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Lead Hip Kinematics and Weight Bearing Patterns of Amateur Golfers With and Without Low Back Pain

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Kinesiology

LEAD HIP KINEMATICS AND WEIGHT BEARING PATTERNS IN AMATEUR MALE GOLFERS WITH AND WITHOUT LOW BACK PAIN

by

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Graduate Program in Kinesiology

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Abstract

Purpose**:** The purpose of this study was to investigate the relationship between lead hip kinematics, weight bearing patterns and lumbar kinematic differences between golfers who experience golf related low back pain and golfers who do not. Methods: A total of 12 amateur male golfers were recruited, 7 without low back pain and 5 with low back pain. IRED motion capture was used to determine kinematics and two force plates were used to collect kinetic data. Results: Low back pain golfers externally rotated their lead hip significantly less during address ($p = 0.048$), and internally rotated their lead hip significantly more at peak follow through ($p=0.030$) than golfers without low back pain. Golfers with low back pain bore significantly more body weight on their rear leg ($p=0.030$) at peak follow through then golfers without low back pain. No statistically significant difference was found between groups for lumbar spine kinematics at any phases of the swing. Conclusion**:** This study identified a significant relationship between the orientation of the lead leg segment during the address position and at peak follow through with respect to golf related low back pain. These findings may be an important teaching tool for reducing the risk of golf related low back pain.

Keywords

Golf, Hip, Low, Back, Pain, Internal Rotation, Kinematic, Kinetic

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Table of Contents

Abstract ii

Acknowledgments iii

Table of Contents iv

List of Figures and Tables vii

Chapter 1 1

1 Literature Review 1

1.1 Injury incidence and occurrence 1

1.2 Physical Traits of golfers with low back pain 2

1.3 Golf swing kinematics 3

1.4 Golf swing Kinetics 5

2 Introduction 6

2.1 Kinematics 7

2.2 Kinetic Measures 10

2.3 Purposes 12

2.4 Hypotheses 12

Chapter 2 13

3 Methodology 13

3.1 Participants 13

3.2 Instrumentation 14

3.2.1 Kinematic Equipment 14

3.2.2 Kinetic Equipment 17

3.2.3 Microphone 18

3.3 Golf Equipment 18

3.4 Calibration 18

3.5 Procedures 21
3.5.1 Lead hip internal range of motion test 21
3.5.2 Warm up 22
3.5.3 Golf Swing Testing 22
3.6 Post Processing 23
3.7 Data Reduction 24
3.8 Statistical analysis 25
Chapter 3 25
4 Results 26
Chapter 4 37
5 Discussion 37
5.1 Kinematic Measures 37
5.1.1 Lead Hip Orientation 37
5.1.2 Lead foot Orientation 41
5.1.3 Range of motion test 43
5.1.4 Lead hip range of motion test vs peak follow through lead hip internal rotation 45
5.1.5 Pelvic orientation 47
5.1.6 Lumbar axial rotation 47
5.1.7 Lumbar lateral bend 49
5.1.8 Lumbar flexion/extension 50
5.2 Kinetic Measures 51
5.3 Limitations 53
Chapter 5 55
6 Conclusion 55
References ..... **Error! Bookmark not defined.**

Appendix.. 62

List of Figures

Figure 1: Ben Hogan's suggestions for positioning of the feet for different clubs................. 8

Figure 2: Components of the experiment set up.. 16

Figure 3: Thoracic Rigid body assembly (above) sacrum rigid body assembly (below). 17

Figure 4: Location of calibration markers 19

Figure 5: Rotating platform used for lead hip internal range of motion test 22

Figure 6: Lead foot orientation for both golfers with and without low back pain during address, at ball contact and peak follow through. 26

Figure 7: Lead hip internal/external rotation for golfers with and without low back pain during address, at ball contact and peak follow through. 27

Figure 8: Pelvic orientations in the transverse plane for golfers with low back pain and golfers without low back pain during address, at ball contact and peak follow through........ 28

Figure 9: Lumbar axial rotation for golfers with and without low back pain during address, at ball contact and peak follow through. 29

Figure 10: Lumbar lateral bend for golfers with and without pain during address, ball contact and peak follow through.. 30

Figure 11: Lumbar flexion/extension angle for golfers with and without low back pain at address, ball contact and peak follow through. 31

Figure 12: Percentage of bodyweight on the rear foot for golfers with and without low back pain during address, at ball contact and peak follow though. 32

Figure 13: Percentage of bodyweight borne on the front foot for golfers with low back pain and golfers without low back pain during address, ball contact and peak follow though. 34

Figure 14: Internal rotation range of motion of lead hip of golfers with and without low back pain.. 35

Figure 15: Difference in lead hip internal rotation range of motion test angles compared to lead hip internal rotation at peak follow through.. 36

Table 1: Participant Information ……………………………………………………………13

Appendix A – Low back pain questionnaire

Chapter 1

1 Literature Review

1.1 Injury incidence and occurrence

Golf related lower back injuries can be divided into two types: chronic and acute injuries (Cabri et al., 2009). Chronic injuries, despite the cause, develop over time. In contrast, acute injuries are unforeseen events, such as a golfer hitting a root or rock during their golf swing. This literature review will focus on the more common, chronic lower back injuries (Finn, 2013).In a year-long retrospective mail survey of 1021 Australian amateur golfers, 93 injuries were observed in 78 golfers (McHardy et al., 2007a). This is equivalent to 15.8 injuries per 100 golfers per year. Lower back injuries were identified as the most common injury site (18.3%), followed by elbow and forearm (17.2%) then shoulder (11.8%). Injury mechanism was also reported; 46.2% of the injuries were attributed to the golf swing itself, and 23.7% were attributed to overuse. Participants attributed ball contact in which 23.7% of injuries occurred, the majority of which were wrist and elbow injuries. Follow through was attributed for 21.5% of total injuries. However, low back injuries were spread evenly across all components of the swing. McHardy et al. (2007a) also reported that 61.3% of injured golfers sought medical attention, 47.4% of which consulted a medical practitioner such as chiropractor or physiotherapist.

In a similar retrospective cohort study, the injury data of 703 golfers (643 amateur, 60 professional) was analyzed using a 6 page injury questionnaire (Gosheger et al., 2003). The authors reported that 82.6% of injuries were a result of overuse. Injury rate was higher in professionals (3.06 per golfer) than amateurs (2.07 per golfer). The most commonly reported professional injury site was the spine (34.5%). Amateurs reported elbow (24.9%) as the most common injury site, followed closely by the spine (24.7%). Severity of reported injuries was minor (51.5%), moderate (26.8%), and major (21.7%).

A similar study by (Fradkin et al., 2007) analyzed the injury data of 304 golfers using a questionnaire that covered demographics, golf and warm up history over a 12 month history. 36.5% of golfers reported injuries in the 12 month period (111 injuries). Of these injuries, 37.8% were strains. The most commonly reported mechanism of injury was overuse (29.7%). The most common anatomical location was the back (40 of the 111 injuries). Similar to previously reported data, 64% of golfers missed participation due to injury, and 51.3% reported that their injury had an impact on their daily lives.

The previously mentioned studies do not identify specific structures injured, only the anatomical area. Golf related low back pain can present itself in several ways such as disc herniation, spondylosis, facet pain as well as muscle strain or spasm (Reed and Wadsworth, 2010). Considering that overuse is the major cause of injury in golfers, and the majority of injuries involve the lower back region, it is not surprising that some studies report muscle strains as the most common form of low back injury in golfers (Fradkin et al., 2007).

1.2 Physical Traits of golfers with low back pain

The lower back plays a prominent role in the golf swing. In kinematic terms, a golf swing involves left and right lumbar axial rotation, lumbar flexion and extension as well as left and right bending (Zheng et al., 2008). A comparative study looked at physical characteristics of golfers with and without low back pain and reported that golfers with low back pain presented significantly less lumbar extension flexibility, as well as reduced left hip adduction strength (Tsai et al., 2010). An earlier study by the same authors reported that golfers with low back pain demonstrated reduced hamstring flexibility as well (Tsai, 2005).

The hip joint has also been implicated in golfers with low back pain. The hip joint is the articulation between the proximal femur and the acetabulum. The primary hip motions are flexion/extension, ab/adduction and internal/external rotation, and circumduction. Specific muscles act to produce moments in each of these directions. For example, the gluteus medius muscle is one of the muscles which produces external rotation moments (Prins and Van Der Wurff, 2009). Significant limitations in lead hip passive internal rotation has been reported in golfers with low back pain (Kim et al., 2015; Gulgin, 2005; Vad et al., 2004; Murray et al., 2009) compared to golfers without low back pain. Golfers with a known limited lead hip internal rotation range of motion (<20 degrees) also demonstrated a reduction in lead hip range of motion during a golf swing compared to matched control golfers with a normal lead hip range of motion (>20 degrees) (Kim et al., 2015). Unfortunately no information on low back pain prevalence in these golfers was presented in this study.

1.3 Golf swing kinematics

Golf, like many sports, has gone through an evolution in recent decades in regards to equipment as well as technique. One documented technique change in professional golfers is a transition from “The Classic Swing” to “The Modern Swing” (Vad et al., 2004). The kinematic and kinetic differences between the modern and classic swing are suggested as a potential cause of low back pain in golfers. The modern golf swing emphasizes an increase in shoulder rotation along with limited hip rotation during the backswing (Gluck et al., 2008). This restricted hip rotation is accomplished by keeping the lead foot firmly planted on the ground during the backswing rather than by lifting the heel. By restricting the hip rotation a separation is created between the transverse axis of the hip segment and shoulder segment, which has been termed the “X-factor”. The X-factor created during the modern swing has itself been suggested as a cause of low back pain in golfers (Vad et al., 2004). Cole and Grimshaw (2009) identified that low handicap golfers demonstrated reduced hip rotation during the back swing, paired with increased shoulder rotation, compared to high handicapped golfers. There may be a relationship between X-factor and performance, however, the X-factor as a risk factor for low back pain has only been suggested, not been proven (Vad et al., 2004) . Grimshaw and Burden (2000) investigated this notion in a case study where swing mechanics were altered in an attempt to reduce low back pain. The participant shortened their back swing, reducing the separation between the hips and shoulders, lowering their X- factor. The participant’s low back pain was alleviated within a three month period. The authors did not report any kinematic data on the follow through phase and it would have been interesting to see if there was any changes in the hip and shoulder ranges of motion in the follow through associated with the swing alterations. Lindsay and Horton (2002a) investigated spinal motions of golfers with and without low back pain, but did not observe any significant relationship between X-factor and low back pain.

Lumbar lateral bending has also been indicated as a kinematic difference between the modern and classic swing. Lateral bending refers to the position of the thoracic spine relative to the pelvis and lumbar spine. In the modern swing, golfers laterally bend their torso toward target, while rotating axially away from target, as they perform their back swing. The lateral bending is thought to increase the amount of shoulder rotation, which would lead to an increased X factor (Grimshaw and Burden, 2000).

Only one study reported lead foot orientations during the golf swing. Lynn and Noffal (2010) reported that increased rotation of the lead foot toward the desired target decreased knee moments in the frontal plane. We are not aware of any studies that have evaluated the relationship between lead foot orientation and golfer’s low back pain.

1.4 Golf swing Kinetics

Several studies have investigated the ground reaction forces of skilled compared to unskilled golfers, establishing clear differences in weight transfer patterns between the two groups (Okuda et al., 2010; Queen et al., 2013; Keogh and Reid, 2005). However little literature exists comparing the ground reaction forces of golfers with and without low back pain. A 2005 paper collected ground reaction forces from golfers; it reported that there was no significant difference between spinal loads of golfers with and without low back pain while swinging a driver (Tsai, 2005). Unfortunately weight bearing patterns were not reported in this study. Accordingly, given the significant differences in weight bearing patterns within golfers of high and low skill level, this is a fruitful avenue for future low back pain research.

2 Introduction

Approximately 27.1 million individuals participated in amateur golf in North America in 2010 and that number is expected to increase to nearly 30 million by the year 2020 (Beditz and Kass, 2010). Older golfers (over 50 years old) have been reported to make up 25% of the golfer population, however this older population is responsible for nearly half of the rounds played in a season (Beditz and Kass, 2010). With the increasing age of the general population, an increase in the percentage of golfers that are 50 years or older is also expected. The layperson's perception of golf is a leisurely game that is acceptable for the elderly, as it is thought to have a low risk of injury and to not be very physically demanding (Vandervoort et al., 2012). However, when examined biomechanically, a full golf swing includes extreme ranges of motion (Sinclair et al., 2014) as well as large joint moments and compressive forces at several joints including the knees, hips and spine (Ferdinands et al., 2014). These stressors compound with reduced flexibility and muscle tone in aging individuals and may result in injury (Versteegh et al., 2008).

Between 15.8 and 36.5% of amateur golfers experience an injury in a season (McHardy et al., 2007a; Fradkin et al., 2007; McHardy et al., 2007b). Of these injuries, 82.6% have been identified as chronic injuries that developed over time. Interestingly, the low back region has been reported as the most common injury site in amateur players and the second most common professionals (Sutcliffe et al., 2008; McHardy et al., 2007a; Fradkin et al., 2007). Of the chronic injuries reported, overuse was the self-reported cause of injury in several anatomical regions, including the elbow, knee and the low back (24% of injuries) (Gosheger et al., 2003). It was also reported that 46.9% of reported low back pain was attributed to poor swing technique, and the golfers identified that 41.6 % of low back pain occurred during the follow through (McHardy et al., 2007b). These factors may compound such that overuse and poor swing technique could be comorbid causes of low back pain. While player skill and golf exposure do not seem to differentiate whether individuals experience low back pain while golfing, it appears that there may be differences in swing technique between players who experience pain, and those that do not.

2.1 Kinematics

The first potential difference between golfers with and without low back pain may be related to how the individuals orientate their lead foot in relation to their desired target. This aspect of the golf setup has been overlooked in the scientific literature. Especially regarding any considerations for a causal relationship between lead foot orientation and low back pain. For optimal golf performance, Ben Hogan, one of the game's greatest champions, listed proper lead foot orientation during the address position as part of lesion #2 in his classic book entitled Five Lessons of Golf (Hogan, 1985). He stated that the foot of the lead leg (the leg closest to target) should be rotated towards the target "a quarter turn". See Figure 1.

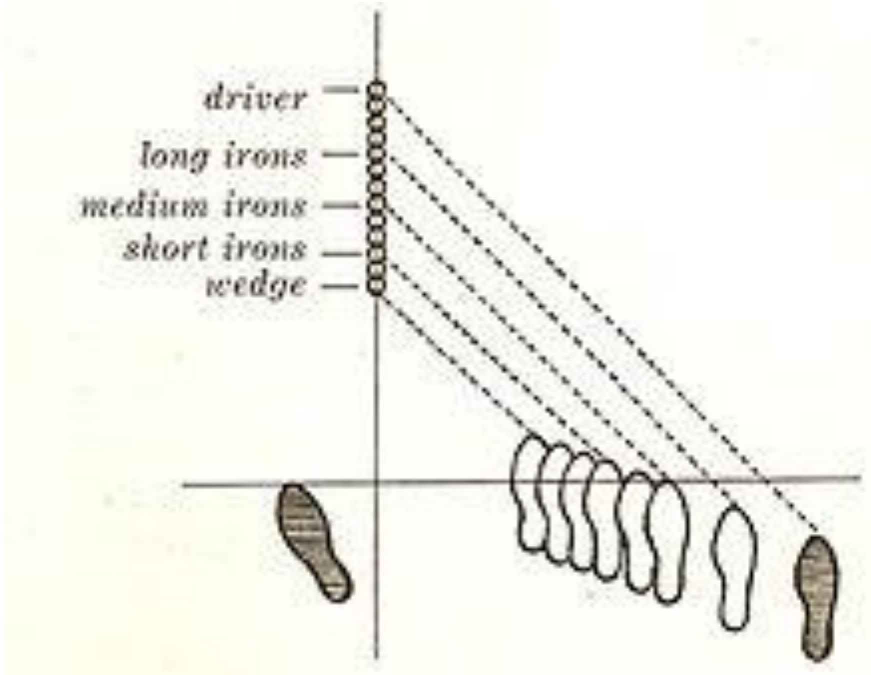

Figure 1: Ben Hogan’s suggestions for positioning the feet for different clubs. The left Foot is lead foot, and he suggests that it should be externally rotated toward the target. Adapted from Five Lessons of Golf (Hogan, 1985).

This rotation of the lead foot will cause an associated external rotation of the lead hip in the address position prior to the initiation of the back swing. The relationship between the orientation of the lead foot, knee moments and lead knee injuries has been investigated in golfers (Lynn and Noffal, 2010). However, the effect of the lead foot orientation on lead hip kinematics in golfers who experience low back pain has not been investigated. It is not known if the lead foot orientations are different between golfers with and without low back pain.

The orientation of a golfer’s lead foot at address will carry over and affect the kinematics of the lead hip during a golf swing; these lead foot orientation differences would contribute to the magnitude of internal and external rotation in the lead hip throughout a golf swing. A golfer's lead hip passive internal and external range of motion is one physical factor that may influence lead foot orientation and therefore lead hip kinematics during the swing. Significant differences in lead hip passive internal rotation ranges of motion have been identified in golfers with and without low back pain. For example, Murray et al 2009 reported that golfers with low back pain, in a prone position with a flexed knee, presented 10° less lead hip internal rotation than golfers without pain. Similarly (Vad et al., 2004) reported that golfers with low back pain had significantly lower FABRES scores (measure of hip rotation) as well as significantly lower lead hip internal ranges of motion. There have also been several case studies which have identified limited internal rotation of the lead hip as a potential risk factor for low back pain in golfers. In these case studies, specific treatment and exercises have been administered for improving lead hip range of motion, resulting in a reduction of low back pain symptoms (Reinhardt, 2013; Lejkowski and Poulsen, 2013). Although informative, these interventions focused on increasing passive hip range of motion outside of the dynamic golfing context and did not include swing or foot orientation modifications. Kim et al (2015) is the first research study to report significant lead hip kinematic differences in golfers with measured deficits in internal hip range of motion when compared to non-limited internal hip range of motion controls. They studied the kinematic differences between thirty professional male golfers with either limited hip internal rotation (range of motion <20º) or the normal hip internal rotation (range of motion ≥30º). Golfers with limited lead hip internal rotation presented greater lumbar flexion, right and left lumbar spine axial rotation and right side bending than golfers with normal hip internal rotation. Unfortunately this study did not report any information regarding history of low back pain. Bilateral hip range of motion differences have also been identified in female golfers when compared to non-golfing control groups in passive internal rotation rests, however no regard to low back pain was given (Gulgin, 2005; Vad et al., 2004). Differences in pelvic and hip kinematics during sport participation have also been reported in athletes with and without low back pain who participate in other rotational sports, such as judo and baseball (Almeida et al., 2012; Van Dillen et al., 2008). At the current time, the literature has shown that low back pain golfers have limited passive internal range of motion in their lead hip, and golfers with limited passive internal range of motion in their lead hip have been shown to have altered swing kinematics. The goal of this study is too go one step further by investigating the relationship between lead limb hip internal rotation and joint kinematics in both golfers that experience low back pain associated with golfing and those that do not.

2.2 Kinetic Measures

Along with kinematic differences, there are also kinetic differences between golfers. Significant differences have been identified in the weight transfer patterns of skilled versus unskilled golfers during the backswing, downswing and the peak maximum vertical ground reaction force of the lead leg (Okuda et al., 2010). In contrast, some studies have not identified differences between skilled and unskilled golfers. For example, Richards et al., (1985) identified similar medial-lateral weight transfer patterns between golfers with a low handicap (<10) compared to those with a high handicap (>20). However, the author did identify differences between the anterior/posterior weight transfer between groups. Nevertheless, little research has evaluated differences in kinetics between golfers with and without low back pain. One study has reported vertical ground reaction forces between golfers with and without low back pain (Tsai et al., 2010). Although they did not report the weight distribution data, they did use the raw ground reaction force data to compare spinal joint moments between groups. They did not find statistically significant differences between groups (Tsai et al., 2010).

Two distinct swing styles regarding weight transfer have been identified: the front foot style and the reverse style (Ball and Best, 2007). Weight transfer is similar at address and back swing between the two styles; the differences are during the downswing. During the front foot style the center of pressure moves to the front foot earlier in the downswing and during ball contact, whereas during the reverse style the center of pressure moves to the back foot during ball contact and follow-through (Ball and Best, 2007). They did not investigate the relationship between level of handicap and swing style. No kinematic research specifically focusing on these two swing styles has been reported, nor has the relationship between these kinetic swing styles and low back pain been investigated. A potential reason for the center of pressure moving to the rear foot in the reverse style would be an increased lateral trunk lean away from target. This movement pattern has been labelled as the reverse C position (Finn, 2013), which is a component of what some authors call the modern golf swing. The reverse C position has been reported as an excessive lateral lean and spinal extension from ball contact to follow through (Finn, 2013). The kinematics inherent in the reverse C are consistent with the kinetic reverse style as described by Ball and Best (2007). This thesis will investigate the relationship between the presentation of low back pain in golfers and weight transfer patterns during the golf swing.

2.3 Purposes

The primary purpose of this thesis was to investigate the relationship between lead hip kinematics of golfers who experience low back pain in relation to golfers without pain. This purpose also encompasses evaluation of the lead foot orientation given its influence on the lead hip internal rotation. The secondary purpose was to investigate the relationship between weight bearing patterns of golfers who experience low back pain and golfers without low back pain. The final purpose was to investigate the relationship between lumbar spinal kinematics between groups.

2.4 Hypotheses

It was hypothesized:

- that golfers with low back pain will have reduced internal rotation of the lead hip when compared to the golfers without low back pain at peak follow through
- Golfers with low back pain will have an increased percentage of body weight on the trail leg during address, ball contact and follow through in relation to golfers without pain
- Golfers with low back pain will have increased axial separation between the thorax relative to the sacrum when compared to golfers without pain

3 Methodology

3.1 Participants

Twelve male recreational golfers between the ages 52-63 (mean = 57) were recruited through a poster campaign at local golf facilities in the area. Each participant completed a low back pain questionnaire (APPENDIX) and based on their answers they were pain. Inclusion criteria were as follows. Golfers without low back pain: must play a minimum of 18 holes of golf per week, 30-65 years of age and no history of golf related low back pain within the last year of play, no other lower body injuries (within 6 months). Golfers with low back pain: must play a minimum of 18 holes of golf per week, 30-65 years of age and they have experienced at least one episode of golf related low back pain within the last year of play. This was defined as pain in the low back musculature during or following a round of golf. The participants believed that their low back pain was directly related to golf, however it did not restrict or stop them from playing or practicing. Individuals were not eligible to participate in the study if they reported any diagnosed low back disorder (such as herniated discs or previous spine surgery) or lower body injury (such as knee or hip replacements) which would potentially alter their normal golf swing. Five of the twelve participants were classified as golfers with low back pain and seven were classified as golfers without low back pain. Their basic demographics are presented in Table 1.

Table 1: Participant information, including their swing direction, amount of golf played per week, handicap, the location and type of their low back pain.

Group	Swing	Rounds/wk	Handicap	Pain Location(side)	Type	Age
No Pain	Right	3	16	--	--	63
No Pain	Right	5	7.6	--	--	56
No Pain	Right	3	15	--	--	54
No Pain	Right	3	8	--	--	52
No Pain	Right	3	9	--	--	55
No Pain	Right	2	9	--	--	52
No Pain	Right	1	18	--	--	54
PAIN	Left	4	10	BOTH	STRAIN	57
PAIN	Right	1	24	BOTH	STRAIN	56
PAIN	Right	1	18	BOTH	STRAIN	60
PAIN	Right	2	22	LEAD	STRAIN	65
PAIN	Right	1	24	LEAD	STRAIN	59

All but one participant swung right handed, as in the path of their club went from right to left. All kinematics and kinetic data were harmonized as if they were right handed, and accordingly this thesis will refer to the left limb as the lead limb and the right limb as the trail limb. The participants had unofficial handicaps ranging from 8-24. The study was approved by Western’s Health Sciences Research Ethics Board, and written informed consent was obtained from all participants.

3.2 Instrumentation

3.2.1 Kinematic Equipment

All kinematic data was collected using a system of three Optotrak 3020 camera banks connected to an Optotrak System Control Unit (Northern Digital Inc., Waterloo, Canada). First Principles software (Version 1.2.4, Northern Digital Inc.) was used for data collection and post processing. Three rigid bodies were constructed: shank, sacrum and thorax. Each rigid body was composed of a wooden base with wired Infra-Red Emitting

Diodes (IREDs) securely attached that served as markers. The shank rigid body had four IREDs, the sacrum and thoracic rigid bodies both consisted of eight markers. Two Optotrak cameras were vertically mounted 6.7 m apart on the left and right posterior wall at a 45 degree angle to the participants hips (Figure 1). The third camera bank was horizontally mounted on a 0.3 m tall platform which was located 3.9 m in front of the golfer. All kinematic data was recorded in 100 Hz. All participants wore a cotton t-shirt with the back removed in order that the rigid bodies were visible. The sacrum rigid body was secured on the midline between the left and right posterior superior iliac spines using a velcro belt around the waist as well as double-sided tape attached directly to the skin. The thoracic rigid body was attached as close as possible to the spinous process of the 8^{th} thoracic vertebrae. It was affixed directly to the skin using double sided tape. An additional block was mounted to the underside of the thoracic rigid body so that the face of the rigid body sat above the musculature on either side of the spine (Figure 2).

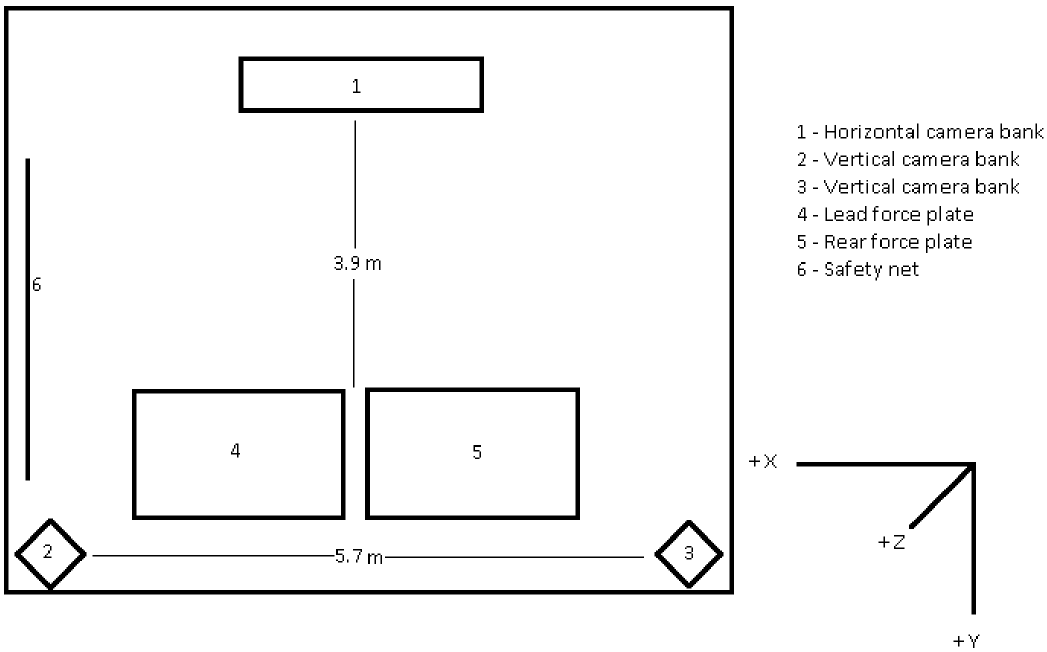

Figure 2: Components of the experiment set up. The golfers stood with one foot on each force plate (labelled 4 and 5) and drove foam golf balls into the safety net. Their kinematics were tracked using the Optotrak camera banks which encircled them (labelled 1, 2 and 3).

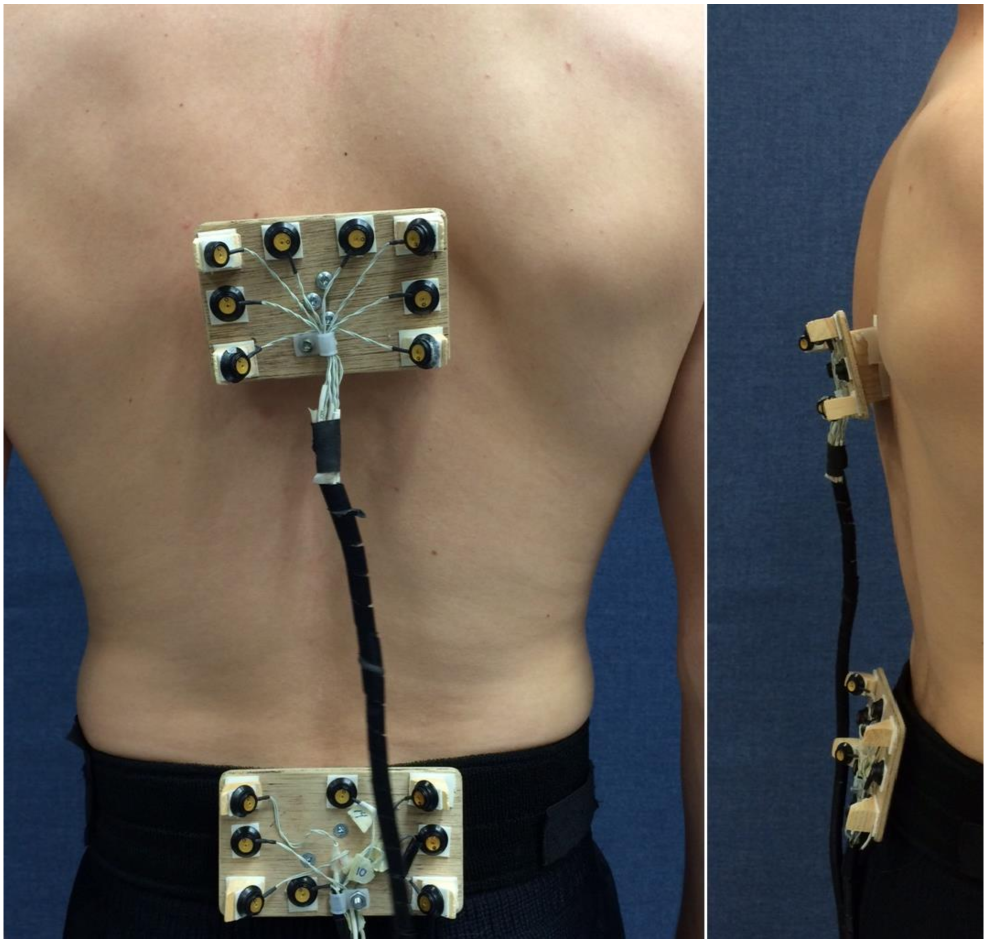

Figure 3: Thoracic rigid body assembly (top) sacrum rigid body assembly (bottom).

3.2.2 Kinetic Equipment

Golfers performed all swings while standing with each foot on separate piezoelectric Kistler force plates (9287B and 9287BA, Kistler Holding AG, Winterthur, Switzerland). The 9287BA had an integrated amplifier and the 9287B had an external amplifier (9865c). A 16 bit, +/- 10 V Kistler A/D board (PCIM-DAS 1062/16) converted the analog signals from the 9287B Kistler force plate at 300 Hz. Bioware software (Version 5.3.0.7, Kistler Holding AG, Winterthur, Switzerland) was used to collect, analyse and export the force and center of pressure data for each of the force plates. The F_z1,2 channel from the 9287B force plate was split such that it was simultaneously recorded using the Optotrak system using a 16-bit analog to digital convertor (ODAU II, NDI, Waterloo, Ontario, Canada). This signal was used to synchronize the Kistler and Optotrak data. The Kistler data were subsequently decimated to 100 Hz to match the Optotrak data.

3.2.3 Microphone

The analog output of a miniature omnidirectional electret condenser microphone (CME-1538-100LB, CUI Inc, Tualatin, OR) was collected together with the $F_Z1,2$ on the Optotrack ODAU system. This signal was used to define the instant of ball contact.

3.3 Golf Equipment

All participants brought their personal golf driver, golf shoes, golf glove (if they used one) along with a pair of athletic shorts. All swings were performed using a foam golf ball hit off of a 7.62 cm rubber practice golf tee into a safety net. The golfers stood such that one foot was on each force plate. A golf driving range practice mat was secured with double-sided tape over the two force plates; this enabled the golfers to obtain traction in their golf shoes and make their swings as natural as possible. The force plate outlines were marked on the practice mat with black tape to ensure the golfers' feet remained on the force plates at all times during testing.

3.4 Calibration

A five second reference position trial was performed that included additional IRED markers placed on various anatomical landmarks. This was performed in order to align the local coordinate system for each rigid body with the anatomical coordinate system (Figure 3). This process was similar to other research protocols (Frayne et al., 2015; Lynn and Noffal, 2010b). The additional individual IRED markers were placed on the following landmarks. For the lead leg segment, reference markers were placed on the medial and lateral malleoli, fibular head and tibial tuberosity. For the sacrum segment, reference markers were placed on the right and left anterior superior iliac spines and a single sacrum marker was placed on the midline, 2 cm below the sacrum rigid body. For the thorax segment, reference markers were placed on the skin overlying the spinous process of the 9th thoracic vertebra (directly below the thoracic rigid body), and overlying the right and left acromion processes. The individual markers were removed before testing began.

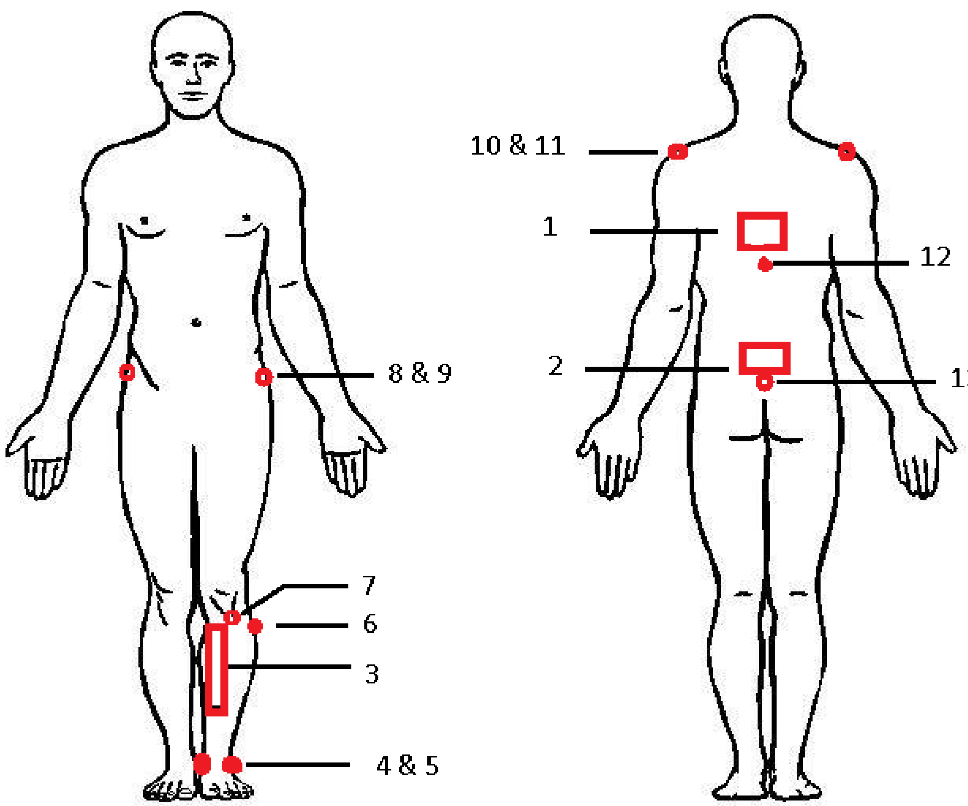

Figure 4: Location of calibration markers, thoracic rigid body and sacrum rigid body. 1) thoracic rigid body 2) sacrum rigid body 3) shank rigid body 4) medial malleolus marker 5) lateral malleolus marker 6) fibular head marker 7)tibial

tuberosity marker 8) left anterior superior iliac spine marker 9) right anterior superior iliac spine marker 10) left acromion process marker 11) right acromion process marker 12) 9th thoracic spinous process marker 13) sacrum marker

The coordinate systems for each of the rigid bodies were aligned to the individual participant's skeleton using commercial software (NDI 6D Architect Version 1.03.03, NDI, Waterloo, Ontario). For the shank rigid body, the ISB convention for a tibiofibular coordinate system was used (Wu et al., 2002), however axis names and directions differ. For example, the ISB convention describes the long axis of the tibia as the Y axis while the long axis of the tibia is called the Z axis in this thesis. The origin was defined as the mid-point of the two malleoli reference markers. The vector from the origin to the lateral malleolus defined +X axis. A vector from the origin in the same Y plane as the tibial tuberosity, bisecting the tibial tuberosity and fibular head marker in the X plane, in the superior direction is +Z. The +Y axis was perpendicular to these two vectors, and oriented in the posterior direction.

A modified ISB (Wu et al., 2002) pelvic coordinate system was used to align the sacrum rigid body to the pelvis. The origin in the ISB convention is located at the center of the acetabulum which is different than this thesis. The single sacrum reference marker defined the pelvic origin. Also, similarly to the tibiofibular coordinate system, the ISB convention describes the vertical axis of the pelvis as the Y axis while that axis is called the Z axis in this thesis. The vector from right anterior superior iliac spine marker to the left was defined as the orientation of the +X axis. The vector from the origin to the midpoint of the line joining the anterior superior iliac spine markers defined the orientation of the -Y axis. The +Z axis was perpendicular to these two vectors, pointing superior.

To align the thoracic rigid body to the thoracic region of the participant, no ISB coordinate system exists. Therefore the thorax was aligned using the single T-9 marker as the origin. The vector from the right acromion process reference marker to the left acromion process reference marker defined the orientation of the +X axis. The +Z axis was defined as the vector from the origin to the midpoint of the line joining the acromion markers, pointing superiorly. The +Y axis was perpendicular to these two vectors, pointing posteriorly. Accordingly the coordinate systems for the thorax, pelvis and leg were all oriented similarly when the participants were standing.

3.5 Procedures

Upon arrival at the research lab (Thames Hall 2125) the participants read the letter of information, and completed the consent form and the low back pain questionnaire.

3.5.1 Lead hip internal range of motion test

The participants lead foot, wearing their golf shoe, was placed and strapped securely to a custom built rotating platform (Figure 4) similar to (Gulgin et al., 2010). The participants began standing in a comfortable stance with their feet shoulder width apart and their feet aligned; they keep their thorax and pelvis stationary. They then actively internally rotated their entire lower lead extremity at the hip while keeping their knee fully extended. Once they reached the end of their active range of motion, the researcher applied a force using a handle mounted to the rear of the apparatus to achieve greater internal rotation. The hip internal rotation was increased until the pelvis began to rotate. The lead hip internal rotation range of motion was identified as the peak internal rotation angle between the shank rigid body relative to the sacrum rigid body.

Figure 5: Rotating platform used for lead hip internal range of motion test

3.5.2 Warm up

In an attempt to replicate the participants typical golfing routines, they were instructed to perform exactly what they would do prior to a round of golf. Whether this was performing a warm up or stretching routine, no instructions or limitations were given.

3.5.3 Golf Swing Testing

Before data collection began, the participants stood behind the force plates while tare voltages were collected. Once cued, the participant stepped forward and positioned their feet on the separate force plates. Participants had as much time as they needed to complete a swing. Once they swung they stepped off of the force plates. This process was repeated 10 times. Post processing revealed that some trials had extensive segments with missing markers and had to be discarded. Each of the participants had at least six trials with minimal missing markers and accordingly six trials were analyzed for each participant.

3.6 Post Processing

First principles software was used in post processing to calculate the relative angles between rigid bodies using Euler angles calculated in the sequence Z-Y-X. Angles between the thorax and pelvis rigid bodies described lumbar motion. Angles between the pelvis and shank rigid bodies were used to describe lead hip rotations. Specifically, a relative angle calculation of the shank with respect to the sacrum was used to define the lead hip orientation during the golf swing at address, ball contact and peak follow through and the internal rotation range of motion test. It was assumed that rotation of the shank rigid body represented an associated rotation of the femur, which is reasonable due to the high stiffness and decreased laxity of the knee when it is in an extended position (Markolf et al., 1976). This approach is similar to the “rigid shank clusters only” method for calculating hip joint motions reported by Schulz and Kimmel (2010), and is consistent with other researchers’ approach that have reported improved estimates of hip joint motion using markers on the tibia rather than the thigh (Wren et al., 2008). This approach for calculating hip motions is more accurate than using thigh marker sets as there is a large amount of skin motion artefact for the markers mounted to the thigh segment

(Schulz and Kimmel, 2010). Whereas the medial portion of the tibial plateau has very little soft tissue between the bone and the skin.

The relative angle between the thoracic rigid body with respect to the sacral rigid body defined the lumbar axial rotation, lumbar lateral bend angle and flexion. These angles were calculated using Euler angles in the sequence Z-Y-X.

The kinematic data contained spikes of noise, likely due to "camera switching" (Kuxhaus et al., 2009) as IREDS were lost to the field of view of one camera bank and picked up by another camera bank. Accordingly a median filter (5 point moving median filter) was used similar to other protocols (Kuxhaus et al., 2009), since typical IIR filters such as Butterworth low-pass filters, are not suitable for this type of signal contamination (Smith, 1997) . During data collection there were short durations when IREDs on a rigid body was not visible, therefore Optotrak could not identify the rigid body, creating gaps in the Euler angle data. These small gaps of missing data were re-constructed using linear interpolation, which has been shown to be an accurate reconstruction method by Howarth and Callaghan (2010).

3.7 Data Reduction

Each of the six trails for each participant were broken down into three phases, address, ball contact and peak follow through. Address was defined as the average position and orientation of the three rigid bodies over a 50 frame span. This 50 frame time span was chosen manually during post processing to identify when the golfer was motionless before beginning their swing. Ball contact was defined as the instant corresponding to the impulse in the analog signal of the microphone corresponding to the club striking the ball. Peak follow through was defined as the peak rotation of the thoracic rigid body relative to the global coordinate system.

3.8 Statistical analysis

Visual analysis of several of the variables revealed several outlying trials that did not reflect the other participants in the group. Due to the presence of these outliers, and the uneven distribution within groups, non-parametric analyses were used (Whitley and Ball, 2002). Un-paired analyses using Mann-Whitney tests were performed using Prism Software (version 6.07, GraphPad Software, San Diego, CA, USA). The threshold for statistical significance was set to 0.05.

4 Results

On average, the golfers without low back pain started in the address position with approximately 10 more degrees of external rotation of their lead foot than golfers with low back pain (Figure 6), though this difference was not statistically significant (p=0.267). This 10 degree average difference was maintained at the other phases (ball contact and peak follow through), though these differences were also not statistically significant (p=0.202 and p=0. 0.431, respectively). Both groups progressively increased the external rotation of their lead foot from address to ball contact to peak follow though.

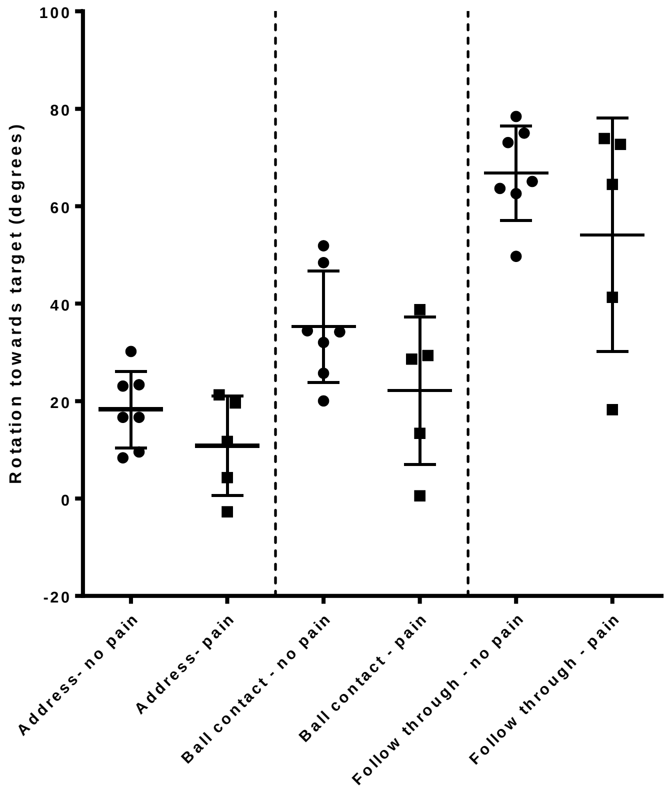

Figure 6: Lead foot orientation for both golfers with and without low back pain during address, at ball contact and peak follow through. 0° represents orienting the lead foot perpendicular to target and positive values represent external rotation of the lead foot (i.e. toward target). On average, the golfers without low back pain externally rotated their lead foot more than golfers with low back pain in all three phases, however these differences were not statistically significant.

On average, golfers with low back pain externally rotated their lead hip significantly less during address than golfers without low back pain (average difference of 12.3°; p= 0.048) (Figure 7). On average, the golfers with low back pain's lead hips were internally rotated at ball contact when the lead hip of golfers without pain was still externally rotated; the average difference was 16.9°, but was not statistically significant (p=0.073). The lead hip internal rotation angle at peak follow through was significantly greater, on average 9° greater, in the golfers with low back pain than the golfers without low back pain (p=0.030).

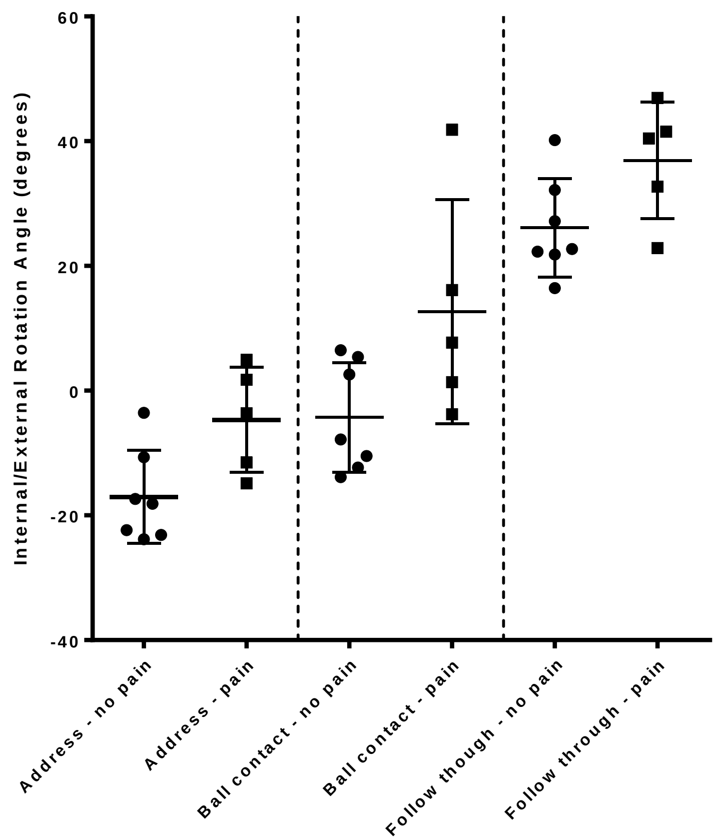

Figure 7: Lead hip internal/external rotation for golfers with and without low back pain during address, at ball contact and peak follow through. 0° represents neutral orientation of the lead hip. Negative values represent external rotation, and positive values represent internal rotation. Golfers with low back pain had significantly less lead hip external rotation at address and significantly more lead hip internal rotation than golfers without pain at peak follow through. No statistically significant difference was found between groups at ball contact.

On average, both golfers with low back pain and golfers without pain began their swings during address with their pelvises rotated toward target (Figure 8). On average, pelvic rotation progressively increased from address, to ball contact and peak follow through. There was no significant difference between global pelvic orientation of golfers with low back pain and golfers without pain at address (p=0.202)), ball contact (p=0.755) or peak follow through (p=0.876).

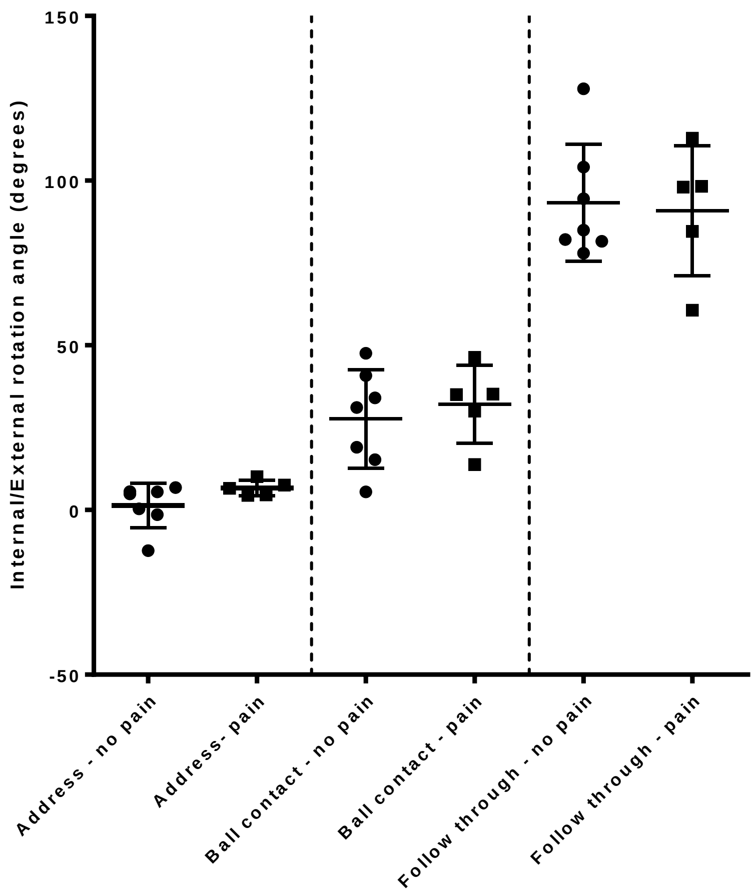

Figure 8: Pelvic orientations in the transverse plane for golfers with low back pain and golfers without low back pain during address, at ball contact and peak follow through. 0° represents the X axis of pelvis (a vector from right ASIS to left ASIS) i.e oriented towards the target. Positive values represent pelvic rotation towards the target. No statistically significant differences were found between groups at address, ball contact or peak follow through.

On average, the golfers without low back pain had more lumbar axial rotation toward target at address than the golfers with low back pain (Figure 9), although this difference was not statistically significant (p= 0.106). On average, at ball contact and peak follow through, both groups rotated their lumbar spine within 4° of each other. (p= 0.755 at ball contact, and p>0.999 at peak follow through).

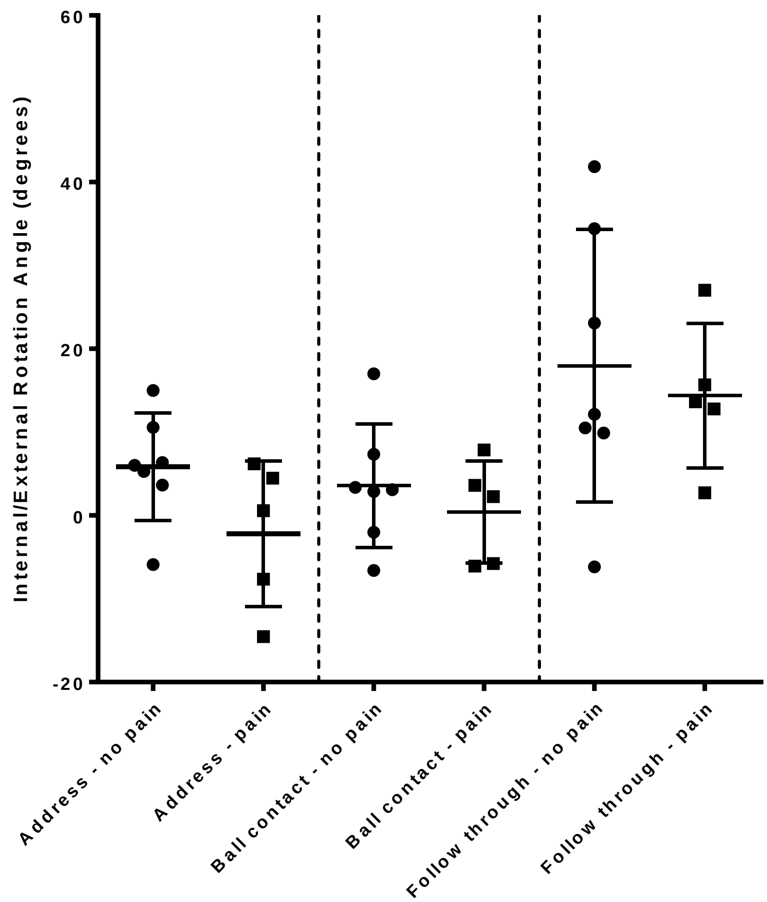

Figure 9: Lumbar axial rotation for golfers with and without low back pain during address, at ball contact and peak follow through. Positive values represent rotation toward target, negative values represent away from target, relative to the pelvis. On average, the golfers without low back pain rotated their lumbar spine towards target more than the golfers with low back pain during all three phases, though it was not statistically significant.

On average, the golfers with and without low back pain addressed the ball with approximately 5° lumbar lateral bend away from target (Figure 10); there was no significant difference between groups (p= 0.876). At ball contact the golfers with low back pain had more lumbar lateral bend than the golfers without pain, although this difference was not statistically significant. On average, the golfers without low back pain increased their lumbar lateral bend at peak follow through while the golfers with low back pain decreased their lateral lean angle. However the differences between groups where not significant at ball contact (p= 0.530) or peak follow through (p= 0.343).

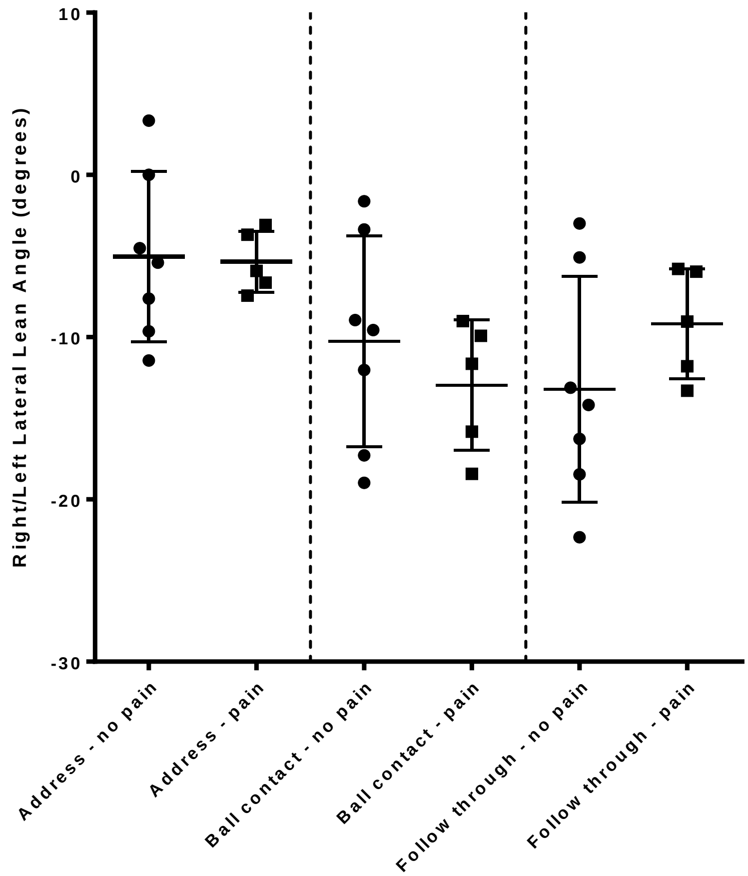

Figure 10: Lumbar lateral bend for golfers with and without pain during address, ball contact and peak follow through. 0° represents neutral (where the X axis of both the thorax and pelvis are oriented in the same direction). Negative is right lateral bend (away from target). No statistically significant difference was found between groups at any of the three phases.

On average, there was no significant difference between lumbar flexion angles between golfers with and without low back pain during address (p= 0.202), at ball contact (p= 0.530) and at peak follow through (p= 0.876). Golfers with low back pain showed less variability in lumbar flexion angles at address compared to golfers without low back pain.

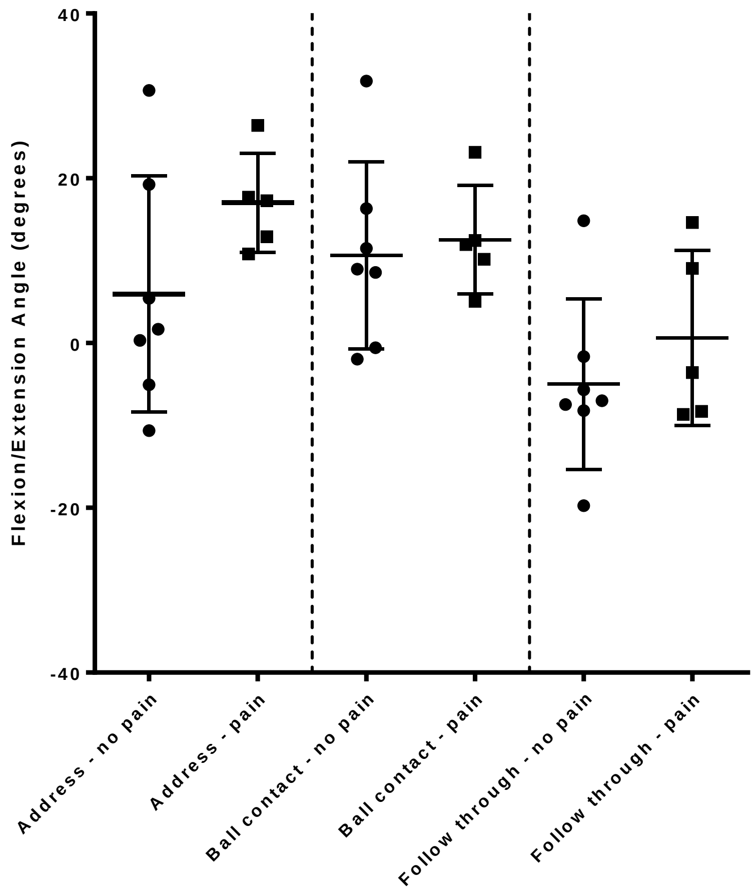

Figure 11: Lumbar flexion/extension angle for golfers with and without low back pain at address, ball contact and peak follow through. 0° represents neutral posture (thoracic Y axis and pelvic Y axis parallel). Positive values represent lumbar flexion. No significant differences were found between groups at any of the three phases.

During the address position on average, golfers with low back pain bore more weight on their rear foot compared to golfers without pain (Figure 12), however the difference was not statistically significant (p= 0.149). Golfers with low back pain, on average, bore more body weight onto their rear foot at ball contact than golfers without low back pain, however this difference was not statistically significant (p= 0.267). On average, golfers with low back pain bore significantly more of their body weight onto their rear foot at peak follow through than golfers without low back pain, which was statistically significant (p= 0.030). These findings indicate a trend between groups for golfers with low back pain to maintain a higher percentage of bodyweight on their rear foot from ball contact to peak follow through compared to golfers without low back pain.

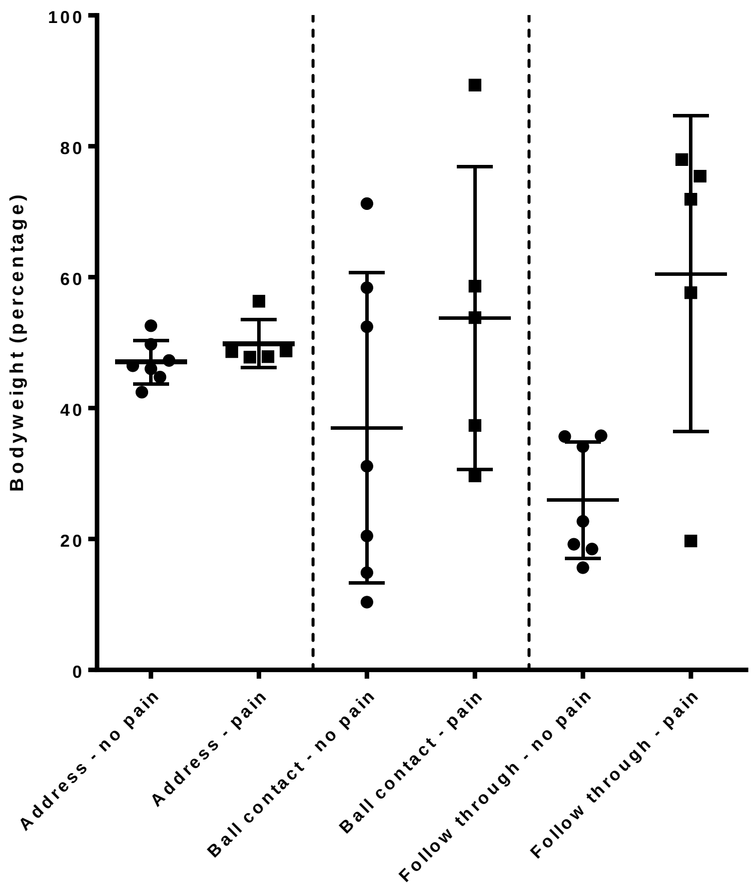

Figure 12: Percentage of bodyweight on the rear foot for golfers with and without low back pain during address, at ball contact and peak follow though. Golfers with low back pain bore significantly more bodyweight on their rear leg at peak follow through compared to golfers without low back pain.

The data about the amount of weight borne on the lead leg mirror the data from the trail limb. During the address position, on average, the golfers with low back pain bore less of their body weight on their lead leg than the golfers without low back (Figure 13); however, this difference was not statistically significant ($p = 0.149$). On average, the golfers with low back pain bore less of their body weight onto their lead foot at ball contact than the golfers without low back pain, although this difference was not statistically significant ($p=0.267$). On the other hand, at peak follow through there was a statistically significant increase in weight borne through the lead leg for the golfers without low back pain compared to the golfers with low back pain ($p = 0.030$). These findings indicate a trend between groups of the golfers without low back pain maintaining more of their body weight on their lead leg from ball contact through to peak follow through.

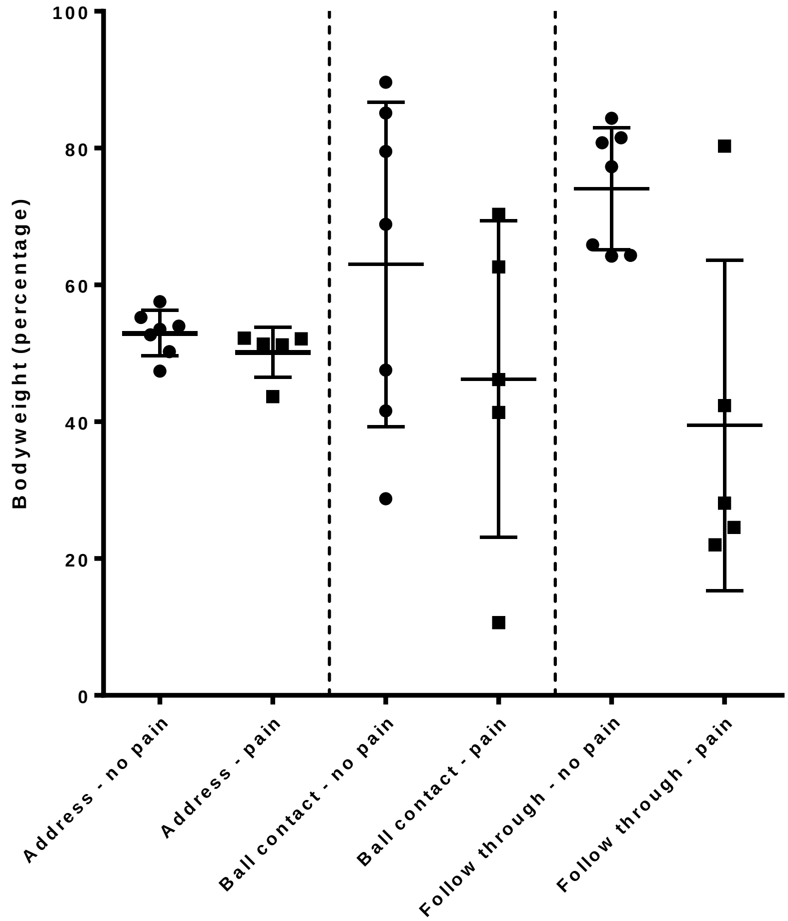

Figure 13: Percentage of bodyweight borne on the front foot for golfers with low back pain and golfers without low back pain during address, ball contact and peak follow though. Golfers with low back pain had significantly less body weight on their lead leg at peak follow through than golfers without low back pain.

We did not observe any statistically significant difference in the lead hip internal rotation range of motion (Figure 14) for golfers with and without low back pain (p= 0.755). Large variability was found for both groups in passive internal rotation.

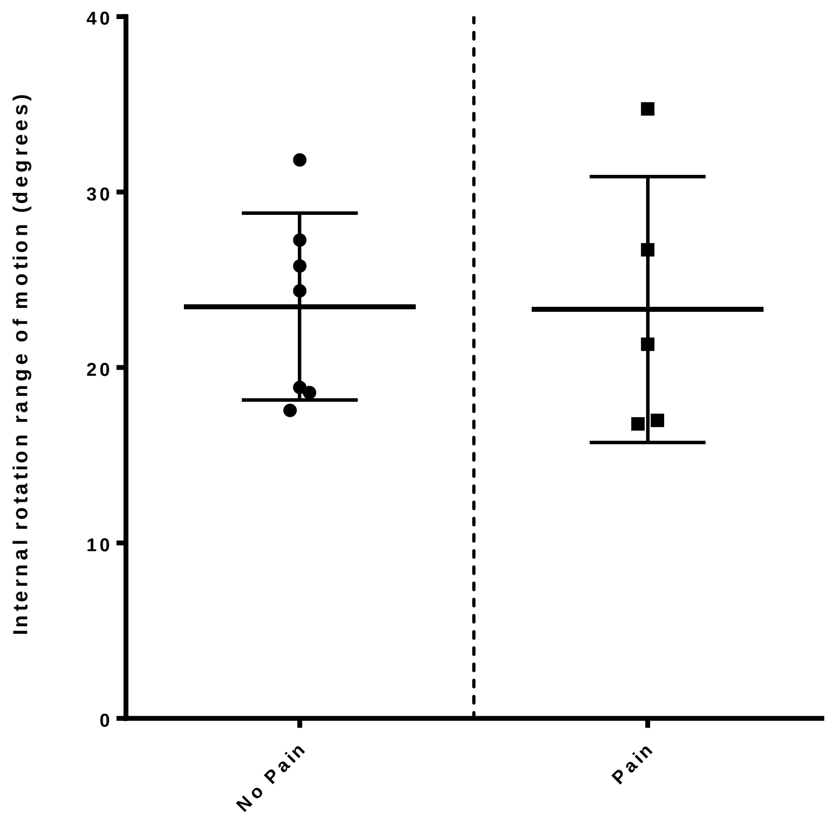

Figure 14: Internal rotation range of motion of lead hip of golfers with and without low back pain. There was no statistically significant difference between groups.

All of the golfers with low back pain exceeded their lead hip internal rotation range of motion at peak follow through, while there was a large amount of variability in the golfers without low back pain – some of the participants had less internal rotation at peak follow through than their passive range of motion, others had similar magnitudes and one participant had a large amount of internal rotation at peak follow through (larger than any of the golfers with low back pain). The amount of lead leg internal rotation at peak follow through compared to their lead hip internal rotation range of motion was significantly greater in the golfers with low back pain compared to the golfers without low back pain ($p = 0.048$; Figure 15).

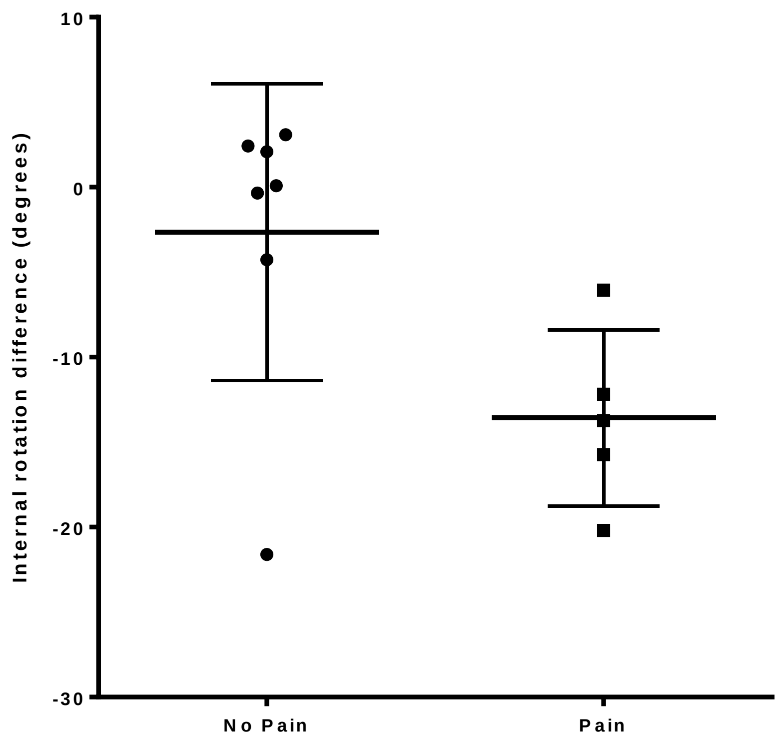

Figure 15: Difference in lead hip internal rotation range of motion test angles compared to lead hip internal rotation at peak follow through. 0° represents no difference in lead hip internal rotation range of motion compared to lead hip internal rotation at peak follow through. Negative values represent a golfer who had larger lead hip internal rotation at peak follow through values than lead hip internal rotation range of motion test values. On average, golfers with low back pain had a significantly larger difference between their internal rotation range of motion test value and peak follow through internal rotation value.

5 Discussion

The purpose of this paper was to investigate the potential kinetic and kinematic differences in golfers with and without golf related low back pain. It was hypothesized: 1) that golfers with low back pain will have reduced internal rotation of the lead hip at peak follow through compared to the golfers without low back pain, 2) that golfers with low back pain will have an increased percentage of body weight on the trail leg during address, ball contact and follow through in relation to golfers without pain, and 3) that golfers with low back pain will have increased lumbar axial rotation compared to golfers without pain.

5.1 Kinematic Measures

5.1.1 Lead Hip Orientation

The main purpose of this study was to investigate the relationship between the lead hip kinematics of golfers who experience low back pain and those who do not. It was hypothesized that the golfers with low back pain would exhibit less lead hip internal rotation at peak follow through than golfers without low back pain. The findings of this study did not support this hypothesis. In fact, we observed the opposite. We observed that golfers with low back pain had significantly less lead hip external rotation at address and significantly greater lead hip internal rotation at ball contact and peak follow through phases.

During the address position the golfers with low back pain presented significantly less external rotation of the lead hip than their pain free counterparts (on average 12.3° less). This decrease in lead hip external rotation at address may be related to the decreased rotation of the lead foot toward target. On average, the golfers with low back pain addressed the ball with their lead foot 7.4° less rotated toward target than the golfers without low back pain. These findings are interesting given that the participants were not given any direction regarding proper stance or orientation of their lead foot – they performed their natural swings. The target location and target direction was the same for each group. Therefore, the trends in lead foot orientation between groups may reflect a difference in stance setup. Since the foot, shank and femur are all part of the same limb, and the stiffness of the knee increases when extended in regards to internal and external rotations (Markolf et al., 1976), a change in the foot orientation will have an associated effect on the orientation of the femoral head in the acetabulum. These findings have important implications for golfers as a small change in their lead foot orientation in relation to their desired target may have a significant effect on their hip kinematics. The relationship between reduced lead hip internal rotation at peak follow through and golf related LBP needs to be investigated further. Future studies could control for lead foot orientation in relation to target with golfers who experience low back pain. For example, they could allow the golfers to swing using their normal address setup while collecting hip kinematics during golf swings, then increase their lead foot rotation toward target in an attempt to identify any potential differences in their hip kinematics. These findings could also be used in an intervention study. For example, golfers with identified low back pain could be instructed to increase their lead foot external rotation towards their target when they play. Back pain could be monitored to identify whether this change in foot orientation causes changes in pain levels.

No statistically significant difference in lead hip internal rotation was identified between groups at ball contact. However, the lead hip of the golfers without low back pain, on average, was still in external rotation at ball contact (4.3°) whereas the lead hip of the golfers with low back pain was already internally rotated 12.6° at ball contact. Although not statistically significant, this 16.9° difference identifies a potential trend in the hip kinematics between each group. This trend is interesting because the goal of the golf swing is ball contact. After ball contact, the goal of the swing has been achieved; now the golfer needs to decelerate in order to maintain balance. The current findings are interesting because the lead hip of a golfer with low back pain is already 12.6° internally rotated at ball contact. Given that there was no significant difference in hip range of motion between groups, this internal rotation position at ball contact means that the golfer has less internal range of motion available to decelerate. Comparatively, the golfers without low back pain made contact with the ball with 4.3° of external lead hip rotation. These golfers achieved the goal of the swing prior to their lead hip becoming internally rotated, meaning they could begin to decrease their momentum while their lead hip was still in external rotation. This reduction of momentum when the lead hip is in external rotation could mean the lead hip never reaches the peak internal rotation range of motion. This trend was observed in the difference in lead hip internal rotation angles between range of motion test and peak follow through; the golfers in the low back pain group surpassed their internal range of motion significantly more than the golfers in the no pain group.

As well, a statistically significant difference was found between the lead hip orientations of the two groups at peak follow through. Golfers with low back pain, on average, had 9° more internal rotation of the lead hip than golfers without pain. The lead hip internal rotation of the golfers with low pain on average reached 36.9°. This significant difference in internal rotation of the lead hip at address and peak follow through appears to be related to the golfers with low back pain presenting less rotation of lead foot toward target at address. Increasing the lead foot rotation toward target has been identified as a successful way of reducing frontal knee moments in golfers (Lynn and Noffal, 2010), but the relationship between lead foot orientation and low back pain has not been previously reported. The range of lead foot rotation from address to peak follow through in the current study in both groups was similar (48.8° and 43.3° for the golfers with and without low back pain respectively), and accordingly the golfers with low back pain had 12.7° less foot rotation toward target at follow through compared to the golfers without low back pain due to the initial orientation of the foot. These results suggest that the degree of lead foot rotation toward target at address could be a potential predictor of the lead foot rotation towards target at peak follow through as well. This highlights the need to monitor the orientation of the lower leg segment when investigating the hip kinematics of golfers, since the orientation of the lead foot appears to have a major impact on the kinematics of the lead hip as the swing progresses. It is unknown if the difference in lead foot orientation between groups is deliberate. It is possible that golfers without LBP are aware of their anatomical limitations or have an increased understanding of golf swing mechanics and increase their lead foot rotation towards target intentionally. Future research should investigate the rationale for golfers adopting their address setup. It may be that some golfers may have learned to externally rotate their lead foot through experience, while others may be following suggestions from golf pros or others.

Alterations of foot orientation have also been investigated in youth baseball pitchers (Kibler et al., 2013), where a 25° alteration in lead foot external rotation in relation to target resulted in a decrease in pitch velocity and accuracy. As well, a limitation in the stride hip internal rotation (what this paper has referred to as lead hip) is correlated with decreased scapular posterior tilt at shoulder maximum external rotation, which reduces performance (Oliver and Weimar, 2014). These findings in baseball literature highlight the influence that the orientation of the lead foot has on hip kinematics and performance in sports that require trunk rotation~~.~~

During the golf swing the lead leg is the pivot point of the swing. If the foot is planted and the knee extended, then the pelvis will rotate around the leg towards the target, which in turn causes the lead hip to internally rotate if hip range of motion allows it. Once ball contact has been made, the golfer must decelerate in order to maintain balance. Deceleration of a body segment has been shown to be a potential source of hamstring injury in soccer players and track athletes (Petersen et al., 2011; Sugiura et al., 2008). These injuries result from the forces the muscle and tendon experience while dissipating the energy of the decelerating segment. This corresponds with the theory of Vad et al.(2004) who postulate that golfers with low back pain are reaching their lead hip peak internal range of motion during the follow through phase of the golf swing. This inability of the head of the femur to continue rotating in the acetabulum could contribute to low back pain. Future research is needed in this area, in order to identify the direct mechanism of injury in relation to hip deceleration and low back pain.

5.1.2 Lead foot Orientation

Lead foot orientation during the address position was hypothesized to be less externally rotated in golfers who experience low back pain than those who do not. We found partial support for this hypothesis. On average, the golfers with low back pain addressed the ball with their lead foot 7.4° less rotated toward target than the golfers without low back pain. These findings are interesting given that the participants were not given any direction regarding proper stance or orientation of their lead foot – they performed their natural swings. The target location and target direction was the same for each group. Therefore the difference in lead foot orientation between groups reflected a difference in stance setup. Increasing lead foot rotation toward target has been identified as a successful way of reducing frontal knee moments in golfers (Lynn and Noffal, 2010), but the relationship between lead foot orientation and low back pain has not been previously reported. The range of lead foot rotation from address to peak follow through in both groups was similar (48.8° and 43.3° for the LBP and no pain groups respectively), and accordingly the golfers with low back pain had less foot rotation toward target at follow through compared to the golfers without low back pain. This increased lead foot rotation toward target at ball contact and follow through may have an effect on lead hip kinematics as the foot and femur are connected via the ankle and knee, and the knee has limited external rotation (Markolf et al., 1976). As a result, rotations of the foot toward the target will cause associated external rotation in the hip.

Alterations of foot orientation have also been investigated in youth baseball players (Kibler et al., 2013), where a 25° alteration in foot external rotation in relation to target can result in a negative effect on energy transfer. Comparatively a limitation in the stride hip (what this paper has referred to as lead hip) internal rotation has been reported to negatively affect scapular kinematics, which is pivotal to the connection between the lower and upper body segments (Holt and Oliver, 2015). These findings in baseball literature highlight the influence that the orientation of the lead foot has on hip kinematics and performance in a sport environment.

It is unknown if the lead foot orientation at setup is deliberate. It is possible that golfers without LBP are aware of their anatomical limitations or have an increased understanding of golf swing mechanics and increase their lead foot rotation towards target intentionally. Future research should investigate the rationale for golfers adopting their address setup. It may be that some golfers may have learned to externally rotate their lead foot through experience, while others may be following suggestions from golf pros or others. Future research should involve a prospective study in which specific instructions to increase lead foot external rotation are given to golfers who experience low back pain while monitoring low back pain incidence with and without these instructions.

5.1.3 Range of motion test

Passive internal range of motion of the hips in golfers has been investigated previously (Gulgin, 2005; Vad et al., 2004; Murray et al., 2009), however there has been little research investigating the lead and rear hip range of motion differences between golfers with and without low back pain. Differences in methodology exist in passive hip range of motion testing, which makes it difficult to compare values between studies. The current study used a weight bearing pivot test with the knee fully extended. No statistically significant difference was identified between the groups for lead hip internal range of motion. This method was chosen due to its close positional relationship to the position of the lead leg at the end of a golf swing. Gulgin (2005) used a similar rotating weight bearing platform to test the internal rotation of the lead hip of golfers and a non-golf playing control group; they also found no statistically significant difference between lead and trail leg. The same author also tested passive hip rotation for the same participants in a prone position with hip extended and the knee flexed to 90°. In this test a statistically significant decrease in internal rotation was found between the lead compared to the trail leg of the golfers, but not in the non-golf playing control group. Several other studies, using the same prone position for testing, identified similar lead leg differences between golfers with low back pain and golfers without low back pain. (Murray et al., 2009) and (Vad et al., 2004) found golfers with low back pain had 10 degrees less passive internal rotation of the lead leg when compared to age, rate of play and handicap matched control participants. Differences in a participant's ability to apply hip internal and external rotational torques have also been found in differing hip angles (Uritani and Fukumoto, 2012). This highlights that changing the angle of a joint influences the strength of the muscles about that joint. Similar hip range of motion findings have also been reported in youth baseball players. Holt and Oliver (2015) reported that passive seated range of motion tests may not accurately reflect the dynamic range of motion of the same joint. To this author's knowledge only one study has evaluated the relationship between lead leg internal rotation and lumbopelvic and thoracic kinematics of golfers. Kim et al. (2015) investigated relative lead and trail hip joint rotations in Korean Professional Golfers with known internal rotation limitations in the lead leg (<20 degrees) compared to normal hip rotation (<20°) control golfers . The golfers with limited lead leg internal range of motion showed significantly increased lumbar flexion, right and left axial rotation and right side bending compared to those with controls. However, this study does not report whether any of their participants had low back pain. It is also important to note that the limited internal rotation group showed significantly less internal rotation of the lead hip at the follow through than the group with non-limited rotation. It has been suggested that there is a causal relationship between limited internal rotation in a passive situation and low back pain related to a golf swing (Vad et al., 2004). Interestingly, in the current study there was no difference in the range of motion test between groups yet the golfers with low back pain had increased lead hip internal rotation at peak follow through when compared to the golfers without low back pain. If limited internal rotation range of motion leads to low back pain in golfers then it would have been expected that the golfers with low back pain of the current study would have presented demonstrated reduced values in range of motion test compared to the golfers without low back pain as well as peak follow through. The potential explanation for the differing results between studies is the golfers' foot position at address. In the Kim et al. (2015) study, based on their figures, the golfers lead foot position was controlled and both golfers with and without low back pain had the same relative foot and hip orientation at address. In contrast, foot position was not controlled in the current study, which allowed for differences in lead foot orientation between groups at address. Accordingly the lead foot positioning in this thesis may influence the swing kinematics, which did not occur in the Korean study.

5.1.4 Lead hip range of motion test vs peak follow through lead hip internal rotation

Not only did the golfers with low back pain demonstrate increased lead hip internal rotation at peak follow through compared to golfers without low back pain, the difference between their lead hip internal rotation at peak follow through and their lead hip range of motion test was also statistically significant. Golfers with low back pain achieved an average of 13.57° more lead hip internal rotation at peak follow through than they did during the range of motion test. These findings are contrary to the hypothesis that golfers with low back pain would have decreased internal rotation of their lead hip during a golf swing. These results also do not support the previous work done by Kim et al. (2015) who demonstrated golfers with identified limited lead hip internal rotation also had reduced internal rotation of their lead hip during the golf swing. A potential explanation for the current studies' results is that golfers with low back pain rotate past their range of motion test values at peak follow through because of weak hip external rotator musculature. These muscles responsible for the deceleration of the pelvis, are unable to produce a strong enough eccentric contraction to adequately decelerate the pelvis before the hip reaches peak internal rotation. This idea has been investigated in femoroacetabular impingement research, where a significant weakness in hip flexion, hip adduction, hip external rotation and hip abduction has been identified in individuals with femoroacetabular impingement compared to controls (Casartelli et al., 2011). It was postulated that if these hip muscles were not strong enough to resist the external force moments could lead to injury. Golfers without pain have stronger hip musculature (Tsai et al., 2010) and therefore may have adequate hip external rotator strength to decelerate the pelvis so that they do not reach their passive end range of motion. Similarly, golfers with low back pain have weaker hip external rotators (Tsai et al., 2010), they may not have adequate hip strength to decelerate the pelvis at the end of the swing. This may mean that other structures must accommodate for this lack of strength, including the possibility of hip impingement at the end range of hip internal rotation. This association between hip musculature weakness and hip impingement is supported by studies in individuals with femoroacetabular impingement, involving mechanical contact between the hip joint structures at terminal hip flexion and internal rotation, compared to controls (Casartelli et al., 2011). Alternatively this energy may transfer down to the knee potentially causing ACL injury (Bedi et al., 2014) or be transferred superiorly to the lumbar spine. While the current study did not specifically evaluate parameters related to decelerations of the hip and pelvis, this may be an interesting approach for future golf research. This may be especially true when the lead foot orientation is also considered, as this appears to affect when the hip would reach its end range of motion. It is likely that several risk factors combine to cause low back pain. For example, a golfer who has a limited internal range of motion of their hip-combined with their lead foot being oriented perpendicular to the target at address could potentially place them at a higher risk of injury.

5.1.5 Pelvic orientation

An important point to consider is that several kinematic studies have identified that there is no significant difference in the pelvic kinematics of golfers with and without low back pain. The current findings support this previous research; we did not observe any statistically significant differences between groups for pelvic orientation at any of the three phases. This is in contrast to the statistically significant differences that we observed in hip joint internal rotation, and highlights the importance of investigating hip joint kinematics rather than exclusively focusing on the motion of the pelvis.

5.1.6 Lumbar axial rotation

In the current study no statistically significant differences were found in lumbar spinal rotations between groups at address, ball contact or peak follow through. During the address position, although not statistically significant, there was a difference in average lumbar axial rotation between groups. The golfers with low back pain were in neutral posture on average, whereas the lumbar spine of the golfers without low back pain was rotated 5.9° toward target. In comparison, Lindsay and Horton (2002b) also found no significant difference in lumbar axial rotational at address, with both groups' spinal rotation being within 1° of each other on average. It would be interesting to see whether our trend of increased lumbar axial rotation at address in golfers with low back pain would be maintained if we had tested a larger number of participants.

No statistically significant difference in lumbar axial spinal rotation was found between groups at ball contact or peak follow through. On average golfers with and without low back pain were within 3.2° of lumbar spinal rotation at ball contact and within 3.6° at peak follow through. The current lumbar axial rotation results support Lindsay and Horton (2002b) findings who also found no significant difference. This study did not record back swing data, which is where previous research has identified differences between golfers with and without low back pain. Interestingly Kim et al. (2015) reported that golfers with identified reduction of hip internal rotation demonstrated reduced axial rotation of the lumbar spine at both backswing and follow through. We have noted that studies have given different instructions to participants about the address position, and these differences may potentially influence the findings. For example, the participants in the Kim et al. (2015) paper were told to assume an "anatomically appropriate position" at address. This anatomical position may not reflect the lead foot external rotation towards the target that the participants would normally adopt. Kim et al. (2015) also represented hip rotation in their figures, in which both groups have equal values at address, which could potentially mean that their lead foot orientation was constrained, which could alter their pelvic and hip kinematics from the golfers' preferred set up position. This control of lead foot orientation could be an explanation for the significant differences that Kim et al. (2015) identified in lumbar axial rotation.

5.1.7 Lumbar lateral bend

No difference was found for lumbar lateral bend between groups at address. The average lumbar lateral bend for both groups of golfers was 5° away from target. The current results support the findings of Lindsay and Horton (2002b) who found no difference between lumbar lateral bend of golfers with and without low back pain ($p= 0.32$). Although no statistically significant difference was found in lumbar lateral bend between groups at either ball contact or follow through, there were trend in the data which may be meaningful. For example, at ball contact the golfers with low back pain presented, on average, 2.7° more lumbar lateral bend than the golfers without low back pain, but at follow through the golfers with low back pain presented 5° lateral less than the golfers without low back pain. This change, in which golfers with low back pain have more lumbar lateral lean at ball contact than golfers without low back pain and then less lumbar lateral lean at peak follow through was also reported by Cole and Grimshaw (2014) although their findings were also not significantly different.

The lack of significant difference in lumbar axial rotation and lumbar lateral lean in the current thesis and previous literature is interesting as these variables have long been thought to be a potential cause of low back pain in golfers (Vad et al., 2004). Future research should focus on increasing the kinematic markers used to monitor lumbar and thoracic kinematics during the golf swing, as there could be differences in intersegmental thoracolumbar kinematics which the current methodology was unable to identify.

5.1.8 Lumbar flexion/extension

Although not statistically significant, trends were identified in lumbar flexion angles for golfers with and without low back pain. Golfers with low back pain presented on average 11.1° more flexion at address than golfers without low back pain ($p=0.202$). These findings are similar to Lindsay and Horton (2002b) who found that golfers with low back pain addressed the ball with 12° more flexion than those without pain, although their results were also not statistically significant ($p=0.09$). The current findings along with the previously mentioned study support the work done by Vad et al. (2004) who reported that golfers with low back pain had significantly reduced lumbar extension range of motion when compared to golfers without low back pain. In comparison, Tsai et al. (2010) reported that golfers with low back pain have reduced hamstring flexibility compared to golfers without low back pain. When applying these flexibility findings to the golf address position, we can begin to understand why golfers with low back pain may present with more lumbar flexion. This may be because extending the lumbar spine anteriorly tilts the pelvis, which lengthens the hamstring muscles. Therefore if a golfer has reduced hamstring flexibility, due to the origin of the hamstrings on the pelvis, their pelvis will be tilted posteriorly, and they will not be able to extend their spine at address, forcing them to adopt a flexed lumbar spinal position at address.

Future studies could investigate flexibility regimes looking at increasing hamstring and lumbar extension measures in golfers with low back pain while monitoring low back pain throughout a season of play.

5.2 Kinetic Measures

There were several statistically significant differences in the weight bearing patterns between golfers who experience low back pain and those who do not. It was hypothesized that weight bearing patterns of the two groups would not only differ, but they would be related to two golf swing techniques as well: the front foot style and the reverse style (Ball and Best, 2007). It was hypothesized that golfers with low back pain would execute the reverse style of golf swing and those without pain would use the front foot swing. The reverse foot swing consists of the golfer transferring a higher percentage of their body weight onto their rear foot at ball contact and follow through (Ball and Best, 2007). In the current study, the golfers with low back pain bore 34.5% more of their body weight at peak follow through on their rear leg then those without pain, which was statistically significant. This meant that, on average, golfers with low back pain at peak follow through bore 60.5% of their bodyweight on their rear leg. At the same point during the swing, golfers without low back pain bore 25.9% of their body weight on their rear leg. Therefore, on average, the golfers with low back pain demonstrated the reverse swing style, and the golfers without pain used the front foot swing style. One potential explanation of the relationship between the kinetic and kinematic differences may be related to the fundamental goal of the golf swing using a driver, which is to drive the golf ball the furthest distance possible. Research investigating golf drive biomechanics for greatest distance (Chu et al., 2010) has identified an optimal pattern: the initial weight transfer should be on the rear foot during the back swing, then a transfer of body weight onto the lead foot during the downswing which is maintained through ball contact and follow through. Not only do the golfers with low back pain in the current study not perform the weight transfer during their swings in an optimal way as described by (Chu et al., 2010), they also differ in weight transfer patterns significantly from the golfers without low back pain. Movement of a person's center of mass is a result of muscle contractions, therefore differences in weight transfer could mean differences in patterns of muscle contraction, the magnitude of the muscle contraction or differences in muscle contraction timing. In a study using golfers with no musculoskeletal problems and a less than five handicap, Bechler et al. (1995) identified that the trail leg hip extensor and abductors, along with the lead leg adductor magnus, initiate pelvic rotation at the beginning of the downswing. As well, they noted that the lead leg vastus medialis and hamstrings stabilize the knee during downswing, ball contact and follow through. It is possible that the golfers with low back pain in the current study did not use this pattern of muscle activation during their swings. Future studies should investigate rear and lead leg musculature differences in golfers with and without low back pain, specifically how these potential differences alter weight transfer patterns.

This correlation between weight transfer patterns could potentially be exploited as a teaching tool. Altering a golfer's kinematics with specific instructions to change a segment orientation during a swing would be difficult to learn and more difficult to incorporate into a swing successfully. However, simply instructing a golfer to focus on transferring the majority of their body weight on their lead foot during the downswing through to ball contact and the follow through phase could be a potentially simple and effective teaching tool. These instructions may alter weight transfer patters of golfers with low back pain which in turn could potentially reduce the risk of injury. Further research should be done using golfers who perform the reverse swing style; this intervention could attempt to alter their kinematics to reduce the risk of injury by instructing them to adopt the front foot style of swing. This should be evaluated in a prospective study focusing on the effectiveness of this type of intervention for reducing back pain.

5.3 Limitations

The first limitations of the current study is the small subject size. With a larger subject size some of the trends identified in lead foot orientation and lumbar flexion angles at address may have reached significance. The second limitation is the measurement of the hip kinematics as the relative motion between the shank and pelvis segments. This approach has been used by other investigators (Frayne et al., 2015; Schulz and Kimmel, 2010) in order to reduce the known issue of soft tissue artifact for the thigh segment (Cappozzo et al., 1995) . This approach assumes that the knee joint is stiff during the swing such that the rotation of the shank reflects the rotation of the thigh. In vitro studies have shown that this assumption is valid when the knee is extended (Markolf et al., 1976) and golf studies have shown that the lead knee is flexed less than 10 degrees at ball contact and follow through (Gatt et al., 1998). Accordingly it is reasonable to assume that this approach to measuring hip kinematics at ball contact and follow through is appropriate in this study. Another potential limitation is that specific flexibility data was not recorded. For example, hip flexion and extension, prone hip internal rotation as well as the Fabres test, could have all been collected without adding a large amount of time to the testing procedure. If these measures had been collected, then comparison of the participant's physical attributes to those in other low back pain studies would have been possible. In addition, recording the position of the tee, in terms of distance anterior to the golfer as well as the tee’s location in relation to the golfer’s lead foot is another variable that could have been recorded. This information could lend itself to potential differences in the way that the golfers with and without low back pain orientate themselves to the golf ball.

Conclusion

The purpose of this study was to investigate the lead hip kinematics, weight bearing patterns and lumbar axial rotation of golfers with and without low back pain. Using motion capture and force plates, passive weight bearing lead hip ranges of motion as well as swing kinematics and kinetics from 12 golfers (5 with pain, 7 without pain) were collected.

Golfers with low back pain presented significantly less external rotation of their lead hip during the address position, and significantly more internal rotation of their lead hip at peak follow through, compared to golfers without low back pain. These differences may be a result of the reduced rotation of the lead foot at address presented by golfers with low back pain, reflecting the trend that we observed, though it was not statistically significant. These findings are meaningful as they could be used as a simple method for reducing the risk of injury by modifying the start position of golfers by rotating the lead foot towards target during the address position.

Golfers with low back pain bore significantly more bodyweight onto their rear leg at peak follow through compared to golfers without low back pain, who bore more body weight on their lead foot at peak follow through. These findings correspond to the front foot style and the reverse style reported by other researchers (Ball and Best, 2007), but we are not aware of any previous research relating these golf styles to low back pain. If the relationship that we observed between low back pain and swing style is a universal finding, then these findings could potentially be employed as a simple teaching tool to reduce the risk of low back pain in golfers.

Interestingly, no significant differences were identified for lumbar axial rotation, lumbar lateral bending or lumbar flexion between groups for any phases of the golf swing. These findings are consisted with the bulk of previous research. The lack of differences could mean that future research should focus on weight bearing patterns and muscle activity as potential differences between groups.

Low back pain is a common ailment of the amateur golfer (Cabri et al., 2009). The current findings have true real world applications as they identify simple potential modifications that could lead to significant changes in a golfer's enjoyment of the game by reducing the likelihood that they would experience low back pain. Future studies should investigate the modification of the lead foot orientation of golfers with low back pain paired with the conscious bearing of body weight on the lead foot during the golf swing.

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Appendix

<u>Questionnaire</u> Participant ID #______________

Golf Questions:

- How many rounds of golf per week do you play? (indicate if round is 9 or 18 holes)
    - _______________
- Are you LEFT or RIGHT handed (please circle)
- What is your approximate golf handicap? ______

Low Back Pain Questions: Do you experience low back pain during or following a round of golf?

- YES or NO If YES, please answer the following questions:

Do you experience pain during other activities? (after cutting the grass, after prolonged sitting, etc)

____

______________ Describe the intensity of your typical pain on a scale from 0-10

____

Describe the duration and type (muscle strain, sudden sharp pain etc)

____

____

____

Does the pain force you to stop practicing or playing when you experience the pain? YES NO (please circle)

Does the pain alter your performance? YES NO (please circle)

Does your pain require treatment? YES NO (please circle)

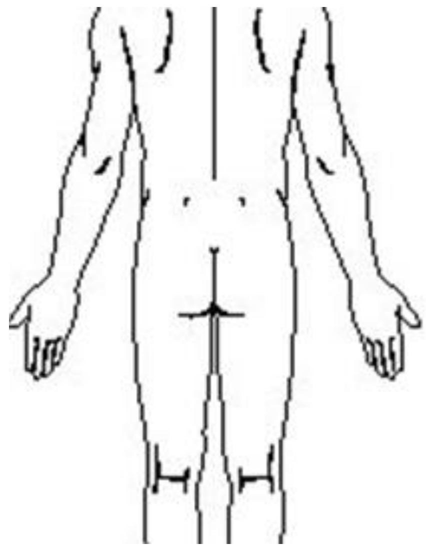
If YES please describe: -

____

____

- Do you have a diagnosed low back disorder? YES NO (please circle)
    - If yes, please describe ____

Please Circle on the figure where you experience your pain:



Participant Contact Information: Participant ID #_______________

- Full Name: ____
- Phone Number: ______ ________ ________, Year of Birth: __________
- Email address:____

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  Completion April 2011

Employment Experience

Level 3 Personal Trainer

GoodLife Fitness, London, ON. (September 2011-Present)

- Provide exceptional service to personal training clients while achieving all individual goals
- Design and implement individualized, specific exercise programs based on client goals and functional analysis of movement patterns using Functional Movement Screens (FMS)
- Specialize in facilitating programs for clients with pain management goals, both chronic and acute pain, resulting from motor vehicle accidents, workplace injuries or overuse
- Responsible for identifying client specific barriers, whether physical or mental, initiating the appropriate program modifications to overcome the obstacle, which ensures successful achievement of client goals

Teacher's Assistant

Western University, London, ON. (January-May, 2014 &2015)

- Instructed and supervised the lab portion of a 3rd year university advanced biomechanics course (Kin 3343 - Biomechanical Analysis of Discrete Skills)
- Reviewed weekly lecture material and provided meaningful and comprehensive instructions for weekly lab assignments
- Responded quickly and accurately to all student inquiries both in person and via email
- Accurately graded up to 30, 8-10 page assignments and returned them within a 10 day period, including significant feedback allowing for future improvement

- Met weekly with the lab coordinator and all teacher's assistants to discuss and assign weekly requirements

Relief Child and Youth Worker

Craigwood Youth Services, Ailsa Craig, ON. (December 2010- May 2011)

- Provided wide continuum of care to youth ages 12-18, including suicide prevention, one-on-one problem solving solutions, and individual and group dispute resolution
- Responsible for the physical and mental safety of youth during and following conflict situations amongst youth or workers, and initiated conflict resolution to achieve and sustain order in the group home
- Built relationships with the youth in order to support them, build self-esteem and work towards improving behavior
- Implemented strategies such as planned daily activities, coordinated treatment interventions, organized recreational and social activities