant differences were found between AC and CLBP individuals in EO (lead) muscle activity onset time relative to the start of the backswing (p=0.045) (Figure 7). Significant differences were also found between AC and CLBP individuals in IO (lead) muscle activity onset time relative to the start of the downswing (p=0.033) (Figure 8). No significant differences were found between AC and CLBP subjects in IO (trail) muscle activity onset time relative to the start of the backswing (p=0.914) (Figure 9). No significant differences were found between AC and CLBP subjects in EO (trail) muscle activity onset time relative to the start of the downswing (p=0.740) (Figure 10).

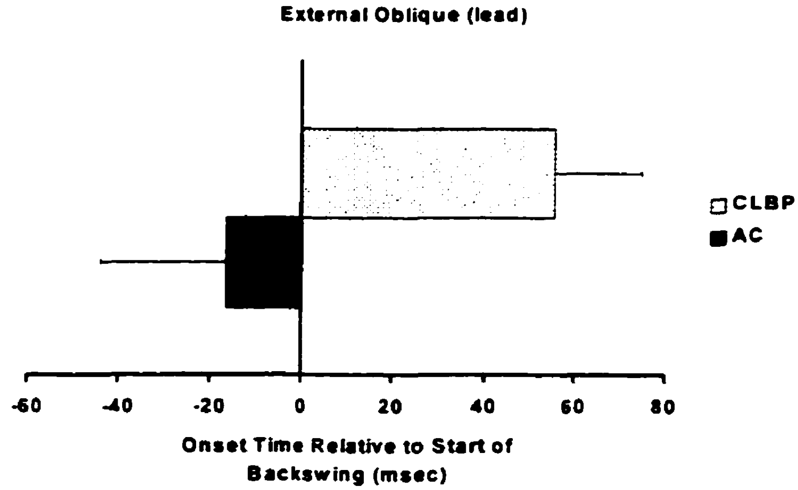

FIGURE 7. EXTERNAL OBLIQUE (LEAD) ONSET TIMES.
External oblique (lead) muscle activity onset times for AC and CLBP subjects.
Onset times are presented in milliseconds (± SEM) relative to the first movement of the golf club in the backswing direction. Significant differences were found between AC and CLBP subjects ($p<0.05$).

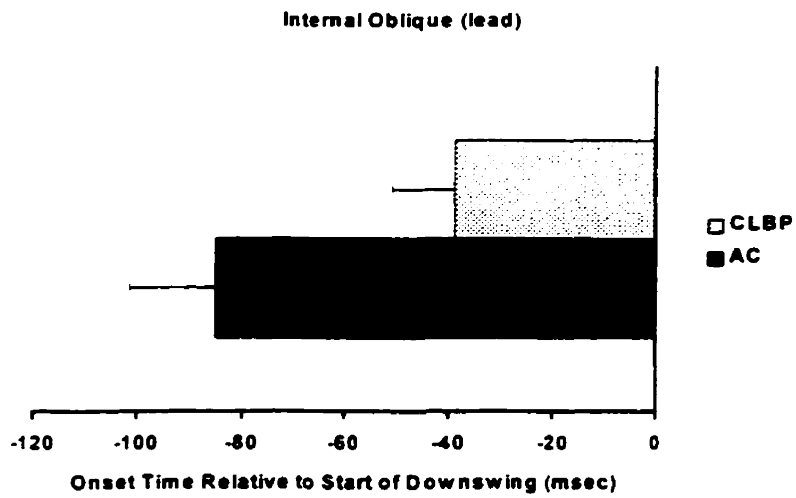

FIGURE 8. INTERNAL OBLIQUE (LEAD) ONSET TIMES.
Internal oblique (lead) muscle activity onset times for AC and CLBP subjects.
Onset times are presented in milliseconds (± SEM) relative to the first movement of the golf club in the downswing direction. Significant differences were found between AC and CLBP subjects ($p<0.05$).

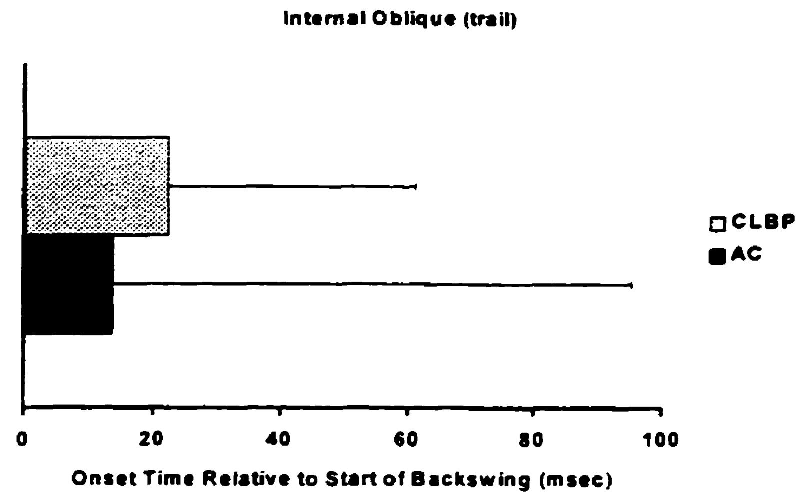

FIGURE 9. INTERNAL OBLIQUE (TRAIL) ONSET TIMES.
Internal oblique (trail) muscle activity onset times for AC and CLBP subjects. Onset times are presented in milliseconds (± SEM) relative to the first movement of the golf club in the backswing direction. No significant differences were found between AC and CLBP subjects (p=0.914).

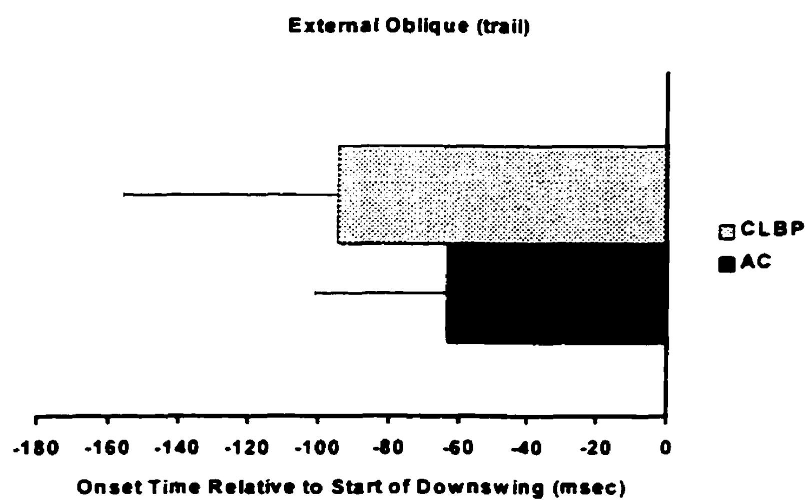

FIGURE 10. EXTERNAL OBLIQUE (TRAIL) ONSET TIMES.
External oblique (trail) muscle activity onset times for AC and CLBP subjects. Onset times are presented in milliseconds (± SEM) relative to the first movement of the golf club in the downswing direction. No significant differences were found between AC and CLBP subjects (p=0.740).

Abdominal Muscle Activity during the Golf Swing

Normalized EMG activity of all abdominal muscles is presented using the same scale for ease of comparison (Figure 11). Similar patterns of abdominal muscle activity were found in AC and CLBP subjects. No significant differences in RMS were observed between AC and CLBP subjects in any abdominal muscle measured in this study with respect to the different phases of the golf swing (p-values ranged from 0.657 to 0.970). All abdominal muscles, with the exception of EO (lead) displayed the same pattern of relative EMG activity during the golf swing. The pattern of muscle activity typically involved an increase in activity from *phase 1* to *phase 2* followed by a decrease in activity to *phase 3*.

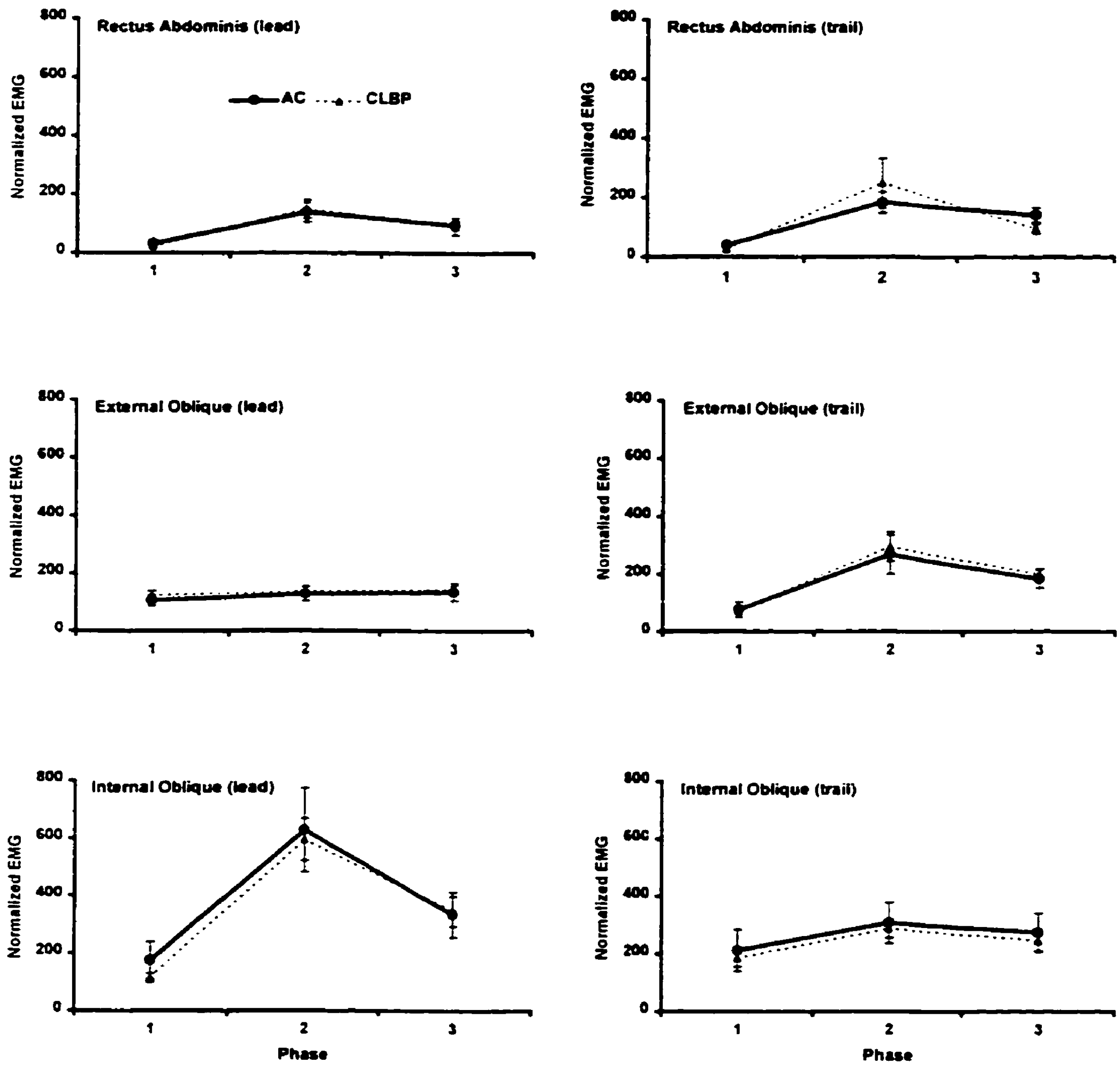

FIGURE 11. ABDOMINAL MUSCLE ACTIVITY DURING THE GOLF SWING.
Abdominal muscle EMG activity throughout the golf swing for AC and CLBP subjects. *Phase 1* = start of backswing – start of downswing; *phase 2* = start of downswing – impact; *phase 3* = impact – finish. Magnitude of activity is expressed as percent of submaximal (double leg raise) RMS.

EMG signals of abdominal muscle activity of one subject during the golf swing further illustrates the pattern of abdominal muscle activity during the golf swing (Figure 12). These EMG signals also show the relationship between opposing muscles during the golf swing. EO (lead) clearly exhibits a distinct burst of activity during *phase 1*, while EO (trail) muscle is relatively inactive during *phase 1*. EO (trail) becomes much more active just prior to the start of *phase 2*. EO (trail) and IO (lead) muscles display similar onset times during the golf swing.

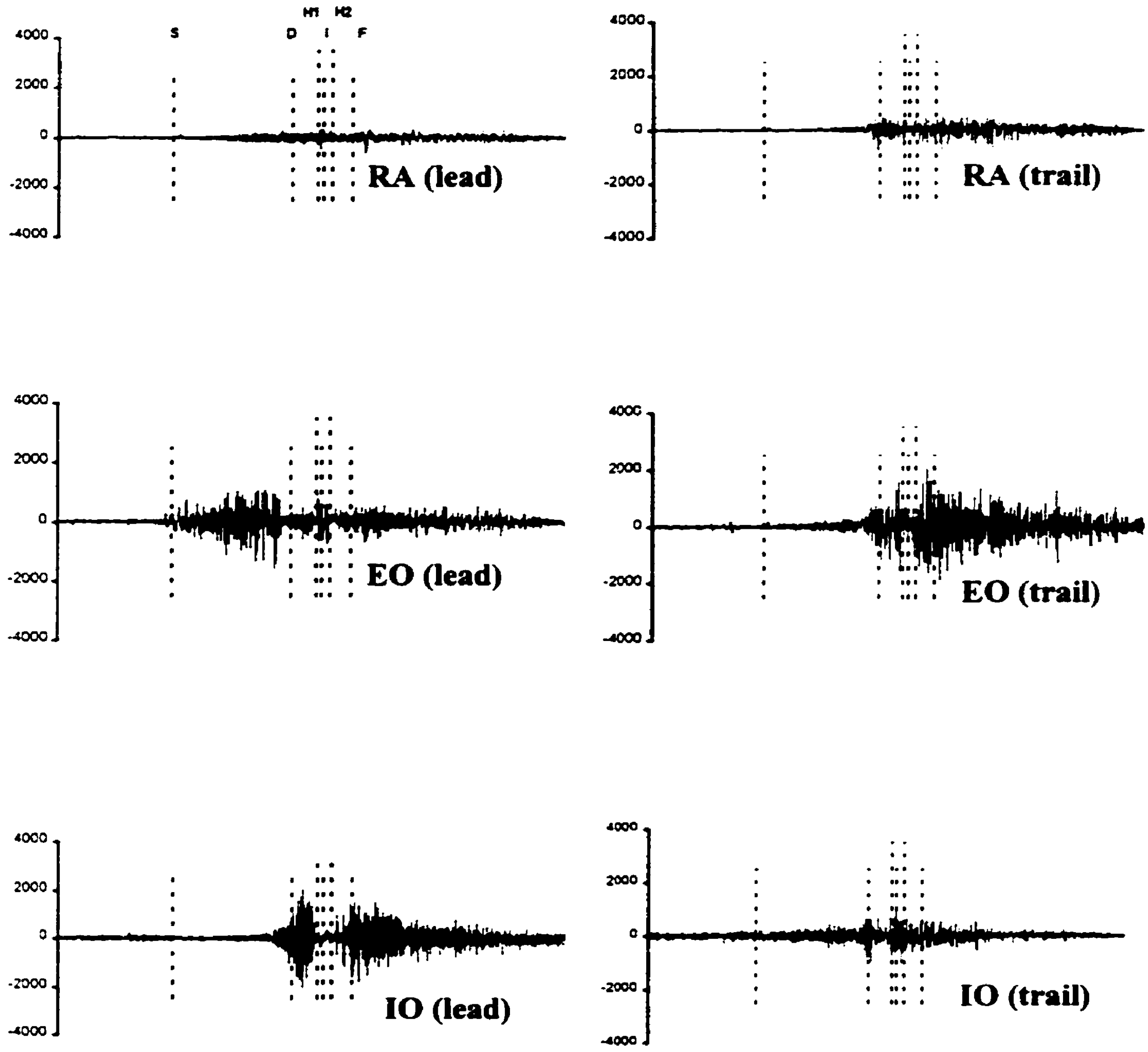

FIGURE 12. EMG SIGNALS DURING THE GOLF SWING.
EMG signals of abdominal muscle activity from one subject during the golf swing. S = start of backswing; D = start of downswing; H1 = club position horizontal to the floor; I = ball impact; H2 = club position horizontal to the floor; F = finish.

Abdominal Muscle Activity during Impact Phase

No significant differences were found in RA, EO, and IO abdominal muscle activity during the *impact phase* between AC and CLBP subjects ($p>0.05$) (Figure 13).

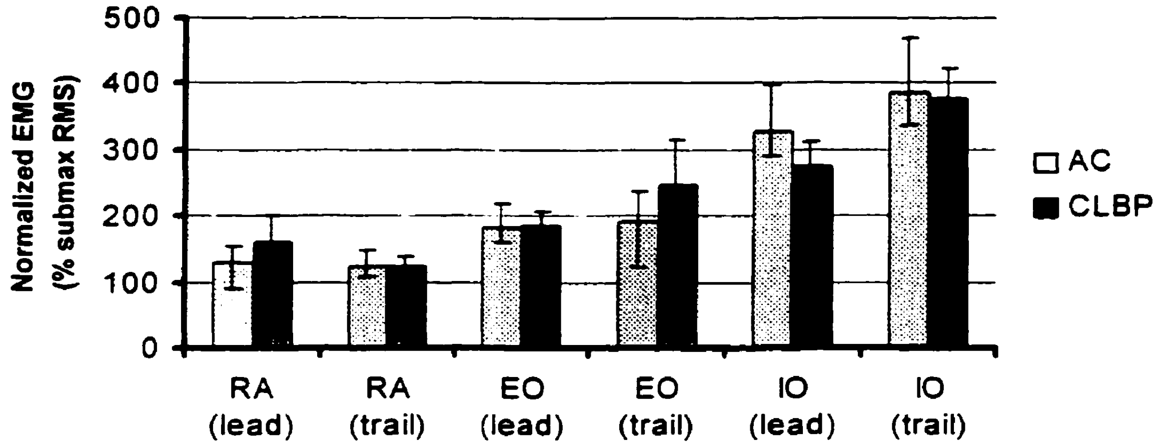

FIGURE 13. ABDOMINAL MUSCLE ACTIVITY DURING THE *IMPACT PHASE*.
Abdominal muscle activity in AC and CLBP subjects during *impact phase* of the golf swing. *Impact phase* represents the time between Horizontal 1 and Horizontal 2 club positions.

Discussion

The purpose of this study was to determine whether there were differences in the magnitude of abdominal muscle activity during the different phases of the golf swing between *elite* male golfers with and without chronic low back pain. Differences in the onset time of abdominal muscle activity during the golf swing between these two populations were also investigated.

Abdominal Muscle Activity Onset Times during the Golf Swing

The results of this study support the hypothesis that *elite* male golfers with CLBP exhibit a delayed onset of IO muscle activity compared to AC subjects. Significant differences in IO (lead) onset times relative to the start of the downswing were found between AC and CLBP subjects ($p=0.033$). Significant differences in EO (lead) onset times were also found between AC and CLBP subjects relative to the start of the backswing ($p=0.045$).

Considering the findings of Hodges & Richardson (1997, 1999a, 1999b) it was deemed necessary to investigate muscle activity onset times during the golf swing to determine a possible relationship with elite male golfers suffering from CLBP. Hodges & Richardson (1997) found TrA to contract before all other trunk muscles during upper limb movement. Transverse abdominis also contracted before the prime mover responsible for the initiation of the limb movement. This muscle was, therefore, considered to be particularly important as a stabilizer of the lumbar spine. Internal oblique was the second trunk muscle to contract during upper limb movement. Hodges & Richardson (1999a) determined the contractions of TrA and IO are delayed in subjects with low back pain and absent from the period preceding the onset of upper limb movement. Rapid movement of the arm or leg is associated with contraction of the abdominal muscles prior to or shortly after contraction of the muscles responsible for initiation of the limb movement (Hodges & Richardson, 1999b). This anticipatory contraction of the abdominal muscles is thought to contribute to preparatory stabilization of the spine against reactive forces resulting from the limb movement (Hodges & Richardson, 1999b).

Hodges & Richardson (1999a) found TrA, IO, and EO onset times to be –39 msec, 28 msec, and 58 msec respectively relative to onset time of the deltoid in non low back pain subjects. Onset times of TrA, IO, and EO relative to onset time of the deltoid were 125 msec, 82 msec, and 103 respectively for low back pain subjects (Hodges & Richardson, 1999a). Differences in TrA, IO, and EO onset times between non low back pain and low back pain subjects were 164 msec, 54 msec, and 45 msec respectively.

Such findings can be applied to the golf swing in relation to the start of the backswing movement and the initiation of the downswing movement. IO (lead) muscle activity onset times relative to the start of backswing and relative to the start of the downswing might be of particular importance in *elite* male golfers with CLBP. Onset times in the present study were expressed relative to the beginning of club motion in a certain direction rather than relative to activation of another muscle as in Hodges & Richardson's studies. No direct comparisons can be made because of this. However, differences in onset times between control subjects and CLBP subjects in the present study and Hodges & Richardson (1999a) may be compared. Significant differences of onset times between AC and CLBP subjects in the present study are similar to findings of Hodges & Richardson (1999a). The difference in EO (lead) onset time between AC and

CLBP subjects relative to the start of the backswing was 72.1 msec, while the difference in IO (lead) onset time between the same subjects relative to the start of the downswing was 46.1 msec.

It was anticipated that IO muscles, acting as stabilizers during limb movement, would contract prior to movement of the golf club in the backswing direction in AC subjects and after movement of the golf club in the backswing direction in CLBP subjects. Onset time of IO (trail) did not occur prior to the start of the backswing movement on average in AC subjects. Large variations in onset times within this group may have influenced the results though. Five out of the eight AC subjects did exhibit onset times prior to the start of the backswing motion (Appendix E). Large "outliers" within this data certainly affected results. For example, eliminating a large "outlier" from data analysis resulted in a mean value of –62.6 msec for IO (trail) relative to the start of the backswing. The non-significant findings of differences between groups in IO (trail) onset time relative to the start of the backswing, and EO (trail) onset time relative to the start of the downswing may also be due to the large variations in onset times between subjects (Appendix E).

Although AC and CLBP subjects both exhibited IO (lead) onset times prior to the movement of the golf club in the downswing, CLBP subjects significantly lagged behind AC subjects (p=0.033). As a stabilizer of the lumbar spine, contraction of IO (lead) may be particularly important during preparation of the downswing movement of the golf swing.

Abdominal Muscle Activity during the Golf Swing

The results of this study do not support the hypothesis that *elite* male golfers with CLBP exhibit lower EO and IO muscle activity than AC subjects during a maximal effort golf swing with the driver. Though the hypothesis was not supported in this case, there are valuable findings regarding abdominal muscle activity in *elite* male golfers with and without low back pain that can be applied to future studies.

Only two studies have used EMG to investigate trunk muscle activity patterns in male amateur and professional golfers (Pink et al., 1993; Watkins et al., 1996). Pink et al. (1993) were the first to investigate trunk muscle activity during the golf swing in amateur golfers, while Watkins et al. (1996) conducted a similar study with professional golfers. Both studies concluded that the abdominal muscles are very active during the golf swing, especially *trail side* muscles during, what they considered, the *forward swing*, *acceleration*, and *early follow-through* phases. Watkins et al. (1996) believe the trunk muscles are important as stabilizers of the lumbar spine during the golf swing and speculated that trunk muscle activity patterns might be different in injured golfers than in uninjured golfers. Pink et al. (1993) concluded that the next logical step would be to determine which exercises are the most effective in preventing and rehabilitating back injuries in golfers.

These studies have made an important contribution to scientific study of trunk muscle activity during the golf swing, however, it seemed the next logical step should be to first investigate the abdominal muscle activity patterns in golfers with and without low back pain before exploring exercise programs. There are some issues that should be addressed before comparisons can be made with the present study.

Both of these studies divided the golf swing into 5 different phases: *takeaway*, *forward swing*, *acceleration*, *early follow-through*, and *late follow-through*. This method of dividing the golf swing into 5 different phases was initially used during data analysis in the present study. It was concluded that *forward swing*, *acceleration*, and *early follow-through* phases were very short in duration, and might influence RMS calculation. The duration of the golf swing during the *acceleration phase* (horizontal 1 to impact) averaged approximately 46 msec in the present study, while the duration of golf swing during the *early follow-through* (impact to horizontal 2) averaged approximately 63 msec. An example of the small segment of these phases is shown in Figure 4. These phases of the golf swing were found to be a very small segment of the total EMG signal compared to other phases. A small segment used to calculate a RMS is more susceptible to fluctuations in the EMG signal resulting in large variability of RMS values. Larger segments are more robust and preferred for RMS calculation. For these reasons the golf swing was divided into only 3 different phases as described earlier in this paper.

Pink et al. (1993) and Watkins et al. (1996) collected EMG data on abdominal oblique muscles, but it is not clear which abdominal oblique muscle was recorded, as these authors did not describe electrode placement. It seems likely that EMG data were collected from EO muscles since it is easier to determine electrode placement on these muscles compared to IO. Under this assumption, comparisons can be made with EO activity in the present study. Findings from Pink et al. (1993) and Watkins et al. (1996)

showed that the *trail side* abdominal oblique muscle was more active than the *lead side* abdominal oblique muscle during, what they consider, the *forward swing*, *acceleration*, and *early follow-through* phases of the golf swing. Though the present study divided the golf swing into 3 phases, similar findings support the work by Pink et al. (1993) and Watkins et al. (1996) indicating differences between EO (lead) and EO (trail) muscle activity. *Phase 2* in the present study is essentially the same as the *forward swing* and *acceleration* phases combined. All abdominal muscles, except EO (lead), showed higher activation (relative to submaximal activation) during *phase 2* than in *phase 1* or *phase 3*.

Since EO and IO muscles have distinctly different origins and insertions, fiber orientations, and functions, it is important to distinguish between the two. Other researchers (Juker et al., 1998) have recently collected independent muscle activity data from IO and EO using surface EMG. The same electrode placement was employed in the present study as that described by Juker et al. (1998). Pink et al. (1993) do acknowledge in their paper that the surface EMG signal could not be determined as coming from EO or IO muscles due to the likelihood of cross-talk between these two muscles. The present study showed it is possible to measure EO and IO muscles independently during the golf swing. This can be seen in Figure 12 where it is clear that EO (lead) and IO (lead) EMG signals are distinctly different. One would expect the two signals to be similar if the two different sets of electrodes were monitoring activity from the same muscle. Although there is always concern of "cross-talk" between muscles when using surface EMG, distinctly different EMG signals from EO and IO muscles were found in the present study which suggests limited amount of cross-talk (Figure 12).

Sample EMG signals of the abdominal muscles investigated in the present study, show a major burst of activity from the EO (lead) muscle during *phase 1* of the golf swing (Figure 12). This burst of activity suggests EO (lead) muscle is contributing most (of the abdominal muscles) to initiation of movement of the club in the backswing direction. External oblique (trail) muscle is relatively inactive during *phase 1* but becomes considerably more active near the start of *phase 2* indicating its involvement in the initiation of the downswing motion and possible contribution in acceleration of the golf club. Internal oblique (lead) muscle is relatively inactive during *phase 1*, but displays a large burst of activity during *phase 2* (Figure 12). Bursts of IO (lead) muscle activity combined with averaged normalized RMS values during different phases of the golf swing suggest that IO (lead) is particularly involved during the downswing movement. Internal oblique (lead) and EO (trail) muscles appear to have similar onset times (Figure 12). External oblique (trail) is believed to be contributing to the initiation of the downswing movement. Similar onset of IO (lead) muscle activity might be in an effort to assist stabilization of the lumbar spine. Internal oblique (lead) might be important in resisting right side lateral bending of the lumbar spine during the downswing movement and through impact. Given the role of IO as a stabilizer for the lumbar spine (Hodges & Richardson, 1996; Hodges et al., 1996; O'Sullivan et al., 1997), it would be worthwhile to investigate the behavior of this particular muscle in future studies.

Abdominal Muscle Activity during Impact Phase

The results of this study do not support the hypothesis that CLBP subjects exhibit less IO muscle activity than AC subjects during the *impact phase* of the golf swing.

Sugaya et al. (1999) recently reported the highest rotational velocities and lateral bending angles occur just after ball impact and suggest the *impact phase* of the golf swing may be potentially damaging to the lumbar spine. This study also revealed that 51% of golfers with low back pain reported right side low back symptoms (28% left side, 21% central or no laterality), and those reporting right side low back pain experienced aggravation of symptoms during the *impact phase* of the swing. In addition, Sugaya et al. (1999) performed a radiographic study on 10 *elite* male amateur golfers and 16 professional golfers (14 male). X-ray and CT changes showed that those golfers with right-sided low back symptoms exhibited a significantly higher incidence of right side osteophyte formation as well as right-sided degenerative changes at the facet joints, than control subjects. This was the first study to report the location of low back pain in professional golfers and the first to quantify structural changes to the lumbar spine, specifically on the right side. Findings from the current study showed 35% of subjects experience low back pain on the right side, and 35% of subjects experience low back pain on both right side and left side. Sugaya et al. (1999) did not examine muscle activity during the complete golf swing or impact phase. Considering the above it was particularly important to assess muscle activity in the abdominal muscles during this phase of the golf swing.

Others have indicated that the deep abdominal muscles undergo changes in their functional performance in populations with chronic low back pain (Hodges & Richardson, 1996; Hodges et al., 1996; O'Sullivan et al., 1997). Findings by Sugaya et al. (1999) regarding lateral bending of the lumbar spine during the *impact phase* indicate that muscles on the lead side of the trunk may be in a stretched position. Internal oblique and TrA might be particularly important during this phase as stabilizers to help resist such lateral bending.

Measurement of muscle activity in TrA requires the use of fine wire EMG techniques. This technique may be suitable for studies similar to Hodges et al. (1996) where only limb movement is involved. However, use of fine wire EMG to measure TrA function during the present study was impractical and potentially dangerous considering the rapid movements involved during the golf swing. McGill et al. (1996) have determined that surface EMG may be used to estimate function of deep abdominal and back muscles. Internal oblique can be measured just superior to the inguinal ligament where overlying fibres of external oblique are not present (McGill et al., 1996). McGill et al. (1996) concluded that IO and TrA RMS measured with fine wire electrodes were compatible if willing to accept errors in amplitude of 10-15% of MVC (McGill et al., 1996). This suggests that surface electrode measures of IO activity could be used to predict TrA activity during dynamic movements such as the golf swing. Though TrA activity could not be measured in the present study, it is expected that TrA would behave in a similar fashion to IO. Even with the errors associated with predicting EMG amplitudes of deeper muscles, the liabilities of alternative approaches appears to suggest that this is the best approach to investigate muscle function and injury mechanisms of the individual (McGill et al., 1996).

Limitations

A major limitation of this study is the lack of statistical power due to a small sample size. Post hoc sample size calculations were made based on pre and post practice results on 17 subjects. Since several muscles were being measured, a sample size calculation was performed for MF for each muscle. These results indicated a range between 93 and 296 subjects were needed for 80% statistical power of the various muscles for time effect, 8 to 68 subjects to detect a group effect and 21 to 152 subjects for a group by time intervention. Achieving these numbers was not realistic. Every effort was made, however, to recruit as many subjects as possible for this study. Differences between groups could have been detected for some of the muscles.

Surface EMG provides information, within certain limitations, about the neural drive to various components of the musculature (McGill, 1991). Surface EMG is convenient, however, there are certain limitations which should be noted. Surface electrodes may be used effectively only with superficial muscles and cannot be used to detect signals selectively from small muscles (Basmajian & DeLuca, 1985). When using surface electrodes there is always a concern of picking up signals from underlying or adjacent muscles ("cross-talk"). These limitations are often outweighed by the advantages of surface EMG. Surface electrodes are convenient to use, acceptable when the time of activation and the magnitude of the signal contain the required information, and when indwelling electrodes are impractical due to rapid movements (Basmajian & DeLuca, 1985). Variables that influence the detected EMG signal are thickness of the skin, subcutaneous fat, the bulk of the muscle, the proximity of the other muscles (cross-talk) (Basmajian & DeLuca, 1985). Another important limitation of using EMG is direct comparison of absolute values between one subject and another or between one muscle and another cannot be made (Gilmore & Meyers, 1983). The tissue environment is quite variable between subjects thus direct comparison of absolute values is not feasible.

Surface EMG is considered to be a reasonably reliable measure as long as the absolute values are normalized to a known reference. The reliability of EMG measurements of a given muscle is greater during a single testing session when electrodes have remained securely attached to the skin. Determining electrical impedance at the beginning and end of a testing session is commonly performed to insure consistent signals. It is also important to ensure electrodes remain securely attached to the skin throughout testing procedures. Minimal change in electrical impedance was noted at the end of the testing session for all subjects and every effort was made to ensure electrodes remained securely attached to the skin.

Maximal voluntary contractions have been used as a normalizing protocol in many studies. There are problems though in measuring the MVC and interpreting what it means. Does a MVC represent maximum force or maximum activation? Because of the inhibitory feedback of the golgi tendon organs, it is not possible for an individual to recruit all motor units at their maximum firing rates (Winter, 1996). The MVC should therefore be considered the maximum value that a subject can voluntarily generate during an isometric contraction with inhibitory feedback present (Winter, 1996).

In retrospect, it may have been more appropriate to measure muscle activity from the deltoid muscle such as Hodges & Richardson (1997, 1999a, 1999b) to reference abdominal muscle activity to, rather than to club movement. Selection of the exact time of initiation of golf club movement may influence onset time results. It is felt the selection of initiation of club movement was accurate though. The frame number of video data where the beginning of club movement occurred was noted and then converted to milliseconds. One frame of video data (collected at 240 frames/sec) is equivalent to 4.17 msec. Even if the selection of initiation of club movement was off by one video frame, this would account for a small source of error considering the small percentage of time this is relative to the total duration of the golf swing.

Conclusions

This study was the first to compare abdominal muscle activity in *elite* male golfers with and without chronic low back pain. Although differences in abdominal muscle activity during the golf swing and *impact phase* were not seen between AC and CLBP individuals, valuable information can be drawn from this study. The present study supports the work of Pink et al. (1993) and Watkins et al. (1996) indicating an increase in abdominal muscle activity during the downswing movement and through ball impact. It was shown that EO and IO muscle activity during the golf swing can be independently measured. These two muscles were found to have distinctly different onset times indicating discrete functions during the golf swing. It is important to measure these two muscles separately in future studies. Obtaining EMG data from the IO muscles permits predictions regarding TrA muscle activity during the golf swing. These two muscles are believed to be important stabilizers of the lumbar spine and should be investigated further in golfers with CLBP. Significant differences in IO (lead) and EO (lead) muscle activity onset times between AC and CLBP subjects may suggest inappropriate recruitment of these abdominal muscles in CLBP subjects with respect to movement of the extremities at specific instants of the golf swing. Since this is the first study to determine abdominal muscle activity onset times during the golf swing, further studies are needed to determine what onset times in milliseconds really mean, and if onset times are deviating from the norm. Because there is no support from previous data, it is not known if a difference of 50 msec or 100 msec is meaningful. A database of abdominal muscle activity onset times of amateur and professional golfers is obviously needed. Because EMG measurements were made on subjects who had existing chronic low back pain, it cannot be concluded whether differences in abdominal muscle activity between AC and CLBP subjects are a result of the pain. A prospective long-term study would be necessary to determine if abdominal muscle activity is affected by or contribute to onset of pain.

CHAPTER 4: ABDOMINAL MUSCLE FATIGUE AND RECRUITMENT PATTERNS IN ELITE MALE GOLFERS WITH AND WITHOUT CHRONIC LOW BACK PAIN FOLLOWING A TYPICAL PRACTICE SESSION

Introduction

Low back pain is the most common musculoskeletal problem affecting amateur and professional golfers (McCarroll, 1996; Sugaya et al., 1999). Although little is known about the exact causes of low back pain among golfers, development of such pain in amateur golfers is anecdotally attributed to poor swing mechanics, excessive practice, and poor physical conditioning (McCarroll et al., 1990; Hosea & Gatt, 1996; Mallare, 1996). Altered swing mechanics combined with overuse may create repetitive abnormal stresses on the lumbar spine which might lead to injury and pain (Batt, 1993; Mackey, 1995; Sugaya et al., 1999). Professional golfers tend to exhibit more consistent swing mechanics than amateurs, however, they may display poor physical conditioning to the same extent as amateurs. A lack of conditioning in the abdominal muscles might lead to muscular fatigue over time and thus play an important role in the development of low back pain in amateur and professional golfers (Mallare, 1996).

During 18 holes or a typical practice session, repetitive swings may cause muscular fatigue to develop, particularly in the abdominal muscles. Oblique abdominal muscles are known to be active throughout the golf swing especially during the *acceleration phase* and *impact phase* (Pink et al., 1993; Watkins et al., 1996). The *impact phase* of the golf swing is believed to be potentially damaging to the lumbar spine with the highest rotational velocities and lateral bending angles occurring just after ball impact (Sugaya et al., 1999). High levels of abdominal oblique muscle activity during the golf swing may cause muscular fatigue over time, particularly in unconditioned individuals, and perhaps increase the likelihood of injury (Mallare, 1996).

Isokinetic dynamometers have been primarily used to assess trunk muscle fatigue of individuals in the general population. Abdominal muscles are known to fatigue more easily than low back muscles. Furthermore, abdominal muscles in individuals with low back pain fatigue faster than in control subjects (Suzuki & Endo, 1983). Parnianpour et al. (1988) reported that fatigued muscles were slower and took longer to accommodate changes in load. Several studies have also used surface electromyography (EMG) to assess trunk muscle fatigue (Roy et al., 1990; Moffroid et al., 1993; Moffroid et al., 1994; Mannion & Dolan, 1994; Roy et al., 1995; Moffroid, 1997; Oddsson et al., 1997; Peach & McGill, 1998). A shift in the median frequency (MF) of the power spectrum of an EMG signal to lower frequencies during isometric contractions has been shown to be associated with muscular fatigue (Roy et al., 1995). Increase of the root mean square (RMS) of the EMG signal during a sustained submaximal isometric contraction is also an indication of muscular fatigue.

It is also suggested that alterations in trunk movement patterns occur as a result of muscular fatigue (Sparto et al., 1997). The proximal trunk muscles, especially the oblique abdominals, are those which most often tend to fatigue. This pattern of weakening of the prime stabilizing muscles is particularly relevant if the type of movement performed involves rapid repetitive movement of the extremities (Richardson et al., 1992). Considering the nature of the golf swing, these issues may increase the likelihood of developing low back pain.

Though a possible relationship between fatigued abdominal muscles and chronic low back pain has been put forth in the general population, no study has investigated abdominal muscle fatigue in elite male golfers with and without chronic low back pain (CLBP) following repetitive swings. Considering the repetitive nature of the sport of golf and the prevalence of low back pain among amateur and professional golfers it was important to investigate the possible association of fatigued abdominal muscles and low back pain. Furthermore, no study has examined the effects of repetitive golf swings on muscle activity patterns and muscle activity onset times during the golf swing in *elite* male golfers with and without CLBP. Development of abdominal muscle fatigue in *elite* golfers with CLBP during a practice session might be related to one of the following: low back pain, changes in abdominal muscle activity patterns, and abdominal muscle activity onset times.

Purpose

The main purpose of this study was to determine whether *elite* male golfers with CLBP experience greater fatigue in the abdominal muscles than asymptomatic control golfers (AC) following a typical 50-minute *practice session*. Secondary purposes were to determine whether differences exist between CLBP and AC golfers in abdominal muscle activity during the golf swing, muscle activity onset times during the golf swing, and abdominal muscle activity during the *impact phase* of the golf swing following practice.

Hypothesis

1. *Elite* male golfers who experience chronic low back pain will exhibit greater fatigue in the external oblique and internal oblique abdominal muscles than *elite* male golfers who do not experience chronic low back pain after a typical 50-minute practice session.

Subject Inclusion Criteria

Male teaching and/or club professional golfers within the Alberta Professional Golf Association, and low handicap (<5) amateurs within the Alberta Golf Association were given the opportunity to volunteer as subjects for this study. Potential subjects were initially asked to complete a general golf questionnaire (Appendix A) regarding the location, duration, and frequency of back pain, and their playing and practicing habits. Those individuals who had "never" experienced pain in the lumbar region of their back after practicing or playing during the six months prior to completion of the questionnaire were classified as asymptomatic control subjects (AC). Those individuals who had "always" or "often" experienced pain in the lumbar region of their back after practicing or playing for longer than six months prior to completion of the questionnaire were classified as chronic low back pain subjects (CLBP). Individuals were excluded from participating in the study if they were older than 55 years of age. All subjects completed a physical activity readiness form (PAR-Q) (Appendix B) and gave their informed consent (Appendix C) prior to any testing procedures.

Methods

All testing was conducted in the Human Performance Laboratory at the University of Calgary, Calgary, Alberta, Canada. Ethics approval was granted by the Conjoint Faculties Research Ethics Committee at the University of Calgary.

Testing Procedures

The testing period consisted of a series of procedures, which were consistent for all subjects. Anthropometric (height and weight) measurements were first made followed by electrode placement on appropriate muscles. Next, a submaximal isometric contraction (double leg raise) was performed to gather muscle activity data to be used as a normalizing measure and a measure of muscular fatigue. After the double leg raise, subjects completed a severity of pain questionnaire. Subjects were then permitted to warm-up for approximately 10 minutes to physically prepare for maximal effort shots with the driver and a 50-minute *practice session*. Subjects then hit 5 maximal effort shots with the driver while video and electromyographic (EMG) data were collected. Subjects then performed a typical *practice session* for 50 minutes (ball striking session with 9, 7, 5, 3 irons; and 3 wood), which was then followed by 5 maximal effort shots with the driver while video and EMG data were collected. Immediately following the final shot with the driver, subjects performed the double leg raise again and then completed the McGill Pain Questionnaire again.

EMG Data Recording

Each subject's skin was prepared for EMG electrode placement by shaving the appropriate areas, abrading the skin with fine grade emery paper, and then cleaning the area thoroughly with an alcohol swab. Pairs of AgAgCl surface EMG electrodes (10 mm active diameter) (CONMED Corporation, Utica, New York, USA) were attached to the skin approximately 25 mm apart (center to center) along the expected muscle fiber direction of the right and left rectus abdominis (RA) (3 cm lateral to umbilicus), external oblique (EO) (15 cm lateral to umbilicus at transverse level of umbilicus), and internal oblique (IO) (below external oblique & just superior to the inguinal ligament). A ground electrode was placed over the left anterior superior iliac spine. Inter-electrode distance and electrode placement were consistent with procedures by McGill et al. (1996) and Juker et al. (1998). EMG signals were pre-amplified and conducted through a battery powered unit (Biovision EMG System, Wehrheim, Germany; input impedance, 10^{12} Ohms; bandwidth, 10 to 1000 Hz). Amplifiers were not more than 12 cm from electrode sites and were taped to the body to minimize movement artifact of the EMG signal. Signals were sampled at 2400 Hz per channel and processed with EVa data collection software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA).

EMG Normalizing Procedure (double leg raise)

Prior to the golf swing trials with the driver, EMG data of the three abdominal muscles were collected during a submaximal isometric contraction in order to normalize the EMG data during the swing. Subjects were asked to raise their feet approximately 1 cm off the floor and hold the position as steady as possible. When the subject achieved a steady isometric contraction, EMG data were collected for 10 seconds. It did not take longer than 2 seconds for any subject to achieve the steady contraction.

EMG signals from maximal voluntary isometric contractions are commonly used for normalization procedures (Basmajian & DeLuca, 1985; Allison et al., 1993). Maximal voluntary isometric contractions for muscles of the trunk are not reproducible in either healthy (McGill, 1991) or low back pain populations (Beimborn and Morrissey, 1988). O'Sullivan et al. (1997,1998) has previously used the double leg raise to normalize EMG data in low back pain populations. Compared to MVC, submaximal contractions are believed to be a more consistent indication of muscle activation. Thus, submaximal voluntary muscle contractions may be a more appropriate tool to use as a normalization standard for subjects with back pain (Allison et al., 1993). The double leg raise is known to require activation of all the abdominal musculature to stabilize the pelvis (Basmajian and DeLuca, 1985).

Measure of Abdominal Muscle Fatigue (double leg raise)

EMG data collected during the 10-second double leg raise maneuver was also used to assess muscular fatigue in the abdominal muscles before and after the *practice session*. The Sorensen test has previously been validated and used to assess back muscle endurance (Moffroid et al., 1994). These authors have used the decline in the median frequency (MF) of the EMG power spectrum during the Sorensen test as a measure of muscular fatigue. It was felt that the double leg raise would offer a simple and effective means for assessing muscular fatigue in the abdominal muscles following the *practice session*. Feedback from healthy pilot subjects indicated that it was difficult to perform the double leg raise for 30 seconds. Considering the well being of the CLBP subjects, and to be consistent, it was decided that all subjects would perform the double leg raise maneuver for 10 seconds. Fatigue was assessed by comparison of MF and root mean square (RMS) for the post-practice double leg raise with the pre-practice double leg raise.

Pain Questionnaire

Subjects were required to complete a severity of pain questionnaire (McGill Questionnaire Short Form) as outlined by Melzack (1987) (Appendix D) prior to, and immediately following the *practice session*. The McGill pain questionnaire consists of 3 sections which provides information on the sensory, affective, and evaluative dimensions of pain experience. Descriptive words representing the sensory and affective dimension of pain experience are rated as either none, mild, moderate, or severe in section 1. A visual analog scale (VAS) is presented in section 2 with "no pain" being represented as "0" and the "worst possible pain" represented as "100". Section 3 is the Present Pain

Intensity (PPI) scale. Subjects were asked to rate the intensity of pain on a scale of "0" to "5" where 0 = no pain; 1 = mild; 2 = discomforting; 3 = distressing; 4 = horrible; 5 = excruciating.

Performance Testing & Practice Session

After electrode placement, double leg raise, and completion of the pain questionnaire, subjects began by warming up for approximately 10 minutes. The warm-up consisted of sub-maximally (1/2 swing) hitting golf balls into a net with an 8 iron. Subjects were asked to warm-up in this manner until they felt ready to hit maximal effort shots with the driver. The warm-up also allowed indication of the adhesiveness of electrodes to the skin. Following the warm-up, subjects hit 5 shots maximally with the driver. EMG data from RA, IO and EO muscles were collected during each of the five shots. Video data were collected simultaneously to synchronize EMG data with the different phases of the golf swing. Subjects then hit golf balls into a net at a rate of one every 30 seconds for 50 minutes with various clubs (9, 7, 5, and 3 iron; and 3 wood). Each club was used for 10 minutes, beginning with the 9 iron and finishing with the 3 wood. The duration of the *practice session* and frequency of shots was determined from the general golf questionnaire (Appendix A). All subjects practiced in the same manner and were instructed to hit each shot with maximal effort. Electromyographic and kinematic data were not collected during the 50-minute practice session.

Following the 50-minute practice session, subjects once again hit 5 maximal effort shots with the driver. Electromyographic and kinematic data were again collected during each of these shots. Subjects then performed the double leg raise again immediately after the last shot with the driver and then completed the pain questionnaire again.

Following each shot with the driver (before and after the practice session) subjects gave verbal feedback on self-perceived quality of the shot on a scale of 1 to 5. Poor ball contact was rated as 1, while solid ball contact was rated as 5. This information was obtained, in part, to determine which of the 5 shots with the driver (before and after the practice session) was the best and would be used for analysis.

Video Data Recording

Four high-speed video cameras (Falcon, 6.0 mm Computar lens, Motion Analysis Corp., Santa Rosa, CA) were used to collect information regarding club position throughout the golf swing and to determine the instant of ball impact. Video data were collected at 240 frames/sec and used to synchronize EMG data to various phases of the golf swing. Cameras were positioned in a semi-circle arrangement to the side of the subject away from the direction of ball flight in order to record several views of club movement for future analysis (Figure 14). Reflective markers were placed on two locations along the shaft of the driver to allow determination of specific phases of the golf swing. A 90-compression golf ball was covered with reflective tape to permit detection of the first indication of ball motion. Video and EMG data were collected with EVa data collection software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA).

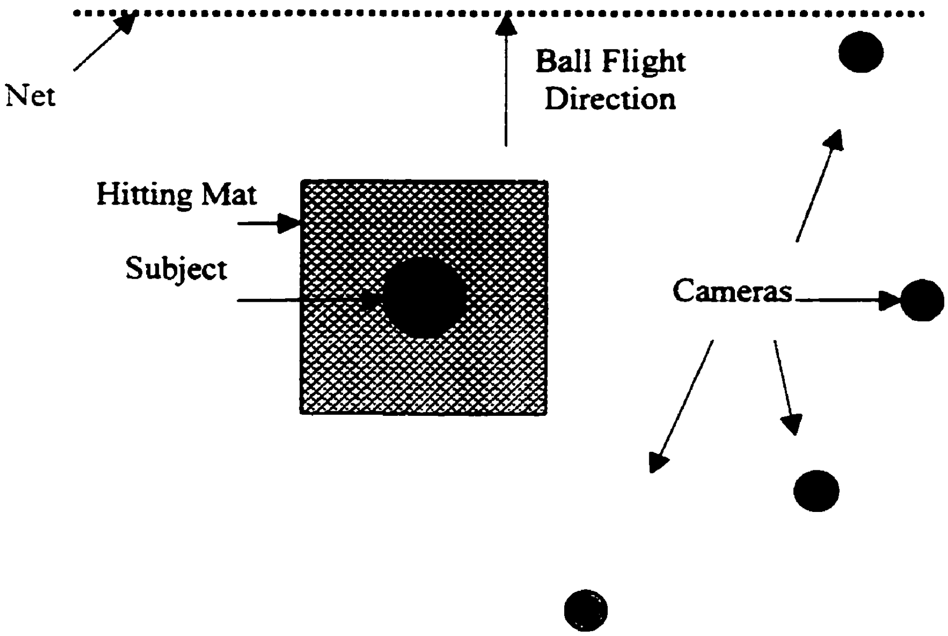

FIGURE 14. VIDEO CAMERA POSITIONING.
Illustration of video camera positioning relative to subject.

Data Analysis

Video Data Analysis

All video data were analyzed using EVa software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA). A straight line was computer generated between the two points represented by the reflective markers placed on the golf club. The video file, which combined data from all four cameras, was advanced one frame at a time to determine the exact time of golf club movement in the backswing direction, which was considered the start of the swing. The same procedure was then used to determine the time at the start of the downswing, club position horizontal to the floor in the forward swing, impact, club position horizontal to the floor on the follow through, and the finish position. The finish position was considered to be the point where the club was above the head and horizontal to the floor (Figure 15). All frame numbers were converted to milliseconds (frame # x 1000/240). This procedure allowed determination of the timing for the sequence of muscle activation and the magnitude of muscle activation for all the EMG signals. The magnitude of these EMG signals was normalized relative to the submaximal signal collected during the leg raise as previously described.

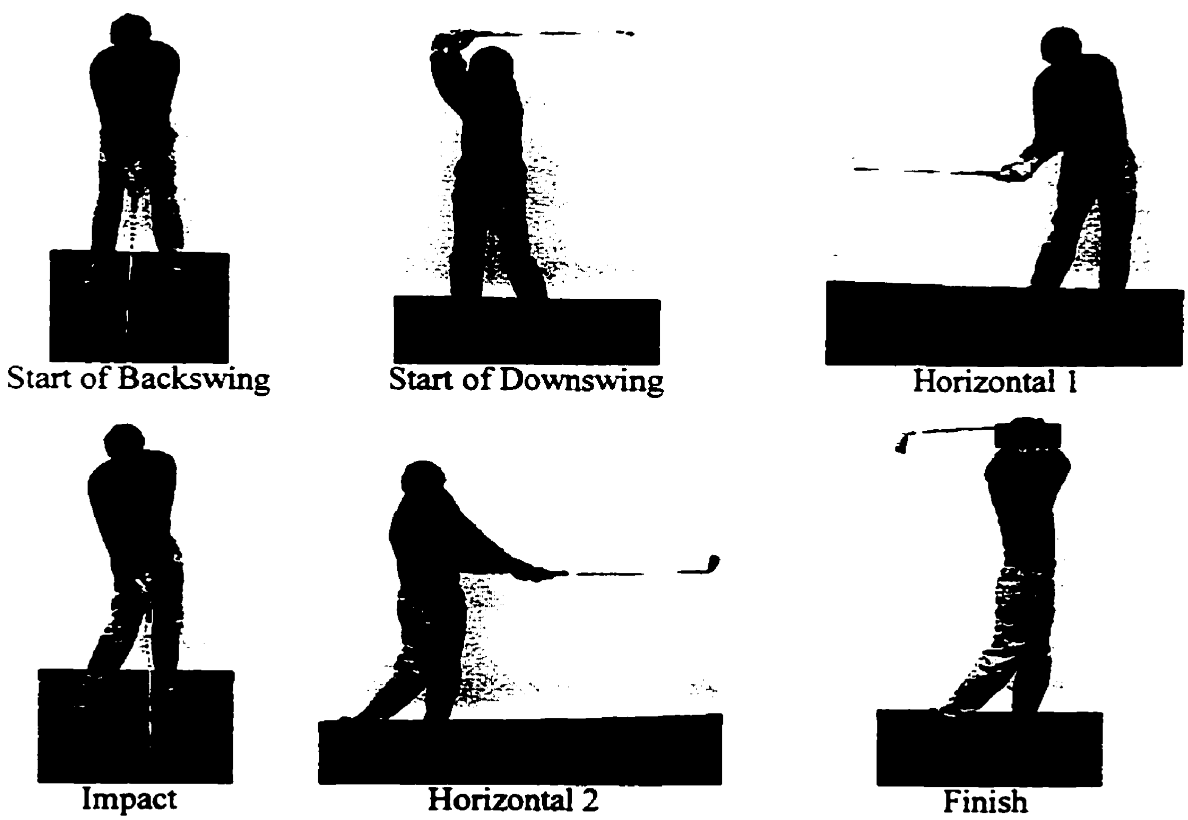

FIGURE 15. CLUB POSITIONS THROUGHOUT THE GOLF SWING.
Illustrations displaying different club positions throughout the golf swing.

EMG Data Analysis

All EMG data were sampled at 2400 Hz and bandpass filtered between 10 and 240 Hz (fourth order butterworth digital filter). Although EMG and video data were collected during each of the 5 shots with the driver, only one trial was chosen for EMG data analysis. The best-rated shot (as indicated by the subject) was used as long as the EMG signals were free of movement artifact. If the EMG signal associated with the best rated shot appeared to be distorted with artifact, then the next best rated shot was used for data analysis.

Root Mean Square Calculation during Submaximal Isometric Contraction

EMG signals of the submaximal isometric contraction (double leg raise) were analyzed in the same manner for all subjects. To avoid artifacts of the filtering process, a 2000 msec selection of each EMG signal was chosen beginning at 1000 msec and ending at 3000 msec (Figure 16). This 2-second selection was chosen because the average total duration of the golf swing for all subjects was 1474.8 ± 20.5 msec (Appendix D). Thus, it was felt that a 2000 msec sample was an adequate duration to calculate RMS to normalize EMG signals during the swing. EMG Signals were not rectified.

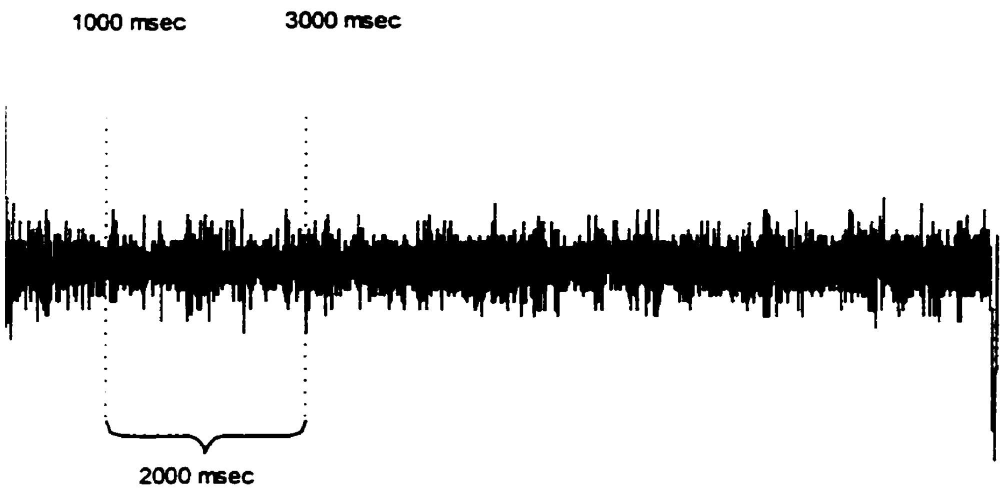

FIGURE 16. EMG NORMALIZING SIGNAL.
EMG signal recorded from a representative abdominal muscle during double leg raise. This illustration shows the time period where the RMS was calculated, which was then used as a normalizing value. The large effect at the start and end of the EMG signal is due to filtering artifact.

Root Mean Square Calculation during Different Phases of Swing

The magnitude of muscle activity during different phases of the golf swing was calculated with Kintrak (versions 5.2 & 6.0, University of Calgary, Calgary, Alberta, Canada). The RMS for each of the 3 phases (*Phase 1*: start of back swing to start of downswing; *Phase 2*: start of downswing to impact; *Phase 3*: impact to finish) was calculated with results in millivolts. Root mean square values were also calculated during the *Impact Phase* (horizontal 1 to horizontal 2). Markers were manually set on EMG signals in milliseconds according to the previously determined video times (Figure 17). Root mean square values for each phase were averaged within AC and CLBP groups.

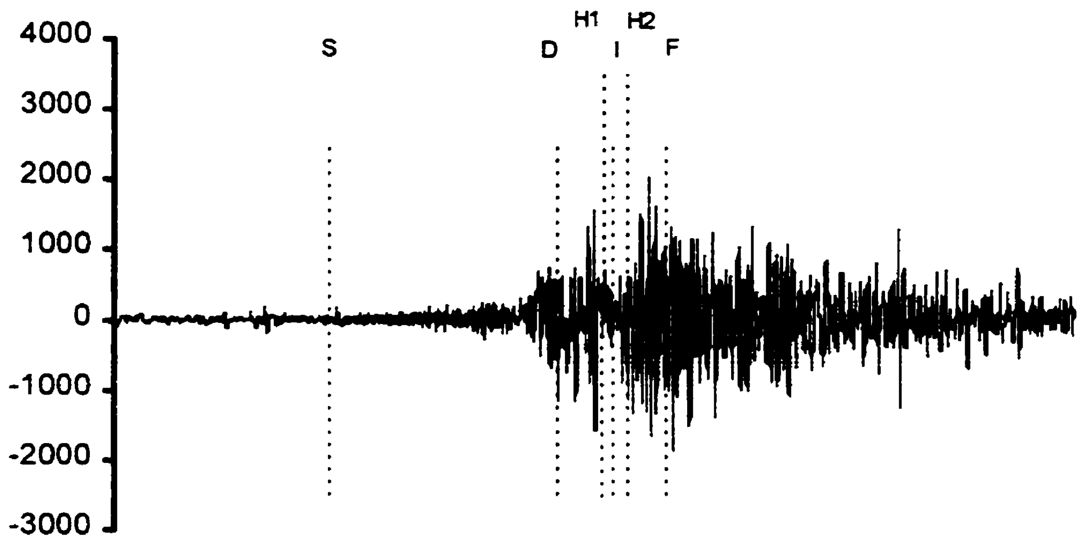

FIGURE 17. MARKER SETTINGS.
Marker settings used to calculate RMS values of various phases of the golf swing. S=start of back swing; D=start of downswing; H1=club horizontal to floor during forward swing; I=ball impact; H2=club horizontal to floor during follow-through; F=finish of swing. Duration of entire EMG signal is 4 seconds. EMG signal was recorded from EO (trail) muscle.

Onset Time of Muscle Activity during the Golf Swing

Using non-rectified EMG signals, onset times of individual abdominal muscles were determined using Kintrak (version 5.2, 6.0, University of Calgary, Calgary, Alberta, Canada). Hodges & Richardson (1999) have identified EMG onset times as the point where the mean of the 50 subsequent samples exceeded the background level of activity by two standard deviations. This procedure was initially employed for the present data analysis, however, it failed to accurately select an appropriate onset time. This process often selected an onset time, which was apparently unrelated to the golf swing. This was probably because abdominal muscle activity varies considerably during "baseline" conditions. For this reason, the onset times of substantial abdominal muscle activity were calculated as the time when the signal exceeded 7 SD from the mean of the "quietest" muscle activity of the whole signal. Onset time was calculated as 7 SD above the mean of a 200-millisecond segment (1/20th of the whole sample) where the quietest activity in the signal occurred (Figure 18). Use of 7 SD consistently selected times when substantial EMG activity occurred (i.e. related to the golf swing). This procedure was used for all abdominal muscles and subjects.

Computer identified onset times were compared to visually selected onset times and found to accurately identify the major burst(s) of EMG activity. In addition, all identified onset times using Kintrak (version 5.2, 6.0, University of Calgary, Calgary, Alberta, Canada) were checked visually to ensure that they were in fact muscle bursts and not movement artifact or ECG signals. All onset times for each muscle were recorded and then expressed relative to specific times during the golf swing which were determined from the video data analysis.

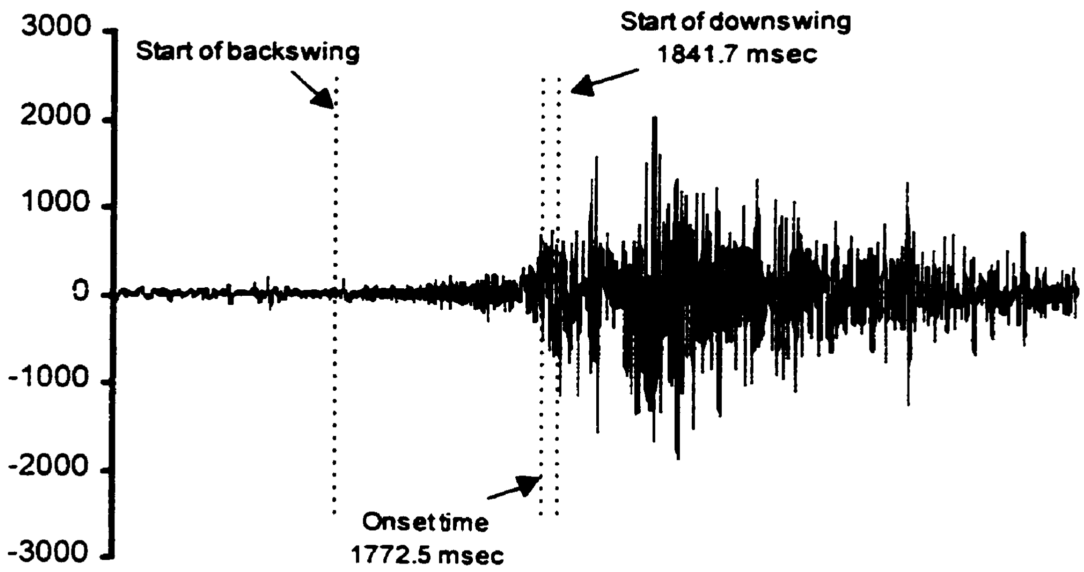

FIGURE 18. ONSET TIME SELECTION.
Example of computer program (Kintrak) calculation of muscle activity onset time. Onset time was calculated as 7 SD above the mean of a 200-msec segment (1/20th of the whole sample) where the quietest activity in the signal occurred. The entire EMG signal was 4 seconds in duration. EMG signal was recorded from EO (trail) muscle.

Determination of Muscular Fatigue

The 10-second submaximal isometric contraction (double leg raise) was also used to permit determination of muscular fatigue in the abdominal muscles before and after the *practice session*. The 10-second EMG signal was divided into 8 equal segments 1.25 seconds in duration (Figure 19). The median frequency (MF) of the EMG signal in each of these segments was then calculated (Kintrak, version 5.2, University of Calgary, Calgary, Alberta, Canada). The mean of the first 3 MF values (segments 1, 2, 3) was calculated to give an indication of muscular fatigue before and after the *practice session* (Figure 19).

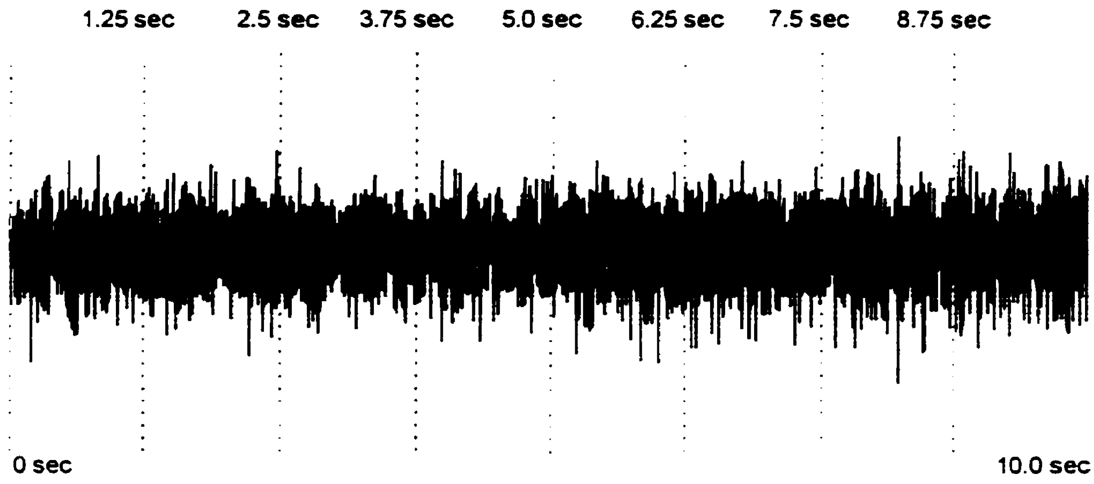

FIGURE 19. MF CALCULATION.
EMG signal of submaximal isometric contraction used to calculate MF.
The area between each marker indicates segments where MF calculations were performed. Median frequency values were calculated from 8 equal segments.

Calculation of Ball Speed

Video data of ball movement was tracked with EVa data collection software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA). A mathematical program was written specifically to incorporate this video data to calculate ball speed in m/s (Matlab, The Math Works, Inc., Natick, Mass). Ball speed in m/s was then converted to km/h and mph (Microsoft Excel).

Statistical Analyses

All data were normally distributed (Kolmogorov-Smirov Test). A 2 way ANOVA with repeated measures was used to determine significant differences in abdominal muscle activity onset times following the 50-minute *practice session* and differences in abdominal muscle activity during the *impact phase* following the 50-minute *practice session.* A 2 way ANOVA with repeated measures was also used to determine significant differences in abdominal muscle fatigue following the 50-minute *practice session.* No obvious differences in abdominal muscle activity patterns were observed between AC and CLBP subjects during the golf swing, therefore no statistical analyses were performed to detect significant differences in pattern of muscle activation. Significant differences in severity of low back pain following the 50-minute *practice session* were determined with a paired samples t-test. This test was chosen since AC subjects exhibited no pain before or after the 50-minute *practice session.* The Statistical Package for the Social Sciences was used for all statistical analyses.

Results

Demographic and Descriptive Information

Eight AC subjects (8 professionals) (29.4 ± 2.0 years; 81.7 ± 2.4 kg; 1.8 ± 0.0 m; 25.3 ± 0.6 BMI; Mean ± SEM), and 17 CLBP subjects (10 professionals, 7 amateurs) (36.1 ± 2.7 years; 81.8 ± 2.2 kg; 1.8 ± 0.0 m; 25.4 ± 0.6 BMI) participated in this study. Asymptomatic control subjects ranged from 20 to 39 years of age, while CLBP subjects ranged from 17 to 55 years of age. Three CLBP subjects were older than 50 years of age. Chronic low back pain subjects were individuals who had always experienced low back pain in the lumbar region of their back after playing or practicing for longer than six months prior to completion of the general golf questionnaire (Appendix A). The majority of CLBP subjects experienced low back pain either on the right side of the body or on both sides (Table 3). The CLBP subjects were individuals who had experienced low back pain for some time and continued to play golf regardless of their condition. CLBP subjects were, therefore, not asked to incur pain they would not have normally imposed on themselves.

TABLE 3. LOCATION OF LOW BACK PAIN OF CLBP SUBJECTS.

	Left	Center	Right	Both sides
# of responses	2	3	6	6
%	12	18	35	35

Abdominal Muscle Activity Onset Times

Significant differences in EO (lead) onset time relative to the start of the backswing were found between AC and CLBP subjects both before and after the *practice session* ($p<0.01$) (Table 4). The onset time of abdominal muscle activity relative to the start of the backswing measured in this study did not significantly change as a result of the *practice session* in either group (EO-lead: $p=0.690$; IO-trail: $p=0.200$) (Table 4). The onset time of abdominal muscle activity relative to the start of the downswing measured in this study did not significantly change as a result of the *practice session* in either group (EO-trail: $p=0.198$; IO-lead: 0.966) (Table 5).

TABLE 4. ABDOMINAL MUSCLE ACTIVITY ONSET TIMES.
Onset times of the EO and IO muscles before and after the practice session are presented relative to the first movement of the golf club in the backswing (start of backswing). Asterisks indicate a significant difference between AC and CLBP subjects ($p<0.05$).

	Relative to Start of Backswing			
	EO(lead) Before	**EO (lead) After**	**IO (trail) Before**	**IO (trail) After**
AC	-16.6 ± 27.4	-41.7 ± 16.4	13.8 ± 81.4	73.2 ± 124.1
CLBP	55.5 ± 19.4 *	67.2 ± 22.3 *	22.4 ± 38.7	85.0 ± 65.9

TABLE 5. ABDOMINAL MUSCLE ACTIVITY ONSET TIMES.
Onset times of the EO and IO muscles before and after the practice session are presented relative the first movement of the golf club in the downswing direction (start of downswing). Asterisks indicate a significant difference between AC and CLBP subjects ($p<0.05$).

	Relative to Start of Downswing			
	EO(trail) Before	**EO (trail) After**	**IO (lead) Before**	**IO (lead) After**
AC	-63.2 ± 37.9	-55.1 ± 30.4	-84.9 ± 16.5	-69.0 ± 32.1
CLBP	-94.8 ± 61.3	-73.1 ± 54.7	-38.8 ± 11.7 *	-53.8 ± 17.3

Severity of Low Back Pain Following Practice Session

AC subjects experienced no low back pain before or after the *practice session*. A significant increase in severity of low back pain was found for CLBP individuals after the 50-minute *practice session* ($p=0.006$). Average VAS scores for CLBP subjects were 23.5 ± 6.1 before the practice session and 34.4 ± 5.6 after the practice session.

Abdominal Muscle Fatigue Before and After Practice Session

No significant differences were found for MF in abdominal muscle EMG during the double leg raise maneuver following the *practice session* in either AC or CLBP subjects ($p>0.219$) (Table 6). No significant differences were found for RMS in abdominal muscle EMG during the double leg raise maneuver following the *practice session* in either AC or CLBP subjects ($p>0.271$) (Table 6).

TABLE 6. MEAN MF AND RMS VALUES BEFORE AND AFTER PRACTICE.

	RA (lead)	RA (trail)	EO (lead)	EO (trail)	IO (lead)	IO (trail)
Mean MF Values for AC Subjects (8)						
Before Practice	90.5 ± 7.8	83.4 ± 5.2	67.7 ± 4.1	59.6 ± 4.1	92.2 ± 10.3	92.2 ± 9.7
After Practice	88.3 ± 6.9	84.3 ± 5.4	67.3 ± 3.9	60.2 ± 2.9	89.9 ± 9.1	93.4 ± 9.2
	p=0.646	p=0.813	p=0.840	p=0.620	p=0.219	p=0.254
Mean RMS Values for AC Subjects (8)						
Before Practice	0.13 ± 0.06	0.09 ± 0.04	0.12 ± 0.02	0.14 ± 0.03	0.07 ± 0.01	0.08 ± 0.02
After Practice	0.14 ± 0.06	0.11 ± 0.05	0.15 ± 0.03	0.17 ± 0.03	0.08 ± 0.01	0.08 ± 0.02
	p=0.852	p=0.738	p=0.558	p=0.554	p=0.581	p=0.926
Mean MF Values for CLBP Subjects (17)						
	RA (lead)	**RA (trail)**	**EO (lead)**	**EO (trail)**	**IO (lead)**	**IO (trail)**
Before Practice	79.2 ± 3.7	81.8 ± 4.4	68.9 ± 2.7	65.1 ± 2.5	77.1 ± 5.4	78.1 ± 5.6
After Practice	80.2 ± 3.6	81.5 ± 4.4	70.2 ± 2.6	66.6 ± 2.6	73.2 ± 4.4	80.9 ± 6.9
	p=0.646	p=0.813	p=0.840	p=0.620	p=0.219	p=0.254
Mean RMS Values for CLBP Subjects (17)						
Before Practice	0.08 ± 0.01	0.09 ± 0.01	0.07 ± 0.01	0.09 ± 0.01	0.06 ± 0.01	0.08 ± 0.01
After Practice	0.09 ± 0.01	0.11 ± 0.02	0.09 ± 0.01	0.10 ± 0.01	0.08 ± 0.01	0.09 ± 0.01
	p=0.766	p=0.271	p=0.331	p=0.793	p=0.387	p=0.658

*Numbers in parentheses represent number of subjects.
*p-values represent a comparison of before vs. after practice.

Ball Speed

No significant differences were found in ball speed following the *practice session* in either group (p>0.865) (Table 7).

TABLE 7. BALL SPEED BEFORE AND AFTER PRACTICE FOR AC AND CLBP SUBJECTS.

	Before Practice	After Practice	
	Ball Speed (km/h)	**Ball Speed (km/h)**	**% change**
AC (8)	241.9 ± 2.9	242.2 ± 2.9	0.08
CLBP (17)	235.3 ± 5.6	234.7 ± 4.6	-0.24

*Numbers in parentheses represent number of subjects.

Abdominal Muscle Activity of AC and CLBP Subjects during impact phase

No significant differences in abdominal muscle activity during the *impact phase* were found in AC subjects following the *practice session* (p>0.348) (Figure 20).

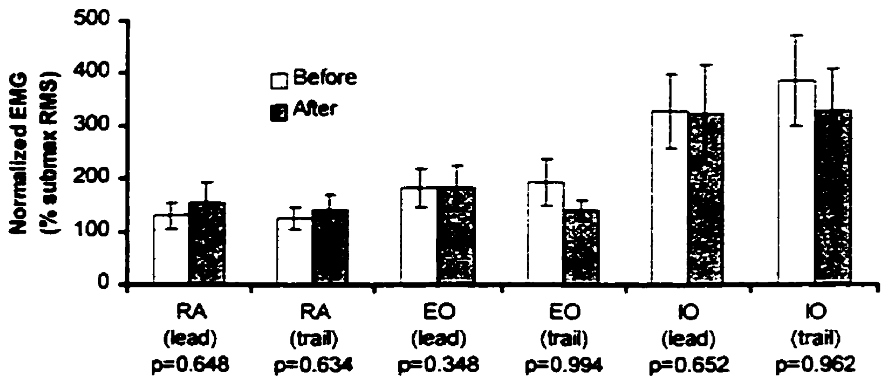

FIGURE 20. AC ABDOMINAL MUSCLE ACTIVITY DURING *IMPACT PHASE*.
Abdominal muscle activity of AC subjects during *impact phase* before and after practice. *Impact phase* represents the time between Horizontal 1 and Horizontal 2 club positions. RA = rectus abdominis; EO = external oblique; IO = internal oblique.

No significant differences in abdominal muscle activity were found during the *impact phase* in CLBP subjects following the *practice session* (p>0.282) (Figure 21).

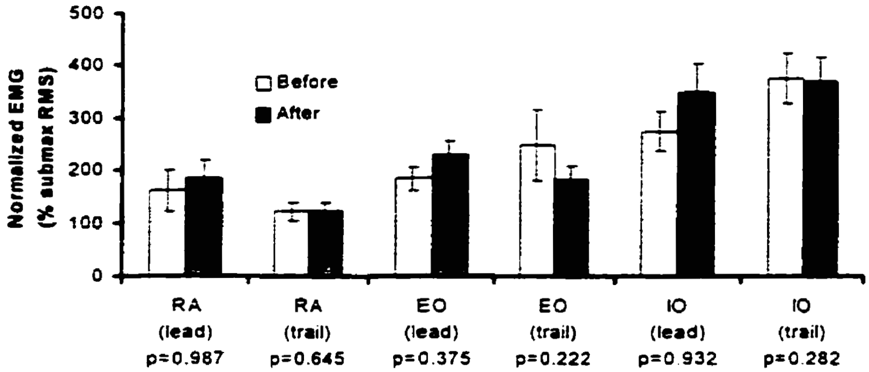

FIGURE 21. CLBP ABDOMINAL MUSCLE ACTIVITY DURING *IMPACT PHASE*. Abdominal muscle activity of CLBP subjects during *impact phase* before and after practice. *Impact phase* represents the time between Horizontal 1 and Horizontal 2 club positions. RA = rectus abdominis; EO = external oblique; IO = internal oblique.

Abdominal Muscle Activity during the Golf Swing in AC and CLBP Subjects

Normalized EMG activity of all abdominal muscles is presented using the same scale for ease of comparison (Figures 22 & 23). Similar patterns of abdominal muscle activity were found before and after the *practice session* in AC and CLBP subjects. The pattern of muscle activity typically involved an increase in activity from *phase 1* to *phase 2* followed by a decrease in activity to *phase 3*.

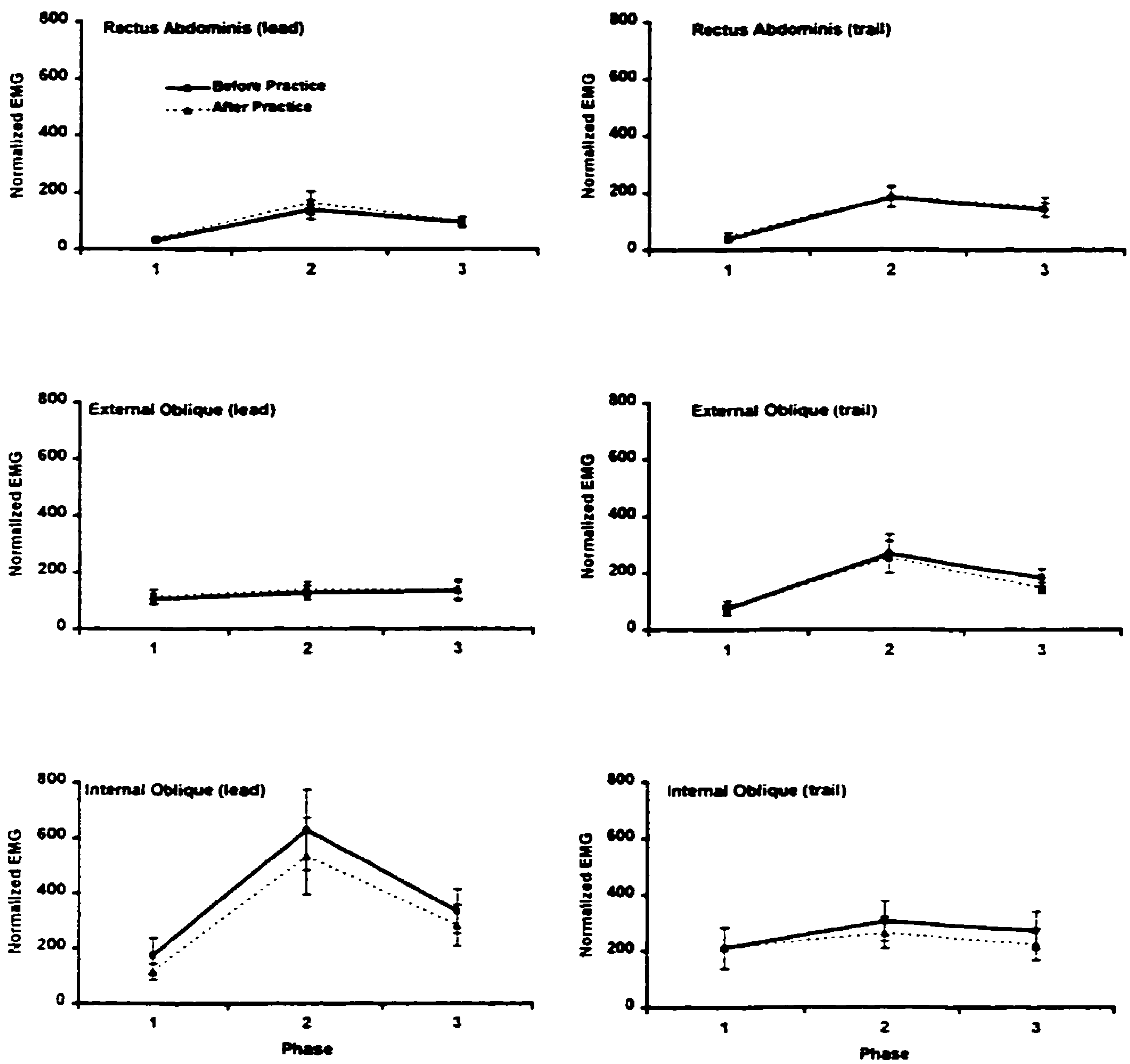

FIGURE 22. AC MUSCLE ACTIVITY THROUGHOUT THE GOLF SWING.
Muscle activity of AC subjects throughout the golf swing before and after practice. *Phase 1* = start of backswing – start of downswing; *phase 2* = start of downswing – impact; *phase 3* = impact – finish. Magnitude of activity is expressed as a percentage of submaximal (double leg raise) RMS.

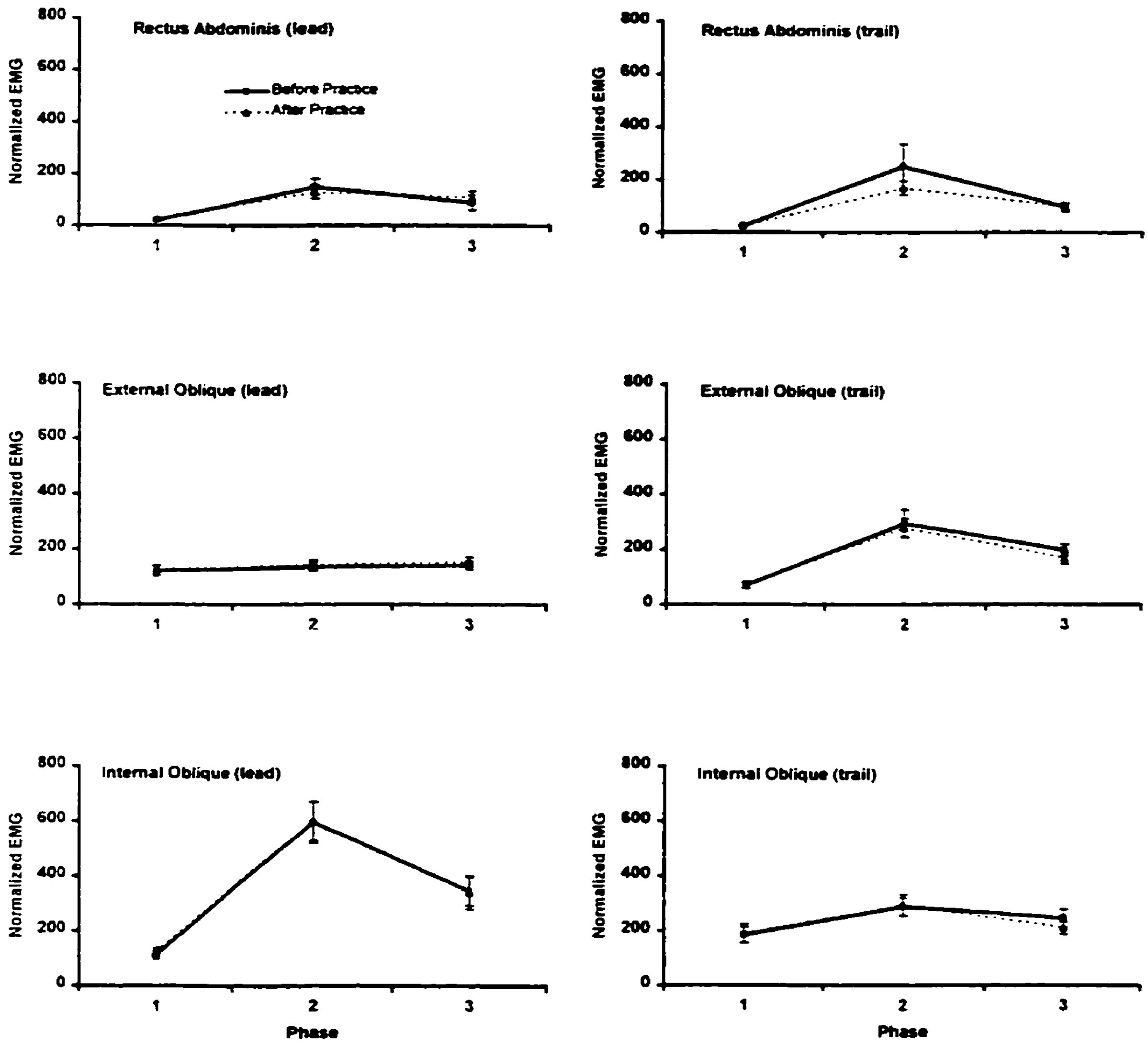

FIGURE 23. CLBP MUSCLE ACTIVITY THROUGHOUT THE GOLF SWING.
Muscle activity of CLBP subjects throughout the golf swing before and after practice. *Phase 1* = start of backswing – start of downswing; *phase 2* = start of downswing – impact; *phase 3* = impact – finish. Magnitude of activity is expressed as percentage of submaximal (double leg raise) RMS.

Discussion

Abdominal Muscle Fatigue Following Practice session

The main purpose of this study was to determine whether *elite* male golfers with CLBP experience greater fatigue in the abdominal muscles than AC golfers following a typical 50-minute *practice session*. Although CLBP subjects experienced a significantly greater amount of low back pain following the 50-minute *practice session*, no significant differences were found between CLBP and AC subjects in abdominal muscle fatigue as measured with MF or RMS ($p>0.219$) (Table 6). Furthermore, ball speed did not significantly change in either group following the *practice session*. This performance measure may offer another indication of absence of muscular fatigue. It would seem likely that if muscular fatigue had developed as a result of the *practice session*, a decrease in ball speed would have been observed. The hypothesis that abdominal muscles fatigue during a typical *practice session* was not supported in this case. Of particular importance with respect to this observation is that greater pain was experienced in spite of the absence of evidence for muscle fatigue.

No previous study investigated the effects of repetitive golf swings on abdominal muscle fatigue in either CLBP subjects or pain free subjects. Therefore, no direct comparison with available literature is possible. Several studies have investigated the effects of repetitive bending, lifting, and twisting movements on trunk muscle fatigue in the occupational or industrial setting (Parnianpour et al., 1988; Sparto et al., 1997; Sparto & Parnianpour, 1998). These studies have primarily investigated low back muscles. Parnianpour et al. (1988) had subjects perform trunk flexion and extension movements as quickly and accurately as possible while exerting maximum efforts until exhaustion. These authors suggested fatigued muscles are less able to compensate any perturbation in load or position of the trunk.

Individuals with CLBP are known to experience fatigue more quickly in the abdominal muscles following repetitive bending, lifting, or twisting (Parnianpour et al., 1988; Sparto et al., 1997; Sparto & Parnianpour, 1998). Subjects in these studies performed repetitive bending, lifting, and/or twisting movements until exhaustion. Subjects in the present study hit a golf ball every 30 seconds for 50 minutes, as well as 5 shots with the driver before the *practice session* and after the *practice session*. The frequency of ball striking and duration of the *practice session* was based on answers to questions regarding practicing habits (Appendix A). Most subjects indicated that although this was typical of their practice habits, they did not feel particularly fatigued at the end of the *practice session*. Perhaps the duration of the *practice session* was not long enough or ball striking was not frequent enough to induce fatigue in the abdominal muscles of both CLBP and AC subjects in the present study.

Healthy pilot subjects indicated the submaximal isometric exercise (double leg raise) was difficult to sustain for 30 seconds, therefore the duration of this maneuver was predetermined to last only 10 seconds. It is commonly observed that the spectral shift of the EMG signal is most dramatic near the beginning of a sustained contraction (De Luca, 1985; Mannion & Dolan, 1994). Considering this and the well being of the CLBP subjects, it was felt 10 seconds was an adequate amount of time to assess abdominal muscle fatigue after the *practice session*.

For fatigue to appear over reasonably short contraction times (i.e. 10 seconds), it is important that the muscles are contracted at relatively high force levels. Normally, a submaximal contraction used to assess muscular fatigue is approximately 80% of a maximal voluntary contraction (MVC) (Oddsson et al., 1997). Contractions with higher force levels cause a faster shift of the EMG power spectrum to lower frequencies. This is to be expected because muscles under greater tension will fatigue more rapidly (Redfern, 1992). It is not known what percentage of a MVC the submaximal contraction was in the present study. The double leg raise used to assess abdominal muscle fatigue may not have been taxing enough to detect changes in abdominal muscle fatigue.

Trunk muscle fatigue can be assessed mechanically by timing the ability of a person to hold specific postures or to perform specific trunk movements with or without an external load (Moffroid, 1997). Most studies dealing with trunk muscle fatigue have employed repetitive lifting tasks or rotations in an isokinetic dynamometer. Dynamic mechanical fatigue tests add variables of velocity and direction, so that the measurements become more complex (Moffroid, 1997). Furthermore, diagnostic tests to measure abdominal muscle fatigue can be influenced easily by factors that are under volitional control. Factors such as motivation, pain tolerance, competitiveness, boredom, and fear of injury considerably influence performance of repetitive movements or duration of static postures (Mannion & Dolan, 1994; Peach & McGill, 1998). Mechanical fatigue tests rely on the popular assumption that fatigue is a single point in time wherein contractile failure occurs (i.e. the time when an individual can no longer hold a specific posture). Rather, muscle fatigue is considered to be a time dependent process related to biochemical events within the muscles (De Luca, 1985; Roy et al., 1990). Access to biochemical and physiological data within the muscle or the nervous system could reveal time dependent changes indicative of a fatigue process, even though the externally observable mechanical performance would not be altered until the failure point (De Luca, 1985).

Measuring changes in the EMG power frequency spectrum is a common method for assessing fatigue in muscles (Roy et al., 1990; Moffroid et al., 1994; Roy et al., 1995; Moffroid, 1997; Oddsson et al., 1997; Peach & McGill, 1998). Surface EMG measurements of the median frequency are non-invasive and independent of the subject's effort level (Moffroid et al., 1994). The MF is directly related to slowing of muscle fiber conduction velocity, hence it is independent of voluntary effort and is preferred for assessing muscular fatigue (Moffroid, 1997). Indices of muscle performance that are based on spectral parameters of the surface EMG signal may provide a more objective measure of muscle performance than purely mechanical indices (Roy et al., 1995).

Because EMG can monitor fatigue changes of the muscle from the initial part of the contraction, the subject is not required to sustain the contraction until exhaustion. The present test did not require the subject to perform a maximal voluntary contraction. This is important considering there is little confidence in what the MVC of a person is if testing is done during an episode of back pain (Moffroid, 1997).

Patterns of Abdominal Muscle Activity Following Practice Session

A secondary purpose of this study was to investigate the effects of repetitive golf swings on patterns of abdominal muscle activity. Significant differences in EO (lead) onset times, relative to start of backswing, were found between CLBP and AC subjects both before and after the *practice session* ($p<0.05$) (Table 4). Significant differences in IO (lead) onset times relative to the start of the downswing between CLBP and AC subjects were only found prior to the *practice session* ($p<0.05$) (Table 5). Changes in abdominal muscle activity onset times might have been expected as a result of repetitive swings, however, no significant differences were noted in either group ($p>0.05$) (Tables 4 & 5). No previous research has been conducted on the effects of repetitive swings on the onset time of abdominal muscle activity. Therefore no direct comparison with available literature is possible.

P. W. Hodges and C. A. Richardson are the leading researchers investigating abdominal muscle activity onset times in subjects with and without low back pain in the general population. They have not assessed abdominal muscle activity onset times before and after repetitive movements involving the trunk though. Hodges and Richardson (1999) found subjects with low back pain failed to recruit TrA or IO in advance of fast limb movement. The contraction of muscles associated with movement of a limb, other than those producing the movement, are believed to contribute to the maintenance of both the position of the center of mass over the base of support and the stability of the affected joints (Hodges & Richardson, 1997). This muscle activity occurring prior to the activity of the prime mover of the limb, is referred to as "feedforward" because it cannot be initiated by feedback from the limb movement (Hodges & Richardson, 1997). Repetition of specific movement patterns can lead to patterns of overactivity in some muscles and a related underactivity in others (Richardson et al., 1992).

Other researchers suggest there is some evidence that trunk muscle coordination is compromised by muscle fatigue, which may decrease trunk stability and thus lead to injury (O'Brien & Potvin, 1997). Given the overlap between functional tasks of trunk muscles during the golf swing, there is a need for coordination and control by the central nervous system in recruiting these muscles over a long period of time. This coordination and control could be compromised by the onset of fatigue (Parnianpour et al., 1988).

The results from the present study indicate the onset time of EO (lead) muscle activity, relative to the start of the backswing, is occurring earlier in AC subjects and later in CLBP subjects following the practice session, though not statistically significant (Table 4).

Severity of Low Back Pain Following Practice Session

Although neither abdominal muscle fatigue nor patterns of abdominal muscle activity were affected by the *practice session*, it is important to note that severity of low back pain did increase as a result of the *practice session*. Chronic low back pain subjects experienced a significant increase in low back pain following the 50-minute *practice session* ($p<0.05$), while AC subjects did not experience any low back pain before or after the practice session. These findings would indicate repetitive golf swings are aggravating some part of the musculoskeletal system, which results in pain in the lumbar region of the back.

Limitations

A major limitation of this study is the lack of statistical power due to a small sample size. Post hoc sample size calculations were made based on pre and post practice results on 17 subjects. Since several muscles were being measured, a sample size calculation was performed for MF for each muscle. These results indicated a range between 93 and 296 subjects were needed for 80% statistical power of the various muscles for time effect, 8 to 68 subjects to detect a group effect and 21 to 152 subjects for a group by time intervention. Achieving these numbers was not realistic. Every effort was made, however, to recruit as many subjects as possible for this study. Differences between groups could have been detected for some of the muscles.

Surface EMG provides information, within certain limitations, about the neural drive to various components of the musculature (McGill, 1991). Surface EMG is convenient, however, there are certain limitations which should be noted. Surface electrodes may be used effectively only with superficial muscles and cannot be used to detect signals selectively from small muscles (Basmajian & DeLuca, 1985). When using surface electrodes there is always a concern of picking up signals from underlying or adjacent muscles ("cross-talk"). These limitations are often outweighed by the advantages of surface EMG. Surface electrodes are convenient to use, acceptable when the time of activation and the magnitude of the signal contain the required information, and when indwelling electrodes are impractical due to rapid movements (Basmajian & DeLuca, 1985). Variables that influence the detected EMG signal are thickness of the skin, subcutaneous fat, the bulk of the muscle, the proximity of the other muscles (cross-talk) (Basmajian & DeLuca, 1985). Another important limitation of using EMG is direct comparison of absolute values between one subject and another or between one muscle and another cannot be made (Gilmore & Meyers, 1983). The tissue environment is quite variable between subjects thus direct comparison of absolute values is not feasible.

Surface EMG is considered to be a reasonably reliable measure as long as the absolute values are normalized to a known reference. The reliability of EMG measurements of a given muscle is greater during a single testing session when electrodes have remained attached to the skin. Determining electrical impedance at the beginning and end of a testing session is commonly performed to insure consistent signals. It is also important to ensure electrodes remain securely attached to the skin throughout testing procedures. Minimal change in electrical impedance was noted at the end of the testing session for all subjects and every effort was made to ensure electrodes remained securely attached to the skin.

The submaximal isometric contraction (double leg raise) used during this study may offer limitations in the ability to measure abdominal muscle fatigue following the practice session. This maneuver was clearly submaximal, therefore the possibility that fatigue may have occurred in fast twitch muscle fibers cannot be ruled out. Median frequency values, which can detect muscle fatigue, tend to recover quite rapidly after muscular contractions have stopped. Detection of abdominal muscle fatigue may have been compromised since fatigue measurements were performed several minutes following the practice session. The delay of this measurement was necessary to prepare the subject for the double leg raise maneuver and to set start the computer data collection program.

Maximal voluntary contractions have been used as a normalizing protocol in many studies. There are problems though in measuring the MVC and interpreting what it means. Does a MVC represent maximum force or maximum activation? Because of the inhibitory feedback of the golgi tendon organs, it is not possible for an individual to recruit all motor units at their maximum firing rates (Winter, 1996). The MVC should therefore be considered the maximum value that a subject can voluntarily generate during an isometric contraction with inhibitory feedback present (Winter, 1996).

In retrospect, it may have been more appropriate to measure muscle activity from the deltoid muscle such as Hodges & Richardson (1997, 1999a, 1999b) to reference abdominal muscle activity to, rather than to club movement. Selection of the exact time of initiation of golf club movement may influence onset time results. It was felt the selection of initiation of club movement was accurate though. The frame number of video data where the beginning of club movement occurred was noted and then converted to milliseconds. One frame of video data (collected at 240 frames/sec) is equivalent to 4.17 msec. Even if the selection of initiation of club movement was off by one video frame, this would account for a small source of error considering the small percentage of time this is relative to the total duration of the golf swing.

Conclusions

This study was the first to investigate the effects of repetitive golf swings on abdominal muscle fatigue and abdominal muscle activity patterns. Although differences in abdominal muscle activity during the golf swing and *impact phase* were not seen in either AC or CLBP subjects as a result of the *practice session*, valuable information can be drawn from this study. Significant differences in OE (lead) onset times between CLBP subjects and AC subjects before and after a *practice session* may indicate muscle dysfunction in CLBP individuals. Such dysfunction may be related to CLBP, however, definite conclusions are not possible as to whether such findings are a result of pain are not possible. Though muscular fatigue was not detected in the abdominal muscles following the *practice session*, perhaps fatigue in these particular muscles is an ongoing process and occurs over a number of *practice sessions* or even a season. The only clinically validated trunk muscle measurement of fatigue is the isometric Sorensen test. Validation of techniques to assess abdominal muscle fatigue with EMG is needed in the future, as well as continued research on issues related to abdominal muscle fatigue in elite golfers with and without low back pain. A significant increase in low back pain was noted in CLBP subjects as a result of a typical 50-minute *practice session*. It would be interesting to investigate the effects of playing 18 holes on low back pain as opposed to a *practice session* considering other factors associated with playing a game of golf. It would seem walking 18 holes while carrying golf clubs and repeated bending while putting, combined with repetitive swings could potentially cause a greater increase in low back pain.

CHAPTER 5: SUMMARY AND FUTURE DIRECTIONS

Summary

The first purpose of this research project was to determine whether there were differences in the magnitude of abdominal muscle activity during the different phases of the golf swing between *elite* male golfers with and without CLBP. In addition, differences in the onset time of abdominal muscle activity during the golf swing between these two populations were investigated. No differences in abdominal muscle activity were noted during the golf swing between AC and CLBP subjects. Significant differences in EO (lead) muscle activity onset time were found between the two groups with respect to the start of the backswing. Significant differences in IO (lead) muscle activity onset time were also found between the two groups relative to the start of the downswing. No significant differences were found in RA, EO, and IO muscle activity during the *impact phase* of the golf swing between AC and CLBP subjects.

The second purpose of this research project was to determine whether *elite* male golfers with CLBP experience greater fatigue in the abdominal muscles than AC golfers following a typical 50-minute practice session. Other objectives were to determine whether differences exist between CLBP and AC golfers in abdominal muscle activity during the golf swing, muscle activity onset times during the golf swing, and abdominal muscle activity during the *impact phase* of the golf swing. Abdominal muscle fatigue did not occur as a result of a typical 50-minute *practice session* as measured with the EMG power frequency spectrum or with RMS.

Furthermore, ball speed did not significantly decease after the 50-minute *practice session* offering another potential indication of absence of fatigue. Significant differences were found between AC and CLBP subjects in EO (lead) muscle activity onset time relative to the start of the backswing following the *practice session*. External oblique (lead) muscle activity onset time (relative to the start of the backswing) occurred sooner than before the practice session for AC subjects, while later in CLBP subjects. No significant differences in muscle activity during the *impact phase* were found in either AC or CLBP subjects following the practice session.

Future Direction

This research project was the first of its kind to investigate abdominal muscle activity and abdominal muscle fatigue in elite male golfers with and without CLBP. Certainly more studies like this are needed in the future to better understand the relationship of abdominal muscle activity during the golf swing to CLBP. Future research should investigate muscle activity, kinematics of spine movement, and ground reaction forces simultaneously to gain a better understanding of the relationship of muscle function to lumbar spine movement. Future studies interested in abdominal muscle activity onset times may wish to measure muscle activity from upper limbs as a reference for abdominal muscle activity onset time. It would also be interesting to measure abdominal muscle activity during the golf swing of players with specific structural changes (osteophyte formation or degeneration) to the spine to gain a better understanding of the relationship of low back pain to abdominal muscle activity.

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APPENDIX A

General Golf Questionnaire

GENERAL GOLF QUESTIONNAIRE

Name:______________________ Age:______

Height (cm):______ Weight (kg):______ Swing: Right or Left

Class: A or B Title: (i.e. Head pro, Associate, Teaching)__________________.

Using the following scale, typically how often do you experience an increase in low back pain after a practice session? (Please circle one)

Never......rarely.......fairly frequently.......often.......always

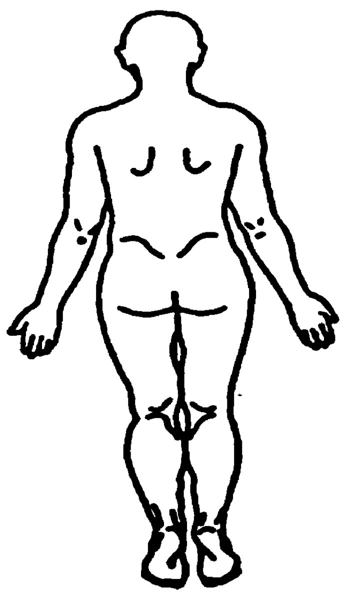
Using the following scale, typically how often do you experience an increase in low back pain after 18 holes? (Please circle one)

Never......rarely.......fairly frequently.......often.......always

How long (in months) have you experienced low back pain after playing or practicing?

___________.

If you experience back pain after playing or practicing please indicate (by shading) on the diagram below where you experience the pain the most.



On average, how many balls do you hit with each club during a practice session? Do not include putting practice. Do not include balls hit while giving lessons.

Driver_____, 3 wood_____, 5 wood_____, 1 iron_____, 2 iron_____, 3 iron_____,
4 iron_____, 5 iron_____, 6 iron_____, 7 iron_____, 8 iron_____, 9 iron_____,
PW_____, SW_____. TOTAL: ______

On average how long do your practice sessions for drive and/or fairway shots last?
__________.

How many practice swings do you take between each shot during your practice sessions?
_________.

On average, how many rounds of golf do you play in *a single month* during the following times of the year:

Early Season (April-May)______ Mid Season (June-Aug)______
Late Season (Sept-Oct)________ Off Season (Nov-Mar)_______

On average, how many sessions in *a single month* do you practice your drive and fairway shots during the following times of the year. Hitting balls before or after a round would count as a practice session. Do not include putting practice. Do not include balls hit while giving lessons.

Early Season (April-May)______ Mid Season (June-Aug)______
Late Season (Sept-Oct)________ Off Season (Nov-Mar)_______

Do you perform strength exercises at least 3 times a week to help your golf game or to prevent a golf injury? Y N

Do you perform endurance exercises at least 3 times a week to help your golf game or to prevent a golf injury? Y N

Do you perform stretching exercises at least 3 times a week to help your golf game or to prevent a golf injury? Y N

TABLE 8. GOLF QUESTIONNAIRE INFORMATION.
Number of balls hit during typical practice session and duration of a typical practice session.

Subject	# of golf balls hit during a typical practice session	Duration of typical practice session (minutes)
1	75	45
2	-	-
3	150	60
4	150	50
5	150	90
6	95	40
7	185	40
8	46	45
9	100	15
10	100	40
11	75	60
12	-	-
13	180	90
14	-	-
15	26	30
16	69	30
17	100	60
18	95	15
19	110	45
20	140	90
21	140	60
22	0	0
23	200	90
24	82	40
25	120	45
Mean	**108.6 ± 10.8**	**49.1 ± 5.3**

TABLE 9. NUMBER OF GOLF BALLS HIT DURING A TYPICAL PRACTICE SESSION. Number of golf balls hit during typical practice session with each club.

	AC subjects	CLBP subjects
Driver	12	16
3 wood	6	5
5 wood	3	3
1-iron	3	1
2-iron	4	4
3-iron	11	7
4-iron	7	4
5-iron	10	7
6-iron	5	7
7-iron	8	8
8-iron	8	6
9-iron	8	10
PW	15	14
SW	18	10
Total	**118**	**104**

APPENDIX B

Physical Activity Readiness Questionnaire

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

YES	NO	
____	____	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
____	____	2. Do you feel pain in your chest when you do physical activity?
____	____	3. In the past month, have you had chest pain when you were not doing physical activity?
____	____	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
____	____	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
____	____	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
____	____	7. Do you know of <u>any other reasons</u> why you should not do physical activity?

NOTE:

1. This questionnaire applies only to those 15 to 69 years of age.
2. If you have temporary illness, such as a fever or cold, or are not feeling well at this time, you may wish to postpone the proposed activity.
3. If you are pregnant, you are advised to discuss the "PARmed-X for Pregnancy" form with your physician before exercising.
4. If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

I have read, understood and completed this questionnaire.

Signature ______________________________ Date ______________________

Signature of Parent ____
or Guardian (for participants under the age of majority)

Witness ______________________________ Date ______________________

<u>Informed use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

APPENDIX C

Informed Consent Form

PARTICIPATION CONSENT FORM

Project title: Low back pain and abdominal muscle characteristics in elite male golfers.

Investigators: John F. Horton, Dr. Brian R. MacIntosh, and David M. Lindsay

This consent form, a copy of which has been given to you with the summary information, is only part of the process of informed consent. It should give you the basic idea of what the project is about, and what your participation will involve. If you would like more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully, to make sure you understand the scope of the study, and your involvement in the study as a subject.

There are three purposes of the proposed study. The first is to determine whether there are differences in the timing and magnitude of abdominal muscle activity during the golf swing between elite male golfers who experience chronic low back pain and asymptomatic control subjects. The second purpose is to investigate the effects of repetitive swings on abdominal muscle fatigue and recruitment patterns. The third purpose is to investigate the effects of two different forms of abdominal endurance training (isometric horizontal side support & sport specific tubing) on low back pain, abdominal muscle fatigue following an 8-week training program.

As a potential subject in this study you will initially be asked general questions regarding your playing and practice habits; and questions regarding the location and duration of possible back pain in order to classify subjects into a chronic low back pain group (CLBP) or asymptomatic control group (AC). If you are accepted into the study, you will then be required to perform submaximal isometric abdominal contractions to determine baseline muscle activity. Following this procedure, electromyographic data from the abdominal muscles will be collected while you hit golf balls into a net during a practice session lasting approximately 50 minutes. The skin will be prepared for placement of markers and electrodes by shaving the appropriate areas, abrading the skin with fine grade emery paper, and then cleaning the area thoroughly with an alcohol swab. Subjects that have been assigned to the CLBP group will then be further divided into 3 equal training groups: horizontal side support exercise group (HSS), sport specific tubing exercise group (SST), and a training control group (TC). Subjects in the HSS and SST training groups will be required to perform the specific exercises daily for 8 weeks. The TC group will not perform any abdominal exercises over the 8-week period. Following the 8-week training period, all subjects will visit the laboratory a second time to be re-tested using the same protocol as described previously. Prior to and at the end of each practice session subjects will be required to complete a severity of pain questionnaire. The time required complete the data collection in each practice session should take approximately 90 minutes.

There are no foreseeable risks involved in this study, although some subjects may experience minor irritation (rash) from the skin preparation for electrode placement. Your participation in this study is entirely voluntary, and you may withdraw at any time. It is also the right of the investigators to terminate your involvement in the study if such a need arises.

The benefits from this study will be numerous and widespread. Findings from this research will permit determination of characteristics of muscle activation sequence and intensity, which are unique to professional golfers who experience low-back pain. This will allow planning of appropriate conditioning and rehabilitative programs and or instruction to promote proper pattern of movement to reduce the incidence of low-back pain.

The results of this research study may be published but your name or identity will not be revealed. In order to maintain confidentiality of your records, John Horton, Brian MacIntosh, and David Lindsay will be the only people who will have access to your personal information and your results from this research. Subjects participating in this study will be given numbers to insure confidentiality, and to avoid bias when interpreting the results.

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in this study as well as the risks and benefits involved, and that you agree to participate. Furthermore, your signature indicates that there are no known medical reasons why you should not participate in this type of study. In no way does this consent waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. If you have any further questions concerning matters related to this research, please contact Dr. Brian MacIntosh, phone 220-3431. If you have any questions concerning the ethical aspects of this study, then you may feel free to contact the Office of the Vice-President, Research (220-3381), and ask for the name and phone number of the Chair-person of the Joint Faculties Research Ethics Committee.

Participant ____________________ ____________________ __________
(Name) (Signature) (Date)

Witness ____________________ ____________________ __________
(Name) (Signature) (Date)

Investigator ____________________ ____________________ __________
(Name) (Signature) (Date)

APPENDIX D

Total duration of the golf swing and phases

TABLE 10. DURATION OF GOLF SWING FOR CLBP SUBJECTS.
Total duration of golf swing and phases of the golf swing.

						% of duration of swing			
Subject	Duration of swing	Phase 1	Phase 2	Phase 3	Impact phase	Phase 1	Phase 2	Phase 3	Impact phase
1	1537.5	941.7	308.3	287.5	108.3	61.25	20.05	18.70	7.04
2	1666.6	1108.3	270.8	287.5	112.5	66.50	16.25	17.25	6.75
3	1391.7	850	266.7	275	116.7	61.08	19.16	19.76	8.39
4	1404.3	841.7	266.7	295.9	120.9	59.94	18.99	21.07	8.61
5	1529.1	975	308.3	245.8	116.6	63.76	20.16	16.07	7.63
6	1437.5	875	316.7	245.8	116.7	60.87	22.03	17.10	8.12
7	1320.9	800	270.9	250	104.2	60.56	20.51	18.93	7.89
8	1379.2	858.3	266.7	254.2	104.2	62.23	19.34	18.43	7.56
9	1708.4	1166.7	295.9	245.8	100	68.29	17.32	14.39	5.85
10	1675.1	1116.7	316.7	241.7	95.9	66.66	18.91	14.43	5.73
11	1295.8	800	270.8	225	100	61.74	20.90	17.36	7.72
12	1208.3	716.7	254.1	237.5	95.8	59.31	21.03	19.66	7.93
13	1225	733.3	225	266.7	104.2	59.86	18.37	21.77	8.51
14	1266.7	758.3	233.4	275	108.4	59.86	18.43	21.71	8.56
15	1641.7	941.7	308.3	391.7	125	57.36	18.78	23.86	7.61
16	1595	966.7	283.3	345	125	60.61	17.76	21.63	7.84
17	1375.1	841.7	287.5	245.9	116.7	61.21	20.91	17.88	8.49
1	1358.4	800	308.4	250	116.7	58.89	22.70	18.40	8.59
2	1754.2	1050	366.7	337.5	133.4	59.86	20.90	19.24	7.60
3	1783.4	1116.7	366.7	300	129.2	62.62	20.56	16.82	7.24
4	1475	950	275	250	100	64.41	18.64	16.95	6.78
5	1508.3	1025	220.8	262.5	91.7	67.96	14.64	17.40	6.08
6	1537.5	875	308.3	354.2	112.5	56.91	20.05	23.04	7.32
7	1520.8	891.7	304.1	325	108.3	58.63	20.00	21.37	7.12
8	1412.6	916.7	258.4	237.5	104.2	64.89	18.29	16.81	7.38
9	1416.7	937.5	245.9	233.3	104.2	66.17	17.36	16.47	7.36
10	1524.9	1008.3	254.1	262.5	100	66.12	16.66	17.21	6.56
11	1516.8	991.7	258.4	266.7	95.9	65.38	17.04	17.58	6.32
12	1350	791.7	279.2	279.1	108.3	58.64	20.68	20.67	8.02
13	1358.3	800	312.5	245.8	108.3	58.90	23.01	18.10	7.97
14	1370.8	800	308.3	262.5	120.8	58.36	22.49	19.15	8.81
15	1449.9	883.3	291.6	275	120.8	60.92	20.11	18.97	8.33
16	1370.9	862.5	258.4	250	95.9	62.91	18.85	18.24	7.00
17	1425	916.7	254.1	254.2	100	64.33	17.83	17.84	7.02
Mean	**1464.5**	**909.1**	**283.0**	**272.4**	**109.5**	**62.0**	**19.4**	**18.7**	**7.5**
SEM	**25.0**	**19.8**	**5.9**	**6.6**	**1.8**	**0.5**	**0.3**	**0.4**	**0.1**

TABLE 11. DURATION OF GOLF SWING FOR AC SUBJECTS.
Total duration of golf swing and phases of the golf swing.

						% of duration of swing			
Subject	**Duration of swing**	**Phase 1**	**Phase 2**	**Phase 3**	**Impact phase**	**Phase 1**	**Phase 2**	**Phase 3**	**Impact phase**
1	1583.3	1033.3	266.7	283.3	104.2	65.26	16.84	17.89	6.58
2	1483.3	933.3	291.7	258.3	104.2	62.92	19.67	17.41	7.02
3	1358.3	791.7	279.1	287.5	120.8	58.29	20.55	21.17	8.89
4	1375.0	791.7	270.8	312.5	120.8	57.58	19.69	22.73	8.79
5	1675.0	1104.2	275.0	295.8	120.8	65.92	16.42	17.66	7.21
6	1745.9	1154.2	287.5	304.2	120.8	66.11	16.47	17.42	6.92
7	1525.0	983.3	262.5	279.2	108.3	64.48	17.21	18.31	7.10
8	1475.0	925.0	258.3	291.7	112.5	62.71	17.51	19.78	7.63
1	1687.4	983.3	270.8	433.3	104.1	58.27	16.05	25.68	6.17
2	1554.1	866.7	279.1	408.3	104.1	55.77	17.96	26.27	6.70
3	1604.2	1091.7	275.0	237.5	100.0	68.05	17.14	14.80	6.23
4	1408.3	945.8	241.7	220.8	104.2	67.16	17.16	15.68	7.40
5	1275.0	766.7	266.7	241.6	100.0	60.13	20.92	18.95	7.84
6	1229.2	725.0	258.4	245.8	100.0	58.98	21.02	20.00	8.14
7	1508.3	979.2	279.1	250.0	112.5	64.92	18.50	16.57	7.46
8	1462.5	925.0	295.8	241.7	112.5	63.25	20.23	16.53	7.69
Mean	**1496.9**	**937.5**	**272.4**	**286.9**	**109.4**	**62.5**	**18.3**	**19.2**	**7.4**
SEM	**36.4**	**31.4**	**3.4**	**14.7**	**2.0**	**1.0**	**0.4**	**0.8**	**0.2**

AC & CLBP Combined

Mean	**1474.8**	**918.2**	**279.6**	**277.1**	**109.4**	**62.1**	**19.0**	**18.8**	**7.5**
SEM	**20.5**	**16.7**	**4.2**	**6.5**	**1.4**	**0.5**	**0.3**	**0.4**	**0.1**

APPENDIX E

Onset times during the golf swing

TABLE 12. ABDOMINAL MUSCLE ACTIVITY ONSET TIMES FOR AC SUBJECTS.

	Relative to start of backswing		Relative to start of downswing	
Subject	**EO (lead)**	**IO (trail)**	**EO (trail)**	**IO (lead)**
1	-22.0	-111.2	19.6	-86.7
2	-27.1	-161.7	-62.5	-89.6
3	-30.4	-54.5	-16.3	-92.5
4	111.7	47.5	-35	-85.4
5	87.9	58.7	-318.3	-175.4
6	-73.3	548.8	-73.4	-80.0
7	-100.5	-95.5	-14.1	-66.6
8	-79.3	-121.7	-5.4	-3.7
Mean	**-16.6**	**13.8**	**-63.2**	**-84.9**
SEM	**27.4**	**81.4**	**37.9**	**16.5**

TABLE 13. ABDOMINAL MUSCLE ACTIVITY ONSET TIMES FOR CLBP SUBJECTS.

	Relative to start of backswing		Relative to start of downswing	
Subject	**EO (lead)**	**IO (trail)**	**EO (trail)**	**IO (lead)**
9	-107.9	-104.6	-53.4	-45.9
10	-18.3	-120.0	-52.9	-4.6
11	35	-104.6	45.0	-126.3
12	37.1	-112.1	15.0	-67.5
13	221.7	10.0	-939.2	-18.3
14	69.6	85.4	-109.2	-58.8
15	43.4	15.9	-57.5	-41.7
16	-72.5	-113.3	44.2	57.1
17	53.7	-46.2	-62.5	-40.9
18	100.9	-45.0	98.0	-81.6
19	105.4	376.6	-79.2	-56.3
20	20.8	9.2	84.2	
21	178.7	436.2	-481.6	-15.4
22	50.9	80.9	-14.6	-117.5
23	79.6	-34.2	-82.1	-9.6
24	111.7	10.4	23.4	4.6
25	34.2	36.7	11.7	2.1
Mean	**55.5**	**22.4**	**-94.8**	**-38.8**
SEM	**19.4**	**38.6**	**61.3**	**11.7**

APPENDIX F

Effects Of Abdominal Endurance Exercises on Low Back Pain and AbdominalMuscle Fatigue In Elite Male Golfers

Introduction

Low back pain is the most common musculoskeletal problem affecting amateur and professional golfers (McCarroll, 1996; Sugaya et al., 1999). Although little is known about the exact causes of low back pain among golfers, development of such pain in amateur golfers is attributed to poor swing mechanics, excessive practice, and poor physical conditioning (McCarroll et al., 1990; Hosea & Gatt, 1996; Mallare, 1996). Altered swing mechanics combined with overuse may create repetitive abnormal stresses on the lumbar spine which might lead to injury and pain (Batt, 1993; Mackey, 1995; Sugaya et al., 1999). Professional golfers tend to exhibit better swing mechanics than amateurs, however, they may display poor physical conditioning as well.

Oblique abdominal muscles are known to be active throughout the golf swing especially during the *Acceleration Phase* and *Impact Phase* (Pink et al., 1993; Watkins et al., 1996). High levels of abdominal oblique muscle activity during the golf swing may cause muscular fatigue over time. A lack of endurance in the abdominal muscles might lead to muscle fatigue and thus play an important role in the development of low back pain in amateur and professional golfers (Mallare, 1996).

A number of epidemiologic studies have addressed the problem of low back pain in amateur and professional golfers and suggest the importance of proper conditioning of the trunk muscles as a form of rehabilitation. The few research studies in the literature dealing with conditioning in golfers primarily deal with increasing strength and flexibility for performance (Westcott et al., 1996; Hetu et al., 1998; Lennon, 1999).

Physical therapists have generally prescribed stabilization exercises for the trunk flexors and extensors as a form of rehabilitation for the treatment of low back pain (Casazza et al., 1998). The objective of exercise in the management of low back pain is primarily to gain strength and endurance; with the goal to prevent and reduce pain caused by excessive loading of the lumbar spine (Mälkiä & Kannus, 1996; McGill, 1998). Gradual and progressive endurance exercises for the trunk muscles are believed to be more beneficial for treatment of low back pain than strength exercises (McGill, 1998). Watkins et al. (1996) and Mallare (1996) suggest trunk muscle strength is important to both the recreational and professional golfer. They point out the need for a trunk-strengthening program for golfers that is oriented toward balance, coordination, and postural control to reduce the risk of injury and as a form of rehabilitation. The few research studies conducted in the past, however, have not been interested in the relationship between trunk muscle conditioning and low back pain. Rather, these studies primarily investigated the effects of strength and flexibility training on performance measures such as clubhead speed. (Westcott et al., 1996; Hetu et al, 1998; Lennon, 1999). There is certainly a lack of scientific research dealing with the rehabilitation of low back pain in golfers. No study to date has investigated the effects of abdominal muscle endurance training on low back pain and abdominal muscle fatigue following repetitive golf swings. The implementation of trunk exercises that specifically target the oblique muscles might be a key component in alleviating low back pain in professional golfers considering the role of these muscles during the rotational and lateral movements of the golf swing.

Purpose

The purpose of this study was to determine whether abdominal endurance exercises performed daily over an 8-week period were effective in alleviating low back pain and amount of abdominal muscle fatigue following a typical *practice session.*

Hypothesis

1. Following 8-weeks of abdominal endurance exercises, elite male golfers with CLBP will exhibit less abdominal muscle fatigue and less low back pain following a typical 50-minute practice session.

Subject Inclusion Criteria

Male teaching and/or club professional golfers within the Alberta Professional Golf Association, and low handicap (<5) amateurs within the Alberta Golf Association were given the opportunity to volunteer as subjects for this study. Potential subjects were initially asked to complete a general golf questionnaire (Appendix A) regarding the location, duration, and frequency of back pain, and their playing and practicing habits. Those individuals who had "never" experienced pain in the lumbar region of their back after practicing or playing during the six months prior to completion of the questionnaire were classified as asymptomatic control subjects (AC). Those individuals who had "always" or "often" experienced pain in the lumbar region of their back after practicing or playing for longer than six months prior to completion of the questionnaire were classified as chronic low back pain subjects (CLBP). Individuals were excluded from participating in the study if they were older than 55 years of age. All subjects completed a physical activity readiness form (PAR-Q) (Appendix B) and gave their informed consent (Appendix C) prior to any testing procedures.

Methods

All testing was conducted in the Human Performance Laboratory at the University of Calgary, Calgary, Alberta, Canada. Ethics approval was granted by the Conjoint Faculties Research Ethics Committee at the University of Calgary.

Testing Procedures

Testing periods consisted of a series of procedures, which were consistent for all subjects. Anthropometric (height and weight) measurements were first made followed by electrode placement on appropriate muscles. Next, a submaximal isometric contraction (double leg raise) was performed to gather muscle activity data to be used as a measure of fatigue followed by completion of a severity of pain questionnaire. After placement of electrodes, double leg raise, and completion of the pain questionnaire subjects were permitted to warm up for approximately 10 minutes to physically prepare for the *practice session*. The warm-up consisted of sub-maximally (1/2 swings) hitting golf balls into a net with an 8 iron. Subjects were asked to warm up in this manner until they felt ready to begin the standardized *practice session*. The warm-up also served to give indication of the adhesiveness of electrodes to the skin. Subjects then hit golf balls into a net at a rate of one every 30 seconds for 50 minutes. Immediately following the *practice session*, subjects performed the double leg raise again, and then completed the pain questionnaire again. This testing session was carried out prior to and following an 8-week intervention involving endurance exercises for the abdominal muscles.

EMG Data Recording

Each subject's skin was prepared for EMG electrode placement by shaving the appropriate areas, abrading the skin with fine grade emery paper, and then cleaning the area thoroughly with an alcohol swab. Pairs of AgAgCl surface EMG electrodes (10 mm active diameter) (CONMED Corporation, Utica, New York, USA) were attached to the skin approximately 25 mm apart (center to center) along the expected muscle fiber direction of the right and left rectus abdominis (RA) (3 cm lateral to umbilicus), external oblique (EO) (15 cm lateral to umbilicus at transverse level of umbilicus), and internal oblique (IO) (below external oblique & just superior to the inguinal ligament). A ground electrode was placed over the left anterior superior iliac spine. Inter-electrode distance and electrode placement were consistent with procedures by McGill et al. (1996) and Juker et al. (1998). EMG signals were pre-amplified and conducted through a battery powered unit (Biovision EMG System, Wehrheim, Germany; input impedance, 10^{12} Ohms; bandwidth, 10 to 1000 Hz). Amplifiers were not more than 12 cm from electrode sites and were taped to the body to minimize movement artifact of the EMG signal. Signals were sampled at 2400 Hz per channel and processed with EVa data collection software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA). A clear plastic template was use to ensure electrode placement during posttesting was the same as in pretesting.

Measure of Abdominal Muscle Fatigue (double leg raise)

Subjects were asked to raise their feet approximately 1 cm off the floor and hold the position as steady as possible. When the subject achieved a steady isometric contraction, EMG data were collected for 10 seconds. It did not take longer than 2 seconds for any subject to achieve the steady contraction. The double leg raise is known to require activation of all the abdominal musculature to stabilize the pelvis (Basmajian and DeLuca, 1985). The EMG data collected during the 10-second double leg raise maneuver was used to assess fatigue in the abdominal muscles before and after the practice session. The Sorensen test has previously been validated and used to assess back muscle endurance (Moffroid et al., 1994). These authors have used the median frequency of the EMG power spectrum during the Sorensen test as a measure of physiological muscle fatigue. It was felt that the double leg raise would offer a simple and effective means for assessing abdominal muscle fatigue following the practice session. Feedback from healthy pilot subjects indicated that it was difficult to perform the double leg raise for 30 seconds. Considering the well-being of the CLBP subjects, and to be consistent, it was decided that all subjects would perform the double leg raise maneuver for 10 seconds.

Pain Questionnaire

Subjects were required to complete a severity of pain questionnaire (McGill Questionnaire Short Form) as outlined by Melzack (1987) (Appendix D) prior to, and immediately following the practice session. The McGill pain questionnaire consists of 3 sections which provides information on the sensory, affective, and evaluative dimensions of pain experience. Descriptive words representing the sensory and affective dimension of pain experience are rated as either none, mild, moderate, or severe in section 1. A visual analog scale (VAS) is presented in section 2 with "no pain" being represented as "0" and the "worst possible pain" represented as "100". Section 3 is the Present Pain Intensity (PPI) scale. Subjects were asked to rate the intensity of pain on a scale of "0" to "5" where 0 = no pain; 1 = mild; 2 = discomforting; 3 = distressing; 4 = horrible; 5 = excruciating.

Practice Session

After placement of electrodes, the double leg raise, and completion of the pain questionnaire. subjects began by warming up for approximately 10 minutes. The warm up consisted of sub-maximally (1/2 swing) hitting golf balls into a net with an 8 iron. Subjects were asked to warm up in this manner until they felt ready to begin the standardized practice session. The warm-up also served to give indication of the adhesiveness of electrodes to the skin. Subjects then hit golf balls into a net at a rate of one every 30 seconds for 50 minutes with various clubs (9 iron, 7 iron, 5 iron, 3 iron, and 3 wood). Each club was used for 10 minutes, beginning with the 9 iron and finishing with the 3 wood. The duration and frequency of the ball striking session was determined from the general golf questionnaire where questions dealing with practice habits were asked (Appendix A). All subjects practiced in the same manner and were instructed to hit each shot with maximal effort. EMG data was not collected during this 50-minute ball *practice session*. Immediately following the 50-minute *practice session*, subjects were required to perform the double leg raise again. This was followed by completion the severity of pain questionnaire again.

8-Week Abdominal Exercise Intervention

Subjects assigned to the CLBP group were randomly divided into three training groups. One group performed daily isometric horizontal side support exercises (HSS) over a period of 8 weeks. A second group performed daily sport specific tubing exercises (SST) over a period of 8 weeks. Subjects in the third group did not perform any abdominal exercises during the 8-week intervention and acted as a training control group (TC). Proper technique for the HSS and SST exercises was demonstrated on the pre-testing day in the Human Performance Laboratory. Subjects in the HSS and SST training groups were also given written descriptions and diagrams pertaining to their particular training program.

Individuals in the CLBP group that were exercising at the time were permitted to continue with their normal programs, however, they were asked not to increase or decrease their activity level or begin any new abdominal exercises. Those subjects in the HSS and SST groups that were performing abdominal exercises at the time were permitted to continue to do so with the addition of the specific exercise required by involvement in this study. All subjects who participated in this study were required to keep a daily journal of activity during the 8-week training period. Following the 8-week training program all subjects were required to visit the laboratory a second time for post-testing where procedures were conducted in the same manner as described in pre-testing.

HSS Training

Subjects were asked to initially hold the horizontal side support in a modified position for as long as possible while timing themselves (Figure 24). This time was then used as a "hold time" for the rest of the 8-week training program and considered to be one set. Subjects performed 2 sets of this exercise on each side of the body daily for the first week and 3 sets on each side of the body daily during the second week.

FIGURE 24. ILLUSTRATION OF MODIFIED HSS.
This position was used during the first 2 weeks of training.

At the beginning of week 3, subjects were required to fully extend the body in during the HSS exercise (Figure 25). Subjects were again asked to time themselves while holding the position for as long as possible. This time was used as a "hold time" for the remainder of the 8-week training period. Subjects preformed 2 sets of the designated time daily on each side of the body during weeks 3 and 4. Subjects then performed 3 sets daily on each side of the body for the remainder of the 8-week training period.

FIGURE 25. ILLUSTRATION OF FULLY EXTENDED HSS.
This position was used during weeks 3-8 of training.

The HSS isometric exercise is known to be safe and effective for individuals with CLBP. McGill (1998) has found high levels of left side EO and IO muscle activity when performed with the left side of the body closer to the ground; and high levels of right side EO and IO muscle activity when performed with the right side of the body closer to the ground. McGill (1998) has also indicated that this exercise also creates low loads on the lumbar spine, which is a particularly important consideration for individuals with CLBP. Preliminary results from the present study supported the work of McGill (1998) by showing the EO and IO muscles to be particularly active during this maneuver (Table 8).

TABLE 14. ABDOMINAL MUSCLE ACTIVATION DURING HSS EXERCISE.
Represented as a percentage of submaximal muscle activation.

	Percentage of submaximal muscle activation					
	RA (left)	**RA (right)**	**EO (left)**	**EO (right)**	**IO (left)**	**IO (right)**
HSS (left side down)	**114.7**	35.2	**128.7**	13.6	**228.3**	86.9
HSS (right side down)	42.7	**78.4**	17.8	**132.3**	70.3	**152.3**

SST Training

Subjects were asked to perform as many repetitions as possible in the backswing direction (Figure 26). Subjects performed 2 sets of the number of repetitions initially "self determined" during weeks 1 and 2. Three sets were performed during weeks 3 and 4. Four sets were performed during weeks 5-8. A string was attached to each tubing apparatus to insure all subjects were training with the same tension.

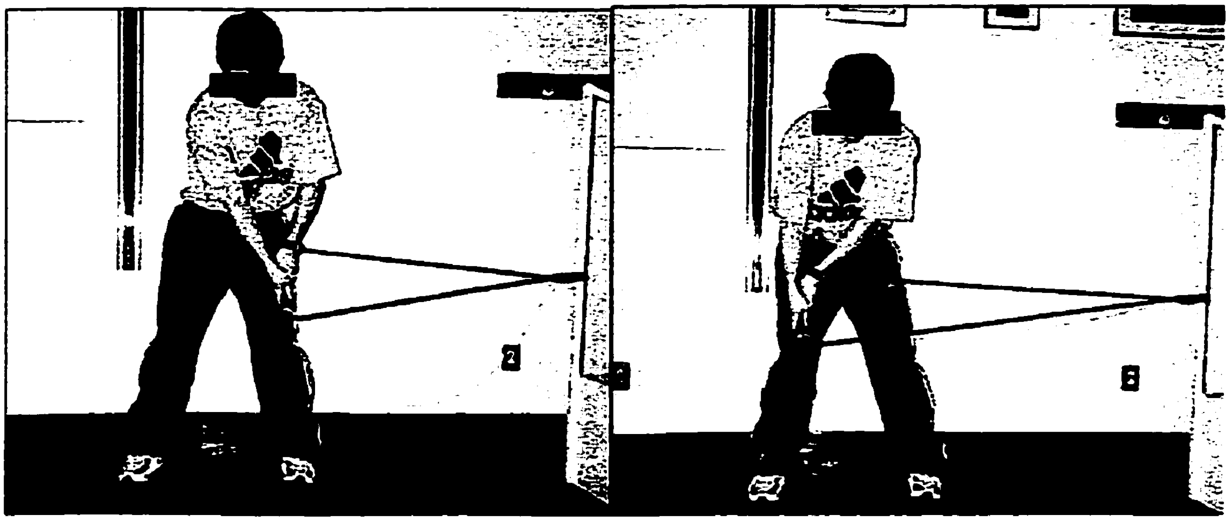


FIGURE 26. ILLUSTRATIONS OF SST EXERCISE DURING THE BACKSWING MOVEMENT. The illustration on the left is the starting position, while the illustration on the right is the finish position. One repetition was when the subject pulled against the resistance from the *lead side* to the *trail side*.

Subjects were asked to perform as many repetitions as possible in the downswing direction (Figure 27). Subjects were required to perform 2 sets of the number of repetitions initially "self determined" during weeks 1 and 2. Three sets were performed during weeks 3 and 4. Four sets were performed during weeks 5-8.

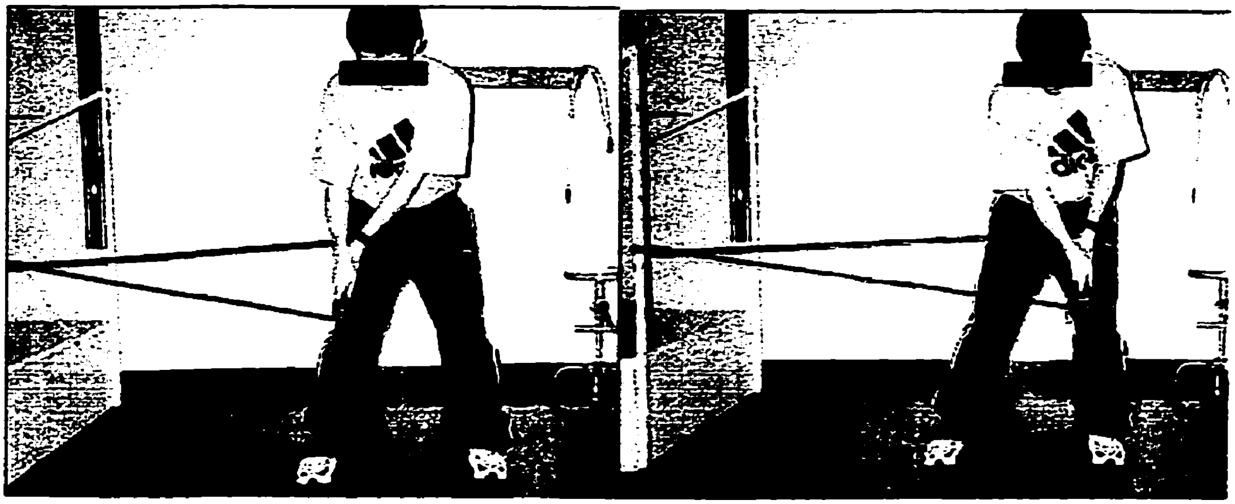


FIGURE 27. ILLUSTRATIONS OF SST EXERCISE DURING THE DOWNSWING MOVEMENT. The illustration on the left is the starting position, while the illustration on the right is the finish position. One repetition was when the subject pulled against the resistance from the *trail side* to the *lead side*.

The SST exercise was chosen because of its specificity to the golf swing. Preliminary data collection indicated the SST exercise predominantly trains the EO (lead) and IO (trail) muscles when performed in the backswing direction (Table 9), and trains the EO (trail) and IO (lead) muscles when performed in the downswing direction (Figure 26). When performed in the backswing direction, the EO (lead) muscle is approximately 2.5 times more active than EO (trail), and IO (lead) is approximately 8.5 times more active than IO (trail) (relative to submaximal activation) (Table 9). When performed in the downswing direction, the EO (trail) is approximately 2.5 times more active than EO (lead), and IO (lead) is approximately 6 times more active than IO (trail) (relative to submaximal activation) (Table 9).

TABLE 15. ABDOMINAL MUSCLE ACTIVITY DURING THE SST EXERCISE.
Abdominal muscle activity during the SST exercise in the backswing and downswing directions.

	Percentage of submaximal muscle activation					
	RA (lead)	**RA (trail)**	**EO (lead)**	**EO (trail)**	**IO (lead)**	**IO (trail)**
Backswing	7.4	6.6	**84.0**	32.8	35.9	**307.7**
Downswing	8.0	7.5	40.8	**99.6**	**122.4**	20.5

Data Analysis

Determination of Muscular Fatigue

The 10-second submaximal isometric contraction (double leg raise) was used to permit determination of muscular fatigue in the abdominal muscles before and after the *practice session*. The 10-second EMG signal was divided into 8 equal segments 1.25 seconds in duration (Figure 28). The median frequency (MF) of the EMG signal in each of these segments was then calculated (Kintrak, version 5.2, University of Calgary, Calgary, Alberta, Canada). The mean of the first 3 MF values -segments 1, 2, 3 was used to give an indication of muscular fatigue before and after the *practice session* (Figure 28).

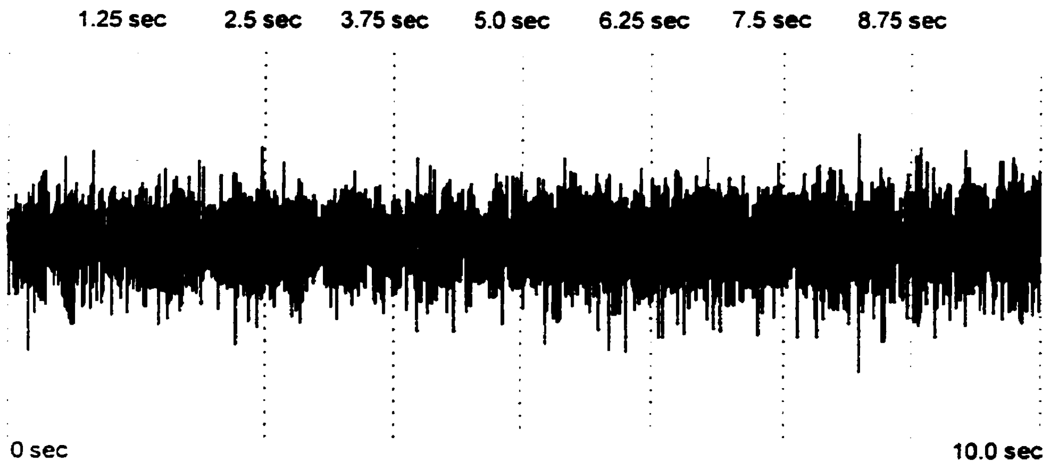


FIGURE 28. EMG SIGNAL OF SUBMAXIMAL ISOMETRIC CONTRACTION.
The area between each marker indicates segments where median frequency calculations were performed. Median frequency values were calculated from 8 equal segments.

Calculation of Ball Speed

Video data of ball movement was first tracked with EVa data collection software (Version 5.2, Motion Analysis Corp., Santa Rosa, CA). A mathematical program was written specifically to incorporate this data to calculate ball speed in m/s (Matlab, The Math Works, Inc., Natick, Mass). Ball speed in m/s was then converted to km/h (Microsoft Excel).

Statistical Analyses

All data were found to be normally distributed (Kolmogorov-Smirov Test). Paired t-tests were used to determine statistical differences in severity of low back pain following the practice session ($p<0.05$). A 3-way ANOVA with repeated measures was used to determine significant differences in abdominal muscle fatigue following the practice session after the 8-week exercise intervention ($p<0.05$). SPSS was used for all statistical analyses. The statistical analyses from this study are preliminary results and should be interpreted with caution, considering the small sample size in this study (n=3; n=7).

Results

Because of subject "drop out" during the 8-week exercise intervention, data from remaining subjects in the HSS and SST training groups were combined to represent "trained" subjects. "Drop out" also occurred within the training control group. Therefore, only data from 7 "trained" subjects and 3 "untrained" subjects were analyzed for this study. Reasons for subject "drop out" are detailed in Appendix G.

Demographic and Descriptive Information

Eight AC subjects (8 professionals) (29.4 ± 2.0 years; 81.7 ± 2.4 kg; 1.8 ± 0.0 m; 25.3 ± 0.6 BMI; Mean ± SEM), and 17 CLBP subjects (10 professionals, 7 amateurs) (36.1 ± 2.7 years; 81.8 ± 2.2 kg; 1.8 ± 0.0 m; 25.4 ± 0.6 BMI) participated in this study. Asymptomatic control subjects ranged from 20 to 39 years of age, while CLBP subjects ranged from 17 to 55 years of age. Three CLBP subjects were older than 50 years of age. Chronic low back pain subjects were individuals who had always experienced low back pain in the lumbar region of their back after playing or practicing for longer than six months prior to completion of the general golf questionnaire (Appendix A). The majority of CLBP subjects experienced low back pain either on the right side of the body or on both sides (Table 10). The CLBP subjects were individuals who had experienced low back pain for some time and continued to play golf regardless of their condition. CLBP subjects were, therefore, not asked to incur pain they would not have normally imposed on themselves.

TABLE 16. LOCATION OF LOW BACK PAIN OF CLBP SUBJECTS.

	Left	**Center**	**Right**	**Both sides**
# of responses	2	3	6	6
%	12	18	35	35

Severity of Low Back Pain

Significant differences were found in severity of low back pain following the pre-exercise intervention *practice session* in both training and training control groups ($p<0.05$) (Table 11). No significant differences were found in severity of low back pain following the post-exercise intervention *practice session* in both training and training control groups ($p>0.05$) (Table 11).

TABLE 17. VAS SCORES.
VAS scores before and after practice pre-intervention and post-intervention. Asterisks indicate significant differences ($p<0.05$).

Pre-Exercise Intervention				
	Before practice	**After practice**	**Change**	**% Change**
Trained (7)	20.0 ± 9.0	28.6 ± 9.9	8.6 *	43.0
Training control (3)	20.0 ± 20.0	41.7 ± 16.9	21.7 *	108.5
Post-Exercise Intervention				
	Before practice	**After practice**	**Change**	**% Change**
Trained (7)	20.7 ± 5.2	30.0 ± 8.1	9.3	44.9
Training control (3)	20.0 ± 15.3	23.3 ± 13.3	3.3	16.5

Abdominal Muscle Fatigue

No significant differences were found in abdominal muscle fatigue following the *practice session* after the 8-week exercise intervention (p>0.05) (Tables 12 & 13).

TABLE 18. MEAN MF VALUES PRE-EXERCISE INTERVENTION.

Mean MF Values Pre-Exercise Intervention

AC Subjects (8)						
	RA (lead)	**RA (trail)**	**EO (lead)**	**EO (trail)**	**IO (lead)**	**IO (trail)**
Before Practice	90.5 ± 7.8	83.4 ± 5.2	67.7 ± 4.1	59.6 ± 4.1	92.2 ± 10.3	92.2 ± 9.7
After Practice	88.3 ± 6.9	84.3 ± 5.4	67.3 ± 3.9	60.2 ± 2.9	89.9 ± 9.1	93.4 ± 9.2
Trained Subjects (7)						
	RA (lead)	**RA (trail)**	**EO (lead)**	**EO (trail)**	**IO (lead)**	**IO (trail)**
Before Practice	76.1 ± 4.9	86.9 ± 6.7	71.6 ± 5.3	70.8 ± 2.4	72.7 ± 7.9	81.7 ± 4.7
After Practice	76.8 ± 4.8	86.0 ± 6.9	74.6 ± 4.6	72.2 ± 3.2	66.8 ± 7.0	80.2 ± 6.6
Untrained Subjects (3)						
	RA (lead)	**RA (trail)**	**EO (lead)**	**EO (trail)**	**IO (lead)**	**IO (trail)**
Before Practice	80.6 ± 6.1	73.5 ± 1.6	63.9 ± 6.7	62.9 ± 4.3	81.3 ± 13.4	92.0 ± 23.3
After Practice	83.0 ± 7.7	73.5 ± 1.6	67.1 ± 7.5	63.3 ± 5.8	79.8 ± 12.5	101.1 ± 29.5

TABLE 19. MEAN MF VALUES POST-EXERCISE INTERVENTION.

Mean MF Values Post-Exercise Intervention

AC Subjects (8)

	RA (lead)	RA (trail)	EO (lead)	EO (trail)	IO (lead)	IO (trail)
Before Practice	87.9 ± 6.1	89.3 ± 2.9	62.5 ± 2.1	64.8 ± 5.2	105.1 ± 12.3	91.9 ± 10.9
After Practice	86.1 ± 6.4	88.9 ± 3.9	62.8 ± 2.3	68.8 ± 5.0	106.0 ± 12.7	94.4 ± 12.3

Trained Subjects (7)

	RA (lead)	RA (trail)	EO (lead)	EO (trail)	IO (lead)	IO (trail)
Before Practice	74.3 ± 4.9	85.8 ± 8.4	71.1 ± 2.3	65.6 ± 3.6	72.4 ± 8.7	74.9 ± 6.8
After Practice	72.2 ± 3.9	85.5 ± 7.8	71.9 ± 1.9	67.2 ± 3.4	70.1 ± 5.7	74.7 ± 8.2

Untrained Subjects (3)

	RA (lead)	RA (trail)	EO (lead)	EO (trail)	IO (lead)	IO (trail)
Before Practice	81.3 ± 7.6	78.6 ± 4.4	71.8 ± 6.7	65.6 ± 3.6	69.8 ± 7.4	86.7 ± 6.5
After Practice	79.3 ± 9.4	76.1 ± 3.3	71.8 ± 6.9	67.2 ± 3.4	57.7 ± 4.0	82.5 ± 6.5

Ball Speed

No significant differences were found in ball speed following the exercise intervention ($p>0.05$) (Table 14).

TABLE 20. BALL SPEED.
Ball speed before and after practice; pre and post exercise intervention.

	Pre-Exercise Intervention		
	Before Practice	After Practice	
	Ball Speed (km/h)	**Ball Speed (km/h)**	**% Change**
AC (8)	241.9 ± 2.9	242.2 ± 2.9	0.08
Trained (7)	225.1 ± 9.9	227.2 ± 6.3	0.91
Untrained (3)	255.4 ± 5.1	252.9 ± 4.9	-0.98

	Post-Exercise Intervention		
	Before Practice	After Practice	
	Ball Speed (km/h)	**Ball Speed (km/h)**	**% Change**
AC (8)	241.5 ± 4.0	241.5 ± 5.6	-0.02
Trained (7)	216.2 ± 5.2	216.6 ± 9.8	0.17
Untrained (3)	251.1 ± 1.4	252.6 ± 1.0	0.60

Discussion

The purpose of this study was to determine whether abdominal endurance exercises performed daily over an 8-week period would be effective in alleviating low back pain and amount of abdominal muscle fatigue following a typical *practice session*. Significant increases in severity of low back pain existed following the pre-intervention *practice session* for both "trained" and "training control" subjects ($p<0.05$), while no significant increases in severity of low back pain existed following the post-intervention practice session ($p>0.05$). The hypothesis that abdominal muscle fatigue would be reduced following the *practice session* as a result of training was not supported in this case. These findings should be interpreted with caution considering the small sample size as a result of "drop out".

A number of epidemiologic studies have addressed the problem of low back pain in amateur and professional golfers and suggest the importance of proper conditioning of the trunk muscles as a form of rehabilitation. The few research studies in the literature dealing with conditioning in golfers primarily deal with increasing strength and flexibility for performance (Westcott et al., 1996; Hetu et al., 1998; Lennon, 1999). These researchers were mainly interested in the effects of strength and conditioning on performance. The main objective was to increase clubhead speed or distance the ball travels. therefore it was logical to be interested in increasing strength and flexibility. No direct comparisons with these conditioning studies are possible with the present study. Some limitations of the present study include: (1) implementing the intervention during the golf season, (2) variability of number of training days for subjects, (3) small sample size, (4) questionable measure of fatigue. Considering the busy schedules of *elite* golfers during the golf season, a goal of the study was to determine if simple abdominal exercises performed daily (in season) could be effective in relieving low back pain and reducing abdominal muscle fatigue following a *practice session*. Scheduling problems existed which made it difficult to ensure the same period of time between pre-intervention and post-intervention testing. The number of days between pre-intervention testing and post-intervention testing ranged from 55 days (7.9 weeks) to 69 days (9.8 weeks). This variability was certainly a limitation of the study.

Surface EMG measurements become less reliable when made on the same subject after successive days between testing sessions. Questions of whether electrode placement is the same during posttesting as in pretesting is always a concern. To ensure electrodes were attached along the muscle fiber in the same direction and same distance from anatomical landmarks, a clear pliable piece of plastic was used in the present study to act as a template for electrode placement. Every effort was made to ensure electrode placement during posttesting was as near as original placements during pretesting.

Several subjects "dropped out" for various reasons beyond the control of the investigator. Considering the small sample size at the beginning of the study, the "drop out" makes it difficult to draw any conclusions about the effectiveness of the exercise intervention. Other possible reasons no changes in abdominal muscle fatigue were seen might be related to: (1) measure of fatigue (double leg raise) is not a validated measure of fatigue like the Sorensen test, (2) duration of double leg raise, (3) intensity of double leg raise. A more detailed discussion of these factors is found in Chapter 4.

Conclusions

Definite conclusions regarding the effectiveness of the abdominal endurance exercises on reducing low back pain and fatigue following a *practice session* cannot be made at this time. A lack of scientific studies investigating the effectiveness of rehabilitation programs on low back pain in golfers exists. Given the extremely busy schedules of *elite* golfers, it would be more appropriate to conduct exercise interventions during the off-season. Future studies should first validate measures for abdominal muscle fatigue specifically for golfers, and then focus on endurance and fatigue measures of the trunk muscles rather than purely strength for increasing performance.

APPENDIX G

Reasons for Subject Drop Out

TABLE 21. REASONS FOR "DROP OUT" OR TERMINATION FROM STUDY.

Subject	Reason for "Drop out" or Termination from Study
17	Lives in Edmonton and could not find time to come back to Calgary for posttesting
18	Repeated "no shows" and cancellations of scheduled testing sessions
19	Repeated "no shows" and cancellations of scheduled testing sessions
20	Back pain became worse
21	Involved in car accident
22	Lives in Edmonton and could not find time to come back to Calgary for posttesting
23	Back pain became worse