A Dissertation

entitled

Hip Rotation Range of Motion Asymmetry in Elite Female Golfers

by

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Submitted as partial fulfillment of the requirements for

the Doctor of Philosophy in

Exercise Science

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An Abstract of

Hip Rotation Range of Motion Asymmetry in Elite Female Golfers

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The purpose of this study was to examine hip rotation ROM in elite female golfers and age-matched controls. Previous studies have shown that glenohumeral joint ER increases in the dominant arm (relative to the non-dominant arm) when participating in sports that require repetitive unilateral overhead throwing/serving motions. However, it is unknown if the lower extremities accommodate in the same way when individuals participate in repetitive motions for a particular sport skill. The current study examined hip rotation ROM anatomical limits in a passive and WB condition. Furthermore, the golfer's hip ROM and velocities during the golf swing were analyzed. Subjects included 15 collegiate golfers (19.6 ± 1.4 yrs.) and 15 age-matched controls (20.5 ± 1.7 yrs.). Each subject was tested for passive (prone) and WB hip rotation ROM. Three trials for each measurement were made bilaterally in both internal rotation (IR) and external rotation (ER), with the mean used for analysis. Kinematic data for the WB ROM and golf swing were collected using an eight camera Motion Analysis System. Separate two-way repeated measures analysis of variance were used to compare group and side for IR and ER (significance at alpha = 0.05). The results indicated that, in general, both golfers and controls have similar hip rotation ROM. However, the golfer's demonstrated a significant decrease in left hip passive IR relative to their right hip. Previous literature has indicated a link with side-to-side hip rotation asymmetry and low back pain. Furthermore, low back pain is the leading injury complaint among golfers, and thus the hip rotation asymmetry may be considered as a contributing factor in low back pain.

Dedication

This dissertation is dedicated to my parents. The time and effort I have put toward completing this degree are dim in comparison to the multiple sacrifices they have made for me over the years! Not only have they made sacrifices to provide a future full of opportunities, they allowed me to explore my interests, without ever pushing me into a career. What appreciated freedom that has been. I love you Mom and Dad.

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Chapter One

INTRODUCTION

Sports are an integral part of every culture, with people participating from early childhood all the way through the late adult years. From the "weekend-warrior" all the way to the professional level, sports are a way of life for millions. Over time, each sport places specific demands on the musculoskeletal system, which may result in tissue adaptation and overuse injuries. As a result, many individuals who participate in sports experience injuries that relate to their participation.

Injury can be defined as damage (or impairment) of body function or structure due to adverse influences or external forces.[4] Each sport has different risks for injury, some minor, some catastrophic. Although athletes may only have concern about how injuries affect the their short-term health, participation in sport may not only present acute injuries, but more chronic injuries that occur as a result of accumulated stress to the body. For example, some retired professional athletes now live with the consequences of the "wear and tear" of their body's soft-tissue structures (such as cartilage) as a result of the accumulated stress placed on the body. Shepard[63] reported that there is a significant difference in the amount of hip osteoarthritis (OA) in former professional soccer players in comparison to age-matched controls. Interestingly, none of the athletes surveyed reported an actual hip injury during their playing years. Thus, there does not have to be an occurrence of an acute injury to a particular body region to experience joint pathology. Quite simply, some injuries may be the result of repetitive movement patterns over time.

Sports often utilize repetitive movements to perform the skills required throughout a match or game. Some sport movement patterns occur bilaterally, or have the potential to occur to both sides equally. For example, a tennis player may use right and left directional trunk rotations during various shots (backhand and forehand) throughout the match. Similarly, swimmers utilize forward flexion of the shoulders equally. However, there are sports where one side experiences movement patterns that the other side does not during the required sport motion. For example, the same tennis player that is right-hand dominant will experience more overhead movements in the right shoulder compared to their non-dominant left shoulder as a result of the serving motion. This unilateral, repetitive rotational movement may lead to adaptations in the range of motion (ROM) on one side and not the other. It is not uncommon for overhead athletes (throwers and servers) to demonstrate a bilateral difference in their ROM as a result of the repetitive demand placed on the dominant arm, relative to the contra-lateral side.[22] Furthermore, baseball hitters that only bat right-handed will always have their left hip facing the pitcher. Thus, all of the lower body rotation occurs around the left or lead hip during the hitting motion. Similarly, golfers have a dominant-hand with which they play, and thus will have the same lead hip experiencing all the rotation during follow-through to the target side. In spite of the known differences in upper extremity adaptations in joint ROM, there is no relevant research that has been performed on lower extremity adaptations to joint ROM in athletes that perform repetitive rotation in one direction.

In healthy adult subjects, bilateral joint ROM (in the lower extremities) has been shown to be symmetrical.[8, 12, 15, 20, 60] However, when there is an existing side-to-side difference (due to surgery or injury), clinicians will attempt to restore the ROM of the involved joint to symmetry with the non-involved joint. During an evaluation, it is important to not only restore the motion at the involved joint, but to assess the movement ability of the entire kinetic chain. As the kinetic chain principle implies, there can be no isolation of body movement for function, but all the parts work together to perform desired function. Thus, when an injury occurs to one area of the body, it has an impact on the entire kinetic chain. Based on this kinetic chain principle, lack of motion in one joint may be responsible for the pain or dysfunction in a more proximal or distal joint. For example, Cilbulka et al.[16] have found that hip rotation asymmetry is associated with episodes of low back pain.

Although the body is able to compensate for a change in joint ROM in order to facilitate function, there are also detrimental adaptations that occur as well. One documented area of potentially problematic joint ROM accommodation is that observed with the overhead athlete, specifically baseball pitchers and tennis players. Athletes in these sports have demonstrated an increase in external rotation (ER) of the glenohumeral joint in the throwing/serving arm relative to the non-throwing or serving arm.[9, 22, 33, 56] This may be advantageous from a performance standpoint, but patients with increased ER ROM[22, 70] have also demonstrated joint instability. Overhead athletes not only gain motion in ER, but also lose motion in internal rotation (IR).[22] As a result of these changes in the ROM, and the demands placed on the soft-tissue during the throwing motion, shoulder pathology is not uncommon. It appears that there is an optimal ROM for each joint. Factors that create more or less motion may place stress on surrounding soft-tissue structure and predispose the involved individuals to injury.

Not only is the ROM that an athlete experiences in a particular task related to injury, but also the velocity at which the extremities move through the ROM. The magnitude of the deceleration is directly proportional to the velocity that the athlete achieves in the throwing motion. Thus, high velocities, which are desirable from a performance standpoint, necessitate high levels of deceleration. It has been speculated that SLAP (superior labral anterior-posterior) lesions in the shoulder are associated with the forceful eccentric contraction of the biceps during the rapid deceleration of the throwing motion in baseball.[5] It is believed that the associated eccentric contraction causes the attachment of the long head of the biceps tendon to pull away the anterior labral complex.

In a similar way, labral pathology of the hip may be due to the excessive demands of dynamic internal moments created as result of rotational movements. Labral pathology of the hip is a more recent diagnosis in athletes, and it has been suggested that the mechanism for an acetabular labral tear is excessive ER with extension of the hip.[46] The occurrence of tears in the athlete's acetabular labrum have been reported in sports that place rotational demands on the hip (such as tennis, golf, and hockey).[10, 46, 50] Although kinematic data on the throwing motion in baseball exists that may illustrate mechanisms of a labral tear in the shoulder, there is currently no evidence of the velocity and ROM of the lead and non-lead hips during a full golf swing to determine if the same potential exists for labral pathology in the hip.

The golf swing is a very quick movement, with the typical backswing taking 0.8-1.0 seconds, and the downswing lasting only 0.1-0.3 seconds for a total swing time ranging from 1.09-1.28 seconds among professionals and amateurs.[52] This type of quick movement may place golfers at risk for labral pathology as the trail hip experiences ER and extension during this rapid downswing phase, which may be the "danger zone" for labral tears to occur in the trail hip. Furthermore, if this is where peak velocity occurs, then a golfer may not even have to exceed their normal joint ROM at the hip for this injury to occur. Not only is the trail hip at risk for labral pathology, but the lead hip experiences a great deal of IR as the entire body weight is transferred to that side during the follow-through. This repetitive rotational stress may cause adaptations in the surrounding soft-tissue on one side and thus lead to hip rotation asymmetry.

If elite golfers who participate in repetitive rotational movements frequently acquire a hip rotation asymmetry, then the concern for subsequent low back pain must be examined, since Cilbulka et al.[16] have found this association. Thus, one of the purposes of this research is to identify if golfers are acquiring a significant side-to-side difference in their hip rotation ROM over time.

Statement of the Problem

There is a lack of quantitative data concerning the range of motion at the lead and trail hips during the golf swing, and if that range of motion exceeds the golfer's anatomical limit at any point in their golf swing. Although other sports have demonstrated alterations in ROM (upper extremity) relative to the demand of the sport, whether the golfer's hip rotation ROM will accommodate to a repetitive rotational demand on the lower extremity remains unknown.

Purpose of the Study

1. To examine passive (NWB) and weight-bearing (WB) hip rotation ROM in golfers and controls.

2. To measure hip rotation (IR/ER) during the golfer's swing.

3. To measure the velocity of the golfer's hips during the golf swing.

Hypotheses

(H1) There will not be a significant group difference between the control and golfer's hip rotation.

(H2) There will be a significant side-to-side difference within the golfer group hip rotation measurements.

(H3) The golfer will exceed their weight-bearing hip rotation anatomical limit during the golf swing.

(H4) Peak rotational (IR/ER) velocity at the hip will be significantly different between the two hips.

Summary

Although golf is a popular sport, no data currently exists verifying the ROM the hip experiences during a full swing, or if that range exceeds the player's anatomical limit. Due to the repetitive nature of rotation on the lead leg during the follow-through phase, the soft-tissue structures may adapt, and thus result in an asymmetrical joint range of motion relative to the contra-lateral joint. Analyzing the kinematics of the full golf swing, as well as obtaining passive ROM measurements may provide insight into the new epidemic of acetabular labral pathology.

Chapter Two

REVIEW OF THE LITERATURE

The literature review will be discussed in three main sections. First, background information on golf (injuries as well as the swing motion) will be covered. Furthermore, in order to understand possible injury mechanisms, the role of rotational velocities in sport will be examined. Secondly, an extensive review of the hip joint will be discussed, with a particular focus on the acetabular labrum. Although the injury mechanism for an acetabular labral tear is unknown, the velocity of sport movement along with anatomical ROM limits may place this tissue at risk for failure. Lastly, hip joint ROM will be discussed, along with the importance of rotational hip rotation ROM symmetry. In combination, available hip rotation ROM and the velocity of rotational movement during the golf swing, may predispose a golfer to hip pathology.

Background of Golf

The Golf Swing Motion

Investigators have often broken down the golf swing into phases for describing the kinematics and/or kinetics that occurs during the golf swing. Typically, the phases of the golf swing include: (1) address position (2) take-away (3) downswing (4) impact and (5) follow-through. The address position is described as the set-up position, where no movement has yet occurred. The take-away phase is the initiation of the backswing to the top of backswing. The downswing is the return of club toward impact. Furthermore, the downswing may be separated into: (a) top of the backswing until the club is horizontal to the ground, and (b) club-horizontal to ground to impact (acceleration phase). The final phase is the follow-through, which occurs from ball impact until the finish of the swing.

The total golf swing occurs in approximately 1.09 seconds (Tour professionals) to 1.28 seconds (amateurs), of which 78% is the backswing, and the remaining is the downswing.[14, 52] As a result of this rapid downswing phase, there will be significant forces acting on the body. In particular, forces acting on the lower body are highest during the transition phase (between the start of the downswing and the club horizontal position), which corresponds with when the vertical ground reaction forces reached a peak magnitude of 150% of total body weight.[18] However, peak rotational forces may occur slightly later (closer to impact) as a result of the transfer of momentum. In the previous study, Cooper et al.[18] measured kinematic and kinetic data on five, male collegiate golfers (Indiana University Golf Team). At ball impact, a significant portion of the body weight is loaded onto the lead leg (75% on front foot vs. 25% on back foot).[18] Thus, although each hip experiences rotational loading, the front hip will experience higher rotational forces as more of the body weight shifts to the lead hip during the much quicker downswing phase of the golf swing. Thus, due to the nature of the golf swing, the lead hip may be more prone to injury or pathology, than that of the trailing hip.

Back and Hip Injuries in Golf

It has been reported that the leading injury among both professionals and amateurs involves the back region.[30, 43, 47] This is not surprising, since compression loads on the lumbar spine during the golf swing have been estimated to be eight times the body weight.[35] Interestingly, hip injuries have ranged from low to unreported on most injury surveys from amateurs and professionals.[7, 28, 48, 49, 66] In spite of the low reported rates of hip injuries, there have been a handful of professional golfers with hip pathology requiring arthroscopic surgery.[42] In the past, there has not been a lot of attention on hip injuries in golfers. However, one particular study has made an association between hip rotation asymmetry and golfers with episodes of low back pain.[68] Thus, this association between hip rotation and low back pain in golfers is important and deserves more attention in the future.

Rotational Velocities in Sport

<u>Rotational Velocities</u>

By definition, velocity is the change of position as function of time. The ability to generate high rotational velocities is quite desirable in sport. Much of sport success is based on the ability to achieve high segmental velocities, which may then be transferred to an object. Athletes are able to generate high velocities using the kinetic link principle and transfer of momentum. The kinetic link principle may be defined as a series of adjacent links, which allows a large base segment to pass momentum to adjacent segments.[71] When a segment decelerates, the velocity of the remaining system increases as it assumes the momentum lost in other segments.[71] For example, the lead (front) leg of the golfer is the base for which all rotation occurs during the follow-through, and the resultant momentum of the golf swing motion is transferred to that side.

Despite the desire to achieve high velocities during sport movement, the body must somehow control the deceleration of the moving limb. It has been reported that baseball pitchers achieve a humeral rotational velocity of 7,000 degrees/second in the throwing motion.[26] The deceleration of the limb requires an eccentric type of muscle contraction, which has also been more associated with injuries.[41] Just as there have been studies on the throwing motion and rotational velocities[26], there have also been studies that have quantified lower extremity rotational velocities.[55] However, these studies have addressed a lower limb moving in an open kinetic chain, such as the kicking leg. Very few studies have examined the lower body rotational velocities achieved at the hip joint while the foot is fixed (closed kinetic chain). One such study that examined lower extremity rotational velocities found that the rotational velocity at the hip reaches a maximum speed (0.075 seconds prior to ball contact) of 714 degrees/second when hitting a baseball.[71] It should be noted that the investigators described hip motion as a vector from the right to the left hip, which is more definitive of the entire pelvic movement, and not separate hip (pelvic-on-femoral) rotation which would occur on each side. Thus, there is still a lack of data describing pure pelvic-on-femoral rotation at each hip separately. Like the baseball hitter, whose foot is fixed during the weight transfer onto the front foot during the bat swing, golfers also experience rotational velocities at the hip in a closed kinetic chain. Thus, there is a lack of quantitative data concerning hip (actual pelvis-on-femoral) rotational velocities for the golfer, and where these might reach a peak.

The Hip Joint

Anatomy of the Hip Joint

The hip joint links the lower extremity with the trunk. The proximal joint surface is the acetabulum, which is formed superiorly by the ilium, posterioinferiorly by the ischium, and anteroinferiorly by the pubis. The concave acetabulum faces lateral, inferior, and anterior, forming a cuplike pocket for the convex femoral head.[54] Furthermore, the acetabulum is deepened by a fibrocartilaginous acetabular labrum. The hip joint is enclosed by a strong, thick capsule, which is reinforced anteriorly by the iliofemoral and pubofemoral ligaments and posteriorly by the ischiofemoral ligament.

Hip Musculature

The hip joint has several surrounding muscles responsible for movement. Sagittal plane movement is provided mainly by the iliopsoas (flexion), rectus femoris (flexion), sartorius (flexion), pectineus (flexion), and the gluteus maximus (extension). Frontal plane movement occurs from muscle activity of the following: gluteus medius (abduction), tensor fascia latae (abduction), adductor longus, brevis, and magnus (adduction), and gracilis (adduction). External hip rotation is traditionally produced by six small rotators (piriformis, superior & inferior gemelli, quadratus femoris, and internal & external obturator), with the gluteus maxiumus contributing due to its posterior attachment inferior to the greater trochanter. Internal rotation is produced by portions of the gluteus medius and gluteus minimus.

Osteokinematics and Arthrokinematics of the Hip

The hip is a synovial ball-and-socket joint with three degrees of freedom, which allows movement to occur about three axes. Motions permitted at the joint are flexion-extension in the sagittal plane around a medial-lateral axis, abduction-adduction in the frontal plane around an anterior-posterior axis, and internal-external rotation in the transverse plane around a longitudinal axis. During open kinematic chain movement the convex femoral head glides on concave acetabulum in direct opposition to movement of shaft of the femur.[54] For example, during external rotation, the femoral head glides anteriorly. During internal rotation, the femoral head glides posteriorly.

Anatomy and Function of Acetabular Labrum

The acetabular labrum is composed of a triangular section of fibrocartilage. This structure lines the acetabular rim circumferentially and joins with the transverse acetabular ligament at the base. The acetabular labrum has been shown to contain free nerve endings.[39] These nerve endings provide sensory input, which may participate in proprioception mechanisms. Histologically, most of the labrum is avascular with the exception of the superficial capsular region.[46]

Little is known about the role of the acetabular labrum. Its presence effectively deepens the acetabulum and may assist in constraining the femoral head.[46] According to Konrath et al.[40], the normal labrum does not increase contact area, distribute load, or reduce contact stresses in the hip. However, the labrum may enhance stability of the hip by providing a negative intra-articular pressure in the hip joint.[46] Those with labral pathology may be at risk for pre-mature degenerative changes, as there appears to be a role of the labrum to seal intra-articular fluids and prevent direct cartilage contact.[23]

Acetabular Labral Pathology

Acetabular labral tears may involve various degrees of tissue failure, and one of the problems is that the orthopedic literature lacks a uniform system for classifying these pathologies.[46] The tears may or may not be associated with articular cartilage injury. Regardless of classification, a majority of labral tears occur anteriorly where the labrum is distinctly thinner.[25, 46, 51, 57] In addition, Ferguson et al.[24], have discussed the material properties of the labrum, and found that the anterior fibers fail sooner than posterior fibers when stressed to failure. Tears occurring posteriorly are typically more associated with acute hip trauma.

Diagnosis of labral pathology has been difficult. Magnetic Resonance Imaging (MRI) results may appear negative, and to date the best diagnostic tool is arthroscopy. Patients may or may not have a history of an acute hip trauma. The main complaints may be a "deep ache", a heavy feeling in the leg, and there may be a "click" or "catch" present.[25, 46] Often this hip pain is misdiagnosed as a groin pull, pubalgia, snapping hip syndrome, contusion, or tight hip flexors.[46] If left untreated, the intra-articular seal is broken and unable to pressurize the joint, allowing more direct contact of cartilage on cartilage. In addition, a deficient labrum, associated with a redundant capsule, may create an abnormal load distribution due to subtle subluxation.[57]

McCarthy et al.[51] have found secondary posterior and lateral tears in the presence of an anterior labral tear, suggesting more displacement of the femoral head, causing fraying of the labrum. In addition, they found that acetabular articular degeneration was dramatically higher in patients with labral abnormalities. Thus, the main result of labral pathology left untreated may be the detrimental effects on the joint, since many researchers have associated labral pathology with dysplasia of the hip.[46]

Role of Sports in Labral Pathology

Athletes who are involved in sports that require repetitive rotation (while the foot is fixed) are at risk of injury to the acetabular labrum.[46] The most common injury pattern for the acetabular labrum is typically associated with hyperextension and ER of the hip.[46] Sports such as golf, tennis, hockey, and soccer involve frequent ER of the hip. Despite the possibilities for acute labral tears to occur in sport, one researcher (an orthopedic surgeon), reported on 55 patients from the general population over a 19 year period, and found that only a small amount of labral tears have a specific event or cause of injury.[25] Thus, a majority of labral tears are atraumatic, suggesting repetitive forces being responsible for the injury. Lohe et al.[44] compared the tensile strength of the transverse acetabular ligament and labrum, finding strain rates of 3.7% and 0.5% respectively. Even when different ligaments or fibrocartilage have the same material properties, they may have more or less stiffness, and yield point to failure.

Several years ago, Andrews et al.[5] reported on repetitive overhead activities (pitching, tennis, swimming), and the relationship with glenohumeral labral tears. These authors suggested that repeated overhead activity with increased anterior-posterior humeral head translation may result in labral fraying, and that large eccentric forces of the biceps tendon may pull away the labral complex. In 1995, Fleisig & Andrews[26] reported on the kinetics of baseball pitching and implications for injury on group of 26 healthy, highly skilled pitchers, using a 3-D Motion Analysis System. They calculated shoulder joint forces and torques using kinematic data, cadaveric body segment parameters, and inverse dynamic equations, and concluded that an anterior force of 380 N during the cocking phase of throwing can lead to an anterior labral tear. Thus, it would only be appropriate to consider that similar accumulative rotations on a fixed lower extremity could possibly cause an avulsion or fraying of the acetabular labrum.

When the foot is in contact with the ground, the lower extremity is described as a closed kinetic chain. When this occurs, forces are transmitted proximally along the extremity. Since sports such as soccer, golf, and tennis require rotation about a fixed foot (closed kinetic chain), there may be potential for significant forces to occur at the hip.

Recognizing that golfers have a fixed front (lead) foot during the follow-through of the golf swing, this limb may experience significant forces transferred via the kinetic chain. In recent years, there have been a handful of professional golfers that have been diagnosed with acetabular labrum pathology.[42] As a result of Dr. Philippon's (orthopedic surgeon) development of the instruments essential to examine these hip pathologies arthroscopically and make the diagnosis, there has been more awareness on this pathology. It is unknown whether this pathology is a direct consequence of their profession or would have occurred even if they had not been involved with golf. Recently, Fitzgerald[25] noted that cystic changes in the labrum are associated with aging. This may suggest that activity is not a main contributor to labral pathology, but essentially a result of aging. However, Buckwalter[13] stated that sports which subject joints to repetitive high levels of torsional loading increase the risk of articular cartilage degeneration. Although it is not known what percentage of the sedentary population has labral pathology compared to athletes, the athlete may be accelerating the process of articular degeneration by continual torsional loading. Furthermore, if an athlete lacks normal range of motion in the hip joint, there could be additional stress applied predisposing them to injury.

Hip ROM Norms

Several different studies[8, 60, 61, 64, 65] have reported varying values for hip ROM. Part of the reason for this is that there has been different methodology regarding the type of motion measured (active vs. passive), and the position for measurement (prone, supine, or seated). Despite the varying ranges among active and passive norms from various sources, there is a common agreement that passive ROM is greater than active range of motion.[54]

Hip ROM can be affected by age, gender, and the position in which the measurement is taken. When comparing the effect of gender on ROM across various age groups, Allander[3] found that females had a greater amount of hip rotation than males in five of the eight age groups. Furthermore, for young adults (mean age 21.8 years), Simoneau[64] found females had greater IR and ER (at the hip) than age-matched males when measuring subjects in the seated and prone position. However, Svenningsen[65] found adult males (mean age 23 years) have more ER than females when measuring the subjects in prone position. This difference in results may be attributed to the fact that Svenningsen[65] subjects were measured passively and Simoneau[64] took active measurements.

Not only will age and gender cause variation in the measurement, but also the position in which subjects are measured. Simoneau et al.[64] found that ER measured in a sitting position (mean 36 degrees) resulted in statistically significant less ROM when compared to the prone position (mean 45 degrees). In further support, Bierma-Zeinstra[8] found that both IR and ER ROM (active and passive) was significantly less in the sitting and supine positions compared with those in the prone position. Thus, it appears that measurement in the sitting position will be significantly less than the prone position.

Since it is known that the position of the hip joint during measurement will influence the results, it may be inferred that the tension on the hip capsule contributes to this measurement. When the hip is flexed, the capsule and ligaments have more laxity, which should allow for more movement relative to a neutral hip joint (more taut hip capsule and ligaments). However, the literature refutes this line of thought, showing more rotation in a prone position compared to seated position.[8, 64] These hip rotation ROM values may then suggest that muscle length, as a result of the joint position, could be the limiting factor.

Regardless of the subject position for measurement, compensatory movement must be controlled for to ensure valid results. Although stabilization of the pelvis and femur during measurement is important, several investigators have been quite vague in describing their methods. One of the limitations of measuring in a seated position is that of properly stabilizing the pelvis from compensatory movement. The investigator must make certain that the subject is not shifting their weight (which changes pelvic position), during the measurement. In comparison, much more adequate stabilization of the pelvis is already provided by the table when the subject is prone, and thus the possible explanation for higher reliability.[6, 16] Another limitation for comparing hip joint ROM measurements in a prone vs. seated position, may lie in the definition of the investigators endpoint. By not having a clearly defined end point for measurement, substitutionary movement from the pelvis may occur. For example, whether or not an investigator allows full movement of the limb for the defining end point, or when the pelvis begins to shift, may make a tremendous difference in measurement values.

The available ROM at a joint not only depends on capsule and muscle, but also the bony congruency. Most clinical studies have not accounted for this contribution. However, a recent study[56] has shown that baseball pitchers with an increased amount of glenohumeral ER, have also demonstrated an increase in glenohumeral retroversion. Osbahr et al. (2002)[56] measured 19 healthy, collegiate baseball pitchers retroversion angle, and found a significant correlation between the amount of retroversion of the humerus and ER. Similarly, the amount of torsion (anteversion or retroversion) at the hip may affect anatomical ROM limits.

Femoral Anteversion/Retroversion

Femoral torsion (anteversion/retroversion) is defined by the angle of the femoral head with the distal femoral condyles. Typically, this angle decreases from approximately 30 degrees at birth to about 8-15 degrees in adulthood (normal 10-15 degrees). The most commonly used measures for femoral anteversion/retroversion are radiographs, ultrasound, magnetic resonance (MR) images, and computed tomography (CT). However, these are expensive tests and may not be appropriate for the clinician seeing athletes. Therefore, the Craig test has been used to obtain an objective measure of femoral anteversion/retroversion angle. For the Craig test, the subject lies prone with the knee flexed about 90 degrees as the examiner palpates the greater trochanter. Then, the examiner passively rotates internally and externally until the greater trochanter is parallel with the examining table. The degree of anteversion/retroversion is based on the lower leg angle with relation to the vertical. Unfortunately, there is no published data on the reliability or validity of this clinical measurement. Clinically, if one is assessing joint range of motion and the subject's internal rotation appears to be greater than normal (and is bilaterally symmetrical), an excessive anteversion angle may be a contributing factor.

Hip ROM Measurement Procedures

Clinical measurement of joint ROM is commonly assessed with a goniometer. There are other measuring devices that have been used, such as plurimeters and inclinometers, but these have been mostly used for measuring spinal ROM. However, Barbee-Ellison et al. (1990)[6] measured 100 healthy subjects and found no difference in the means of passive hip rotation ROM when using the goniometer and the inclinometer. Since the goniometer is the measuring device most available to clinicians, this was the instrument used for assessing hip rotation ROM in this study.

The reliability of hip rotation ROM measurement may be influenced by the number of investigators taking the measurement. For example, when using a goniometer, studies have shown acceptable intra-rater reliability for assessing ROM, whereas inter-rater reliability has not been as high.[6, 12, 64] Thus, the decision was made to use the same investigator for assessing joint ROM during this study. Of all the measurement positions used for assessing passive ROM, the most reliable position is prone. For example, Cibulka et al. (1998)[16] found the prone position to be more reliable than the seated position when examining passive ROM with a goniometer. Furthermore, Barbee-Ellison et al. (1990)[6] measured prone passive ROM and found very strong intratester reliability for IR (ICC = 0.99) and ER (ICC = 0.96). Thus, passive ROM was measured in a prone position for the current study.

Although hip rotation (IR and ER), may be assessed with the patient in supine, prone, or seated position, these measurements are non-weight-bearing (NWB) ROM. Currently, there is no valid or reliable measurement for normal hip rotation in the WB (functional) position. Clinically, restoring normal NWB ROM has significance in regards to the patient with an existing pathology where ROM was restricted. However, for the athlete, a more functional assessment in the WB position may be required to determine what is adequate ROM for a particular sport task. Thus, future research should focus on the association with the required range of movement in sport, and the amount available to the athlete in that condition. It is quite reasonable to infer that an athlete who does not have the available ROM needed for their sport movement may increase their risk of injury by placing excessive stress on the soft-tissue.

Hip ROM and Asymmetry

ROM at a joint depends upon the shape of the bony articulating surfaces (mainly inherited), the collagen structure making up joint capsule, ligaments, muscles (inherited), and the neuromuscular tone (mainly acquired by means of training).[27] Normal, healthy people demonstrate bilateral symmetry in their joint ROM[8, 12, 15, 20, 60], but certain athletes have demonstrated side-to-side differences (in the upper extremity) as a result of the demands of their sport.

Joint ROM changes may occur due to sport participation as well as daily living activities. For example, habitual postures and chronic exercise have been reported to lead to adaptive shortening of muscles and connective tissue.[20] Depending on the activity, this adaptation may occur on one side of the body or both sides. When there is an adaptation on one side, but not the other, asymmetrical joint ROM occurs. Interestingly, most studies that have observed differences in side-to-side joint ROM have not reported on the total ROM available to the joint. For example, normal glenohumeral joint ROM would consist of approximately 90 degrees of ER rotation and 90 degrees of IR. Thus, it is not known what biomechanical effects there may be if someone gains motion in one direction, but loses motion in the other direction (retaining total joint ROM). Although joint ROM asymmetry may not have a detrimental effect on performance, it may have quite an influence on the biomechanical effects of the entire kinetic chain.

Although there is no definitive number for change (gain/loss) in joint ROM before it becomes detrimental, Roach and Miles[61] have suggested that differences in active ROM representing less than 10 percent of the arc of motion are of little clinical significance. For example, if a person has 45 degrees of IR and 45 degrees of ER for a total arc of motion of 90 degrees, then a nine-degree difference would not be significant. Despite the author's opinion about the amount of difference in ROM that would have clinical significance, it is not known exactly how much of a difference may have a biomechanical impact on the joint, and the entire kinetic chain. For example, any loss of rotation at the hip may place excessive mechanical stress on the lumbar spine.[6]

Investigators have proposed that low back pain may be related to limited ROM at the hip.[16] Despite differences in available ER and IR, there is typically bilateral symmetry; thus right side IR equals left side IR. However, a side to side difference in ER has been observed in those with sacroiliac joint dysfunction.[16] Thus, knowledge of hip rotation ROM asymmetry may be valuable input in the overall assessment of low back pain.

Tissue Adaptation and Sport

Tissue Adaptation

Repetitive motion and loading during sport have been associated with adaptations in joint ROM. For example, there are numerous reports that throwing/overhead athletes demonstrate excessive ER and decreased IR in their dominant arm in comparison to non-dominant arm .[9, 22] Bigliani et al. (1997)[9] measured 148 healthy, professional baseball players (pitchers and position players), finding that pitchers had significantly more ER, and less IR than the position players. Thus, the results of their study suggest that the repetitive throwing motions contributed to the differences in bilateral joint ROM. Interestingly, Ellenbecker et al. (2002)[22] compared two groups of unilaterally dominant upper extremity athletes and found that professional baseball players (mean age 22.6 ± 2.0 yrs.) have symmetrical total glenohumeral joint ROM, but the dominant arm has significantly more ER while losing IR. Thus, total joint ROM remains the same. Furthermore, the second group of athletes in the study was elite junior tennis players (mean age 16.4 ± 1.6 yrs.), who were found to have no side-to-side differences in ER, but did have significantly less total joint ROM than the baseball players. It may be possible that the younger tennis players have not been playing long enough to experience joint ROM alterations in the dominant arm, similar to those of the older baseball players. Thus, it is not known specifically how much playing experience is required before alterations in joint ROM may occur. However, in 1996, Kibler et al.[38] examined the relationship between joint ROM changes in the dominant arm with years of playing experience in 39 elite tennis players. The mean age and playing experience of the tennis participants was 18 and 8.8 years respectively. They found that both men and women tennis players experienced the same degree of deficits in ROM, and a moderate negative correlation between dominate arm IR and years of total play. In particular, those playing 6-9 yrs. had a much more significant decrease in IR ROM compared to those playing less than six years.[38]

Not only is there an alteration in measurable joint ROM as a result of sport participation, but more recent evidence has linked this increased ER with an increased retroversion glenohumeral angle.[56, 59] Thus, it appears the demands placed on the glenohumeral joint are actually causing structural changes in the bone, which would be a factor in the amount of motion at a given joint.

Decreased Joint ROM as a Result of Sport Participation

Athletes in sports such as ice hockey actually have demonstrated a decrease in hip ROM (extension) as result of a flexed knee and hip posture assumed during skating[67], suggesting a shortening of the surrounding soft-tissue (capsule and muscle). The previously mentioned study by Tyler et al. (1996)[67] measured 25 professional hockey players and compared their hip extension ROM with 25 age-matched controls. Although, there was no significant difference between the right and left hips, the professional hockey players had significant less hip extension ROM. Thus, it has been demonstrated that the body will accommodate to the level of function needed for the sport.

In addition, repetitive activities may also produce micro-trauma to soft-tissue, which may cause it to respond by shortening and tightening. The result would be a decrease in measurable joint ROM. Recently it has been demonstrated in male, professional golfers with back pain, that hip IR in the lead (front) hip is significantly less than the trail hip.[68] As a golfer goes into follow-through, the lead leg IR, which means the small ER muscles are acting eccentrically. One of the causes of limited IR may be a shortened piriformis (ER), as a result of being overworked in efforts to control the movement eccentrically. The authors hypothesized that asymmetry in hip rotation may be a contributing factor in the golfers with low back pain. Their study only made comparisons within a group of male, professional golfers, those with low back pain, and those with out low back pain. However, there has not yet been a comparison of healthy golfers with a healthy age-matched, non-golfing population to determine if the decrease in IR found in the golfer's with low back pain was simply due to their low back pathology, or tissue adaptation as a result of participation in the sport.

The consequences of soft-tissue adaptations as a result of sport participation may be quite detrimental. A recent study has documented an increase in prevalence of hip osteoarthritis (OA) of former elite soccer players in comparison to age-matched controls.[63] The authors distributed surveys to former elite soccer players (mean age 44 yrs. and playing career length of 16 yrs.), finding a significant higher prevalence of OA of the hip in comparison to age-matched controls from the general public. Although the main contributing factor for OA is not known, it is believed to be attributed to the repetitive loading to the hip joint.[13] Interestingly, none of the athletes previously mentioned reported any hip injuries during their playing career, but they may have suffered consequences from the repetitive motions placed on the joint.

It has been observed in very early arthrosis of the hip, that IR is the first movement to become restricted.[17] This observation may be made during a bilateral assessment of joint ROM, which is key for making comparisons and diagnoses. Thus, joint ROM is not only significant for the patient, but it also helps clinicians determine an appropriate course of action. Furthermore, since labral pathology has been associated with risk for early degenerative changes, it may be possible to observe limited IR in this patient population as well. Future research needs to focus on the bilateral hip rotation ROM for those with labral pathology and those without to determine if this deficit may exist.

Increased Joint ROM as a Result of Sport Participation

Not only is soft-tissue capable of shortening, but also may stretch or increase in laxity. Some of the most studied athletes with an increase in joint ROM are ballet dancers. A significant amount of ER at the hip is required for the 180- degree turnout position, but not all of this motion comes from the hip joint. According to Thomasen (1982), dancers achieve this 180° bilateral turnout by unilaterally externally rotating the hip 70°, the tibia 5°, and 15° at the foot, thus adding up to 180° bilaterally. Although the dancing population uses other joints to achieve the desirable turnout position, these athletes still experience more hip external rotation ROM than the normal population (70° vs. adult norm ranging 45°-50°).

Once again, what is unknown is the time period necessary before these soft-tissue adaptations occur, and how much of the adaptation is occurring in youth sports, prior to skeletal maturation. Kibler et al (1996)[38] study on elite tennis players with a mean age of 18 yrs. did reveal a moderate negative correlation between years of playing experience and the amount of IR deficit. It appears that six years of routine competition may be enough to alter the joint ROM.

As much as losing joint ROM is not desirable, having excessive joint ROM is also concerning with regards to injury potential. For example, the association between increased glenohumeral capsular laxity (in overhead athletes) and impingement symptoms has been documented as early as 1989.[36] Baseball pitchers, in particular, are one group of athletes that experience shoulder pathology such as impingement, glenohumeral instability, and rotator cuff pathology. Much of this has been attributed to the forces placed on the throwing arm, which stretch the glenohumeral capsule and ligaments over time, allowing for subtle subluxations, and secondary impingement.

It is well documented that baseball pitchers have a significant higher amount of glenohumeral ER, as well as associated deficit in IR in the dominant arm relative to the non-dominant arm.[9] Another group of overhead athletes that has been studies in regards with dominant vs. non-dominant joint ROM are tennis players. Ellenbecker (2002)[22] have observed increases in dominant arm glenohumeral ER relative to the non-dominant arm.

Not only is there evidence of increased ER in overhead athletes, but also there is more recent evidence of osseous changes in overhead athletes. Studies on baseball pitchers have revealed a significant difference in the amount of humeral head retroversion between the dominant and non-dominant arms.[56, 59] Thus, not only are there changes in soft-tissue, but now it appears the bone is adapting to the repetitive stress.

Summary

In summary, the demands of sport have been known to alter joint ROM in overhead athletes, but little is known about the accommodations of the lower extremity, in particular hip rotation ROM. Just as the change in joint ROM may cause shoulder pathology, repetitive rotational sports (such as golf) place great demands on the lower extremity where there is potential for adaptation and injury to occur.

Chapter Three

METHODOLOGY

This chapter outlines the procedures and methods used in this study. A detailed description of the subjects, instrumentation, experimental set-up and protocol, as well as statistical analyses of the study are provided. All of the testing and data collection took place in the Applied Biomechanics Laboratory (UTABL) in the Health and Human Services building on the campus of the University of Toledo.

Subject Description

Fifteen elite female golfers (mean age 19.6 ± 1.4 yrs; ht. 163.3 ± 6.5 cm; wt. 59.5 ± 6.6 kg) and 15 aged-matched controls (mean age 20.5 ± 1.7 yrs.; ht. 166.8 ± 7.7 cm; wt. 61.5 ± 10.2 kg) participated in the research study. All participants were right-hand dominant. Both groups were screened and excluded if they had any hip or back pain in the past six months. In addition, the control subjects were screened and excluded for frequent participation in tennis, soccer, or golf (rotational sports). Prior to participation, subjects signed a written consent form as approved by the University of Toledo Human Subjects Research Review Committee (Appendix A).

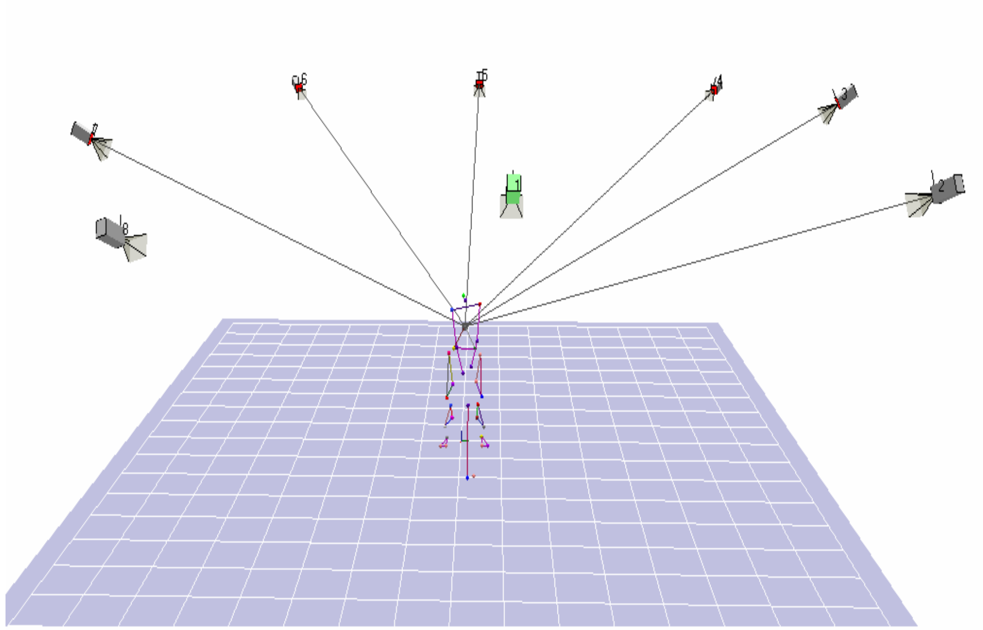
Protocol

Prior to data collection, all subjects received an overview of the procedures, and were provided with the opportunity to ask questions. The control group participants reported to the laboratory on one occasion, for hip ROM measurements, but were not required to make any golf swings. The golfer group participants also reported to the laboratory on one occasion, first having the ROM limits measured (same as the control subjects), and then performing approximately 10 golf swings, during which video data were collected.

Instrumentation

A three-dimensional (3D) motion capture system (Motion Analysis Corporation, Santa Rosa, CA) was used to quantify the movements of each subject (see Figure 1). This system uses EVa 7.0 software (Motion Analysis Corporation, Santa Rosa, CA) for video and analog data acquisition and processing. Eight electronically synchronized Falcon High Resolution cameras (Motion Analysis Corporation, Santa Rosa, CA), sampling at 120 Hz were used for capturing the movement of the retroflective markers (Appendix B) on each subject. Through the use of a Dell PC and the Eva software, the video data was tracked and saved as binary (.trb) files and finally exported to the Kintrac software (Motion Analysis Corporation, Santa Rosa, CA) for analysis.

Figure 1. Lab Set-up with Cameras



Passive hip ROM (non-weightbearing) was measured using a standard 360° plastic goniometer with 12" long measuring arms and 1° intervals. For obtaining weight-bearing hip rotation measurements, subjects stood on a custom built wooden base with a rotating surface, and video data (sampling at 120 Hz) recorded the movement of the markers on the lower extremity (Appendix B).

<u>Experimental Set-up</u>

Eight cameras were spaced at varying positions in the Applied Biomechanics Laboratory (see Appendix C). In order for the marker images from all the cameras to be translated into 3D coordinate values, a calibration was performed prior to each data collection session. The first calibration step involves a cube with eight reflective markers set in pre-determined locations. The cube is placed in the center of the testing area and collected at 120 Hz for one second. Secondly, a wand (with 3 precisely measured and spaced reflective markers) was used to expand the calibration volume. The investigator walked the wand around the testing area while collecting at 5 Hz for total of 120 seconds.

Procedures

All passive ROM was measured in a prone position, on a firm treatment table after a five-minute bike warm-up. The same investigator took all the measurements three times bilaterally (see Appendix D for established intra-rater reliability). For the prone position measurement, the subjects were measured with the knees in 90° of flexion.[29] A seat belt strap was secured over the posterior superior iliac spine region of the subject, and completed a loop under the table. The fulcrum of the goniometer was placed on mid-patella, with the moving arm aligned along the shaft of the tibia midway between the two malleoli, and the stationary arm perpendicular to the ground. Each subject was verbally and visually instructed to make sure the anterior superior iliac spines remain level, and measurement was stopped when pelvic movement (shifting) was necessary for additional rotation.

The designated set of reflective markers (see Appendix C) was used for measures of active hip rotation in the WB status. Subjects stood on a custom-built wooden base so that one foot was fixed (stable), while the other foot (the involved leg for measurement) was free to rotate on a circular disk (see Figures 2 and 3). The subject's weight was equally distributed (50% on right and left sides) during the measurement. All subjects were measured in a WB condition with the stance width, as well as the hip and knee flexion, determined from their self-selected golf set-up position (for a driver). The rotating foot was aligned on the center of the board (axis of rotation) by placing tape lines (for heel and toe alignment) down as visual cues. Although foot alignment on the tape lines had to be specific, the starting angle of the entire rotating board could occur at their natural toe-in or toe-out position, as each subjects start position was used as a marker to determine the maximum amount of rotation. Depending on which direction was being measured, the subject was asked to rotate the foot externally (or internally) as far as possible, and then return to the start position. Measurements of hip IR and ER were made bilaterally, repeating six times in each direction. In order to maintain the level of flexion in the hip and knees during data collection, the subject's position was reset (using a goniometer) after every two trials. The cameras sampled at 120 Hz for a total of four seconds during the WB ROM testing trials. After completion of the various WB measurements, the control subjects were finished with all data collection.

Figure 2. WB ROM Trial

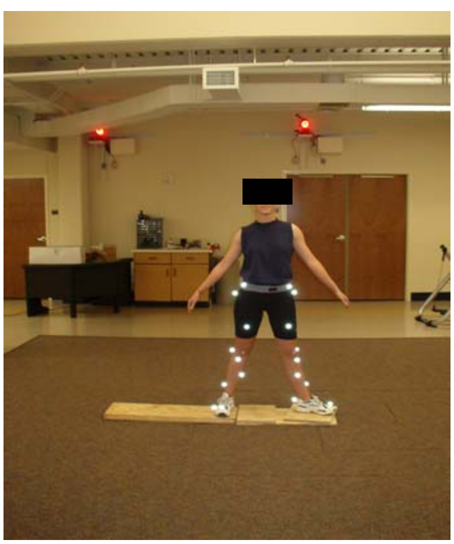
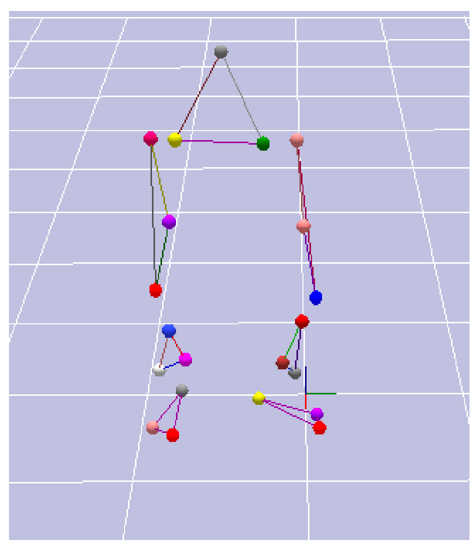
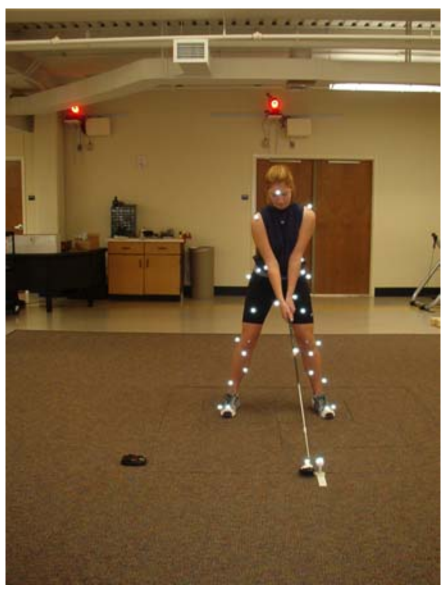


Figure 3. Tracked WB ROM Trial



Golfer subjects then had the complete marker set (Appendix C) placed on prior to proceeding with approximately ten golf swings, as shown in Figure 4. Practice swings were allowed for warm-up, as well as allowing the subject to feel comfortable making a golf swing with the marker set in place. Each golfer assumed their natural stance width with a driver (45" custom-built supplied by the lab). The distance between the lateral borders of the feet was measured in cm, and then two separate strips of tape were placed on the floor for the reference point of all following swings. The golfers hit a wiffle ball with a retroflective marker on top, while the swing speed was measured using the SwingMate device (placed approximately three feet behind the tee). The clubhead velocities were characteristic of elite female golfers (84.0 ± 7.9mph). Each of the full golf swings was captured at 120 Hz with a four second collection period per swing.

Figure 4. Marker Placement for Golf Swings



Data Analysis

Statistical package SPSS version 12.0 was used for the statistical analysis of data. For H1 and H2, the presence of significant group or side differences in passive ROM was determined by separate 2 x 2 (group x side) repeated measures ANOVA's, one for IR and another for ER. Likewise, to test for the presence of significance in WB ROM, separate

2 x 2 (group x side) repeated measures ANOVA's were run for IR and ER. For (H3) descriptives were used comparing the golf swing ROM as a % of available (right hip ER and left hip IR) WB ROM. For comparison of each hip's rotation ROM during the backswing and downswing phases a 2 x 2 (side x rotation) was run to test for the presence of a significant difference in the amount of hip rotation experienced during the golf swing. (H4) was tested using a paired t-test comparing the right and left hip velocities during the downswing. The significance level was set at an alpha level of 0.05 for all analyses.

Chapter Four

RESULTS

One of the main purposes of this study was to determine if there were any differences in joint ROM between the golfers and age-matched non-golfing controls. The subject descriptives of the two groups are reported in Table 1. Two separate types of measurements were made in order to evaluate any differences in hip joint rotation ROM, one in a passive (NWB) condition, and the other in a more functional WB condition. Another purpose of the study was to determine if the there was a side-to-side asymmetry in the subject's hip rotation ROM. The last hypotheses concerned the golfer's hip rotational velocities and ROM during the golf swing. Thus, the results are presented in the order addressing the previous hypotheses.

Subject Background Information

Fifteen elite female golfers and 15 age-matched control subjects, participated in the current study. All subjects were healthy and free of low back or hip pathology in the previous six months.

Table 1. Subject Descriptives

	Means ± Standard Deviations	
	Control (n = 15)	Golfer (n = 15)
Age (yrs.)	20.5 ± 1.8	19.7 ± 1.4
Ht (cm)	166.9 ± 7.7	163.3 ± 6.5
Wt (kg)	61.5 ± 10.2	59.6 ± 6.6

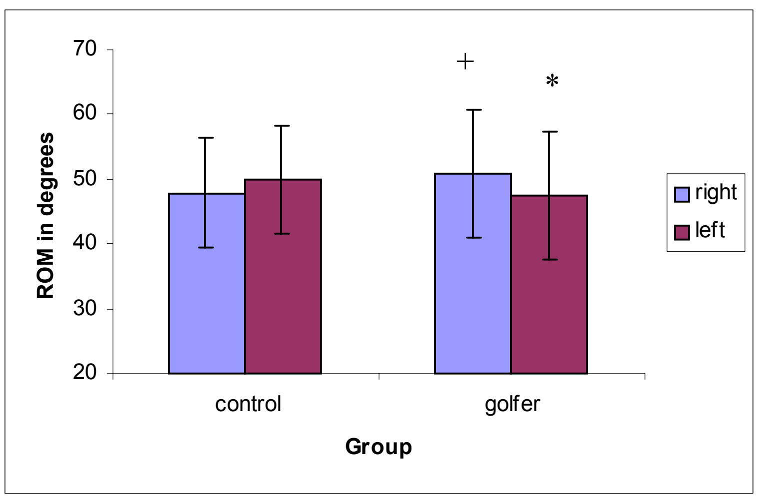
* indicates significance at the 0.05 level

Passive ROM (prone position)

Passive IR ROM

All subjects were measured passively on a firm treatment table, in the prone position. Three measurements were taken on each side, with the mean used for analysis. The results of the 2 x 2 (group x side) repeated measures ANOVA indicated a significant 2-way (group x side) interaction ($p = 0.028$), but a non-significant main effect for group ($p = 0.964$), or side ($p = 0.532$). These are shown graphically in Figures 5, 6, and 7. The means and standard deviations are shown in Tables 2 and 3, with the statistical summary in Table 4.

Figure 5. Group x Side Interaction for Passive Hip IR ROM



* indicates significance at the 0.05 level between the golfer's R-L sides
\+ indicates significance at the 0.05 level between the group's Right side

Figure 6. Group Effect for Passive Hip IR ROM

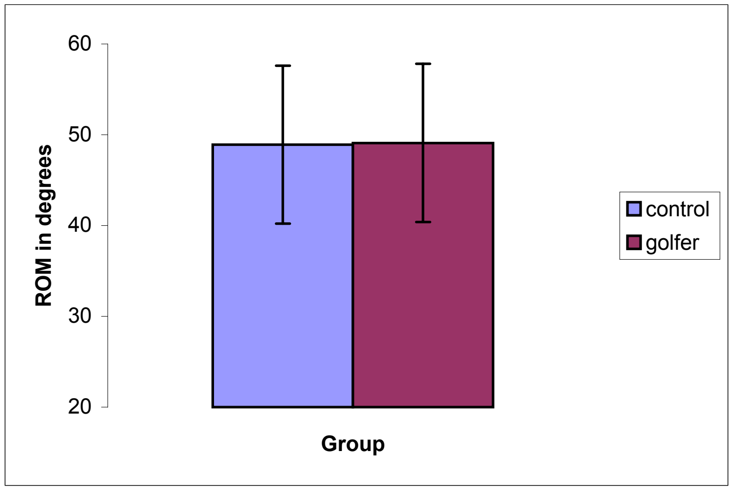


Figure 7. Side Effect for Passive Hip IR ROM

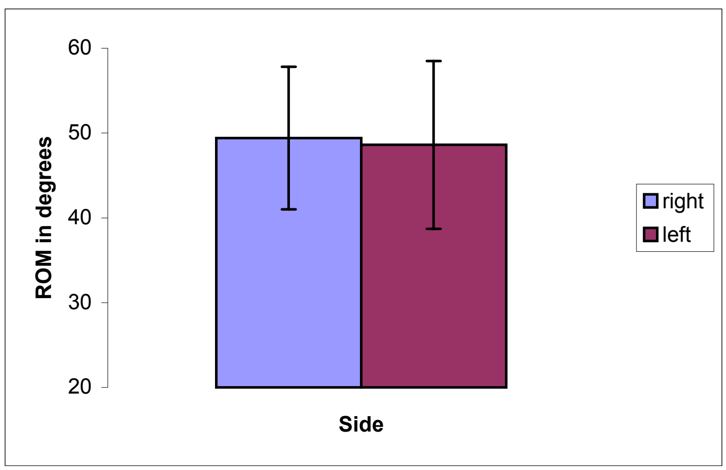


Table 2. Means and Standard Deviations for Passive Hip IR ROM

Group	Means and Standard Deviations (deg.)	
	Right	Left
Control (n = 14)	47.9 ± 7.5	49.9 ± 8.5
Golfer (n = 15)	50.8 ± 9.3^{+}	47.4 ± 11.2*

* indicates significance at the 0.05 level between the golfer's R-L sides
+ indicates significance at the 0.05 level between the group's Right side

Table 3. Means and Standard Deviations for Main Effects in Passive Hip IR ROM

Main Effect	Means and Standard Deviations (deg.)	
Group	Control	Golfer
	48.9 ± 8.7	49.1 ± 8.7
Side	Right	Left
	49.4 ± 8.4	48.6 ± 9.9

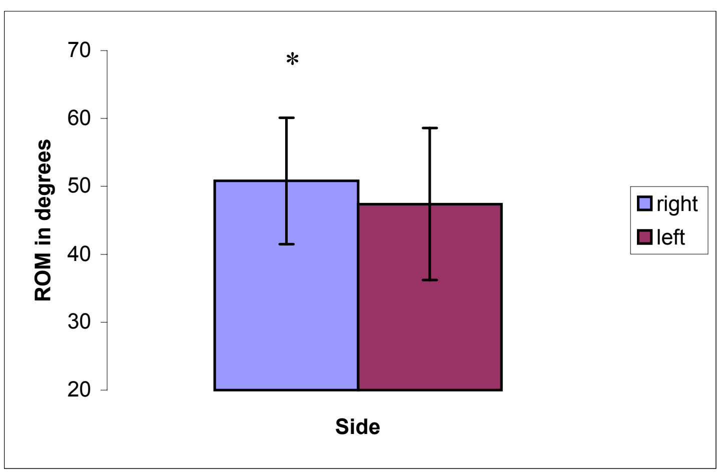
Table 4. Statistical Summary for Passive IR Hip ROM

Interaction	$F_{(1,27)}$	p-value
Group x Side	5.374	0.028*
Group Effect	0.002	0.964
Side Effect	0.402	0.532

* indicates significance at the 0.05 level

Based on the significant finding of a 2-way (group x side) interaction, a Scheffe's post-hoc test was performed. The critical value to detect significance was 2.65. Within the golfer group, the right side IR (50.8 ± 8.4) was significantly greater than the left side IR (47.4 ± 9.9). Figure 8 shows this graphically.

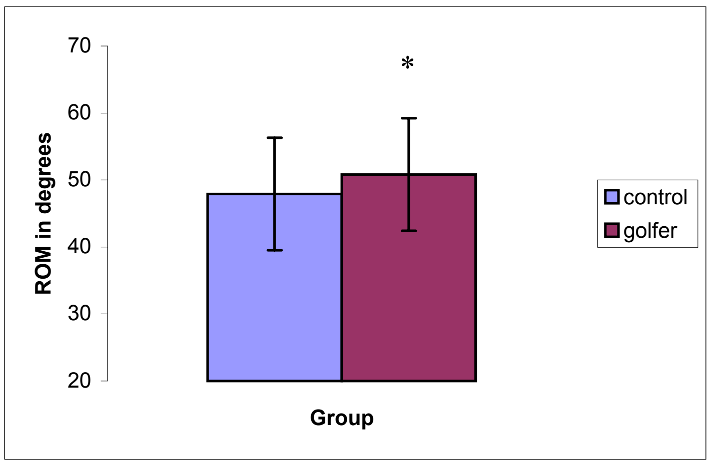
Figure 8. Golfer R-L Differences in Passive Hip IR ROM



* indicates significance at the 0.05 level

In addition, the two groups differed significantly on right side IR. The golfers (50.8 ± 8.4) had more IR on the right side than the controls (47.9 ± 8.4), as shown in Figure 9. This group difference was not evident when the sides were collapsed, as the main side effect from the 2 x 2 (group x side) repeated measures ANOVA revealed a non-significant main effect for group (p = 0.964). Furthermore, the calculated effect size for right side IR between the two groups was very small (0.31).

Figure 9. Group Differences in Right Side Passive Hip IR ROM



* indicates significance at the 0.05 level

Passive ER ROM

All subjects were measured passively on a firm treatment table, in the prone position. Three measurements were taken on each side, with the mean used for analysis. There were no statistically significant differences for the group x side interaction (p = 0.573), main effect for group (p = 0.715), or main effect for side (p = 0.932). These are presented graphically in Figure 10, 11, and 12. The means and standard deviations are shown in Tables 5 and 6, with the statistical summary in Table 7.

Figure 10. Group x Side Interaction Passive Hip ER ROM

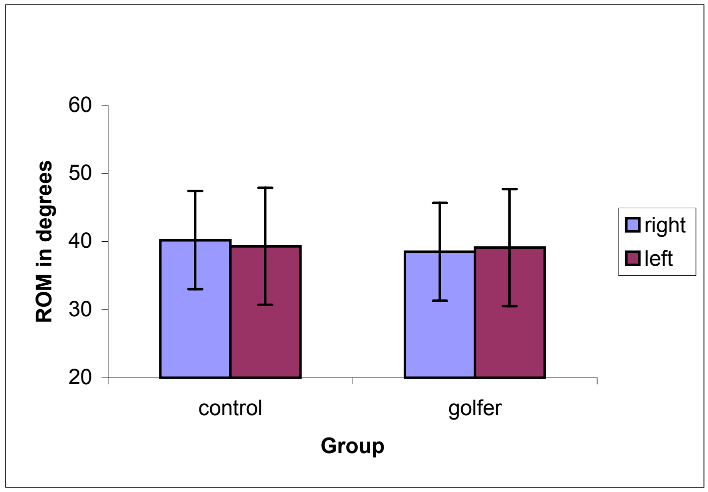


Figure 11. Group Effect for Passive Hip ER ROM

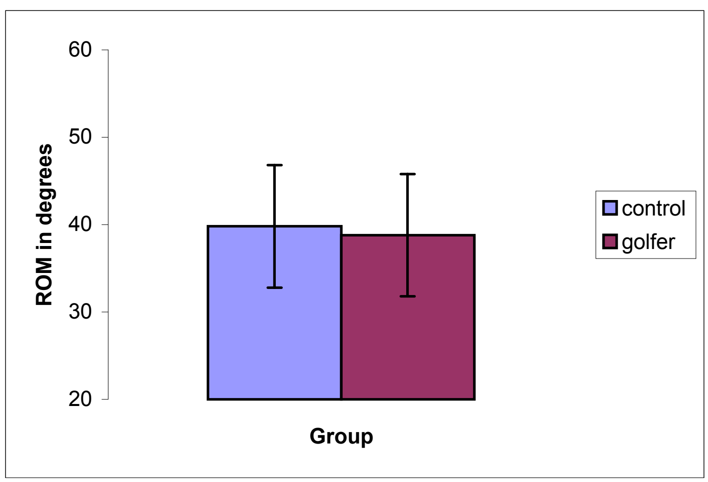


Figure 12. Side Effect for Passive Hip ER ROM

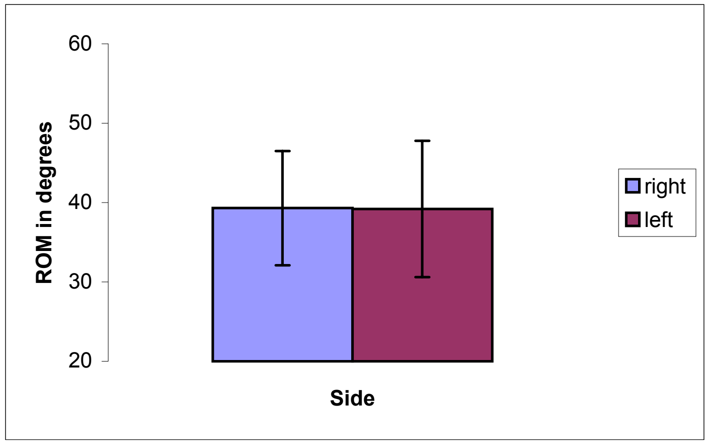


Table 5. Means and Standard Deviations for Passive Hip ER ROM

Group	Means and Standard Deviations (deg.)	
	Right	Left
Control (n = 14)	40.2 ± 6.6	39.3 ± 9.7
Golfer (n = 15)	38.5 ± 7.8	39.1 ± 7.4

Table 6. Means and Standard Deviations for Main Effects in Passive Hip ER ROM

Main Effect	Means and Standard Deviations (deg.)	
Group	Control	Golfer
	39.7 ± 7.0	38.8 ± 7.0
Side	Right	Left
	39.3 ± 7.2	39.2 ± 8.6

Table 7. Statistical Summary for Passive Hip ER ROM

Interaction	$F_{(1,27)}$	p-value
Group x Side	0.325	0.573
Group Effect	0.136	0.715
Side Effect	0.007	0.932

A summary of the overall results for assessment of passive ROM for each group separately is shown graphically in Figures 13 and 14. The means and standard deviations are shown in Table 8.

Figure 13. Control Group R-L Differences in Passive Hip ROM

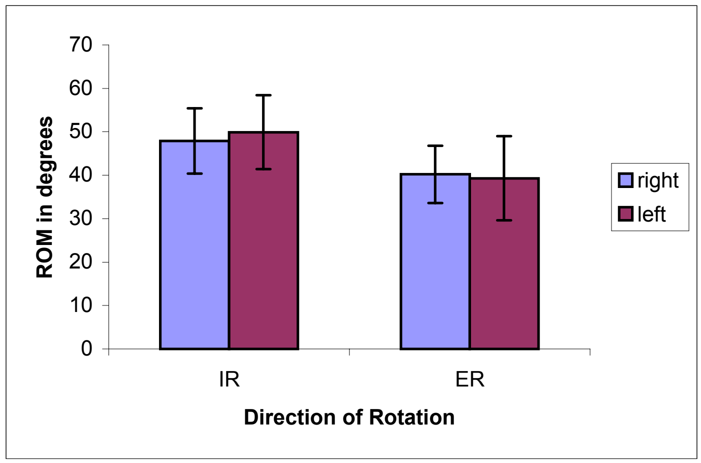
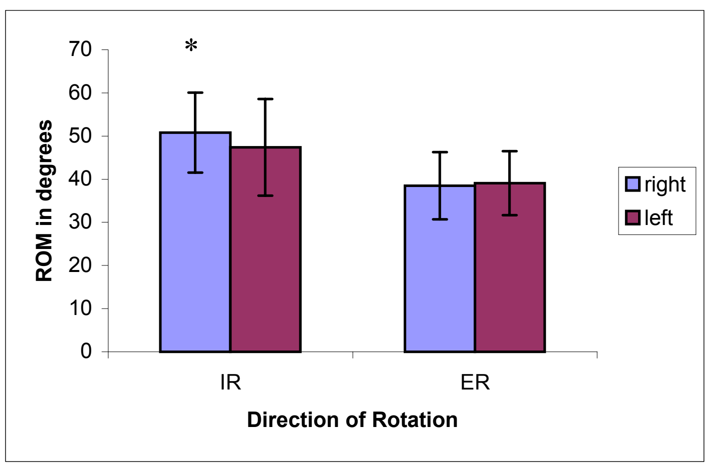


Figure 14. Golfer Group R-L Differences in Passive Hip ROM



* indicates significance at the 0.05 level

Table 8. Summary of Means and Standard Deviations for Passive Hip ROM

	Means and Standard Deviations (deg.)			
Rotation	Control Group (n = 14)		Golfer Group (n = 15)	
	Right	Left	Right	Left
IR	47.9 ± 7.5^{+}	49.9 ± 8.5	50.8 ± 9.3*	47.4 ± 11.2
ER	40.2 ± 6.6	39.3 ± 9.7	38.5 ± 7.8	39.1 ± 7.4

* indicates significance at the 0.05 level between the golfer's R-L side
+ indicates significance at the 0.05 level between the two groups Right side IR

Weight-bearing ROM

Prior to collecting the WB ROM, all subjects were asked to set up in the address position of the golf swing with the driver in their hands. Then, measurements were taken for the amount of hip and knee flexion that they demonstrated, as well as the width of their stance (difference between the lateral borders of the feet). This information was then used to establish their position for the WB ROM test. Both of the group's stance position descriptives are shown in Table 9.

Table 9. Group Descriptives for WB Hip ROM Posture

Stance Description	Means ± Standard Deviations (deg.)	
	Control (n=15)	Golfer (n = 15)
Hip flexion (deg.)	30.3 ± 9.5	38.7 ± 6.0*
Knee flexion (deg.)	25.3 ± 5.5	24.7 ± 7.0
Width of stance (cm)	56.3 ± 6.9	59.5 ± 4.6

* indicates significance at the 0.05 level

<u>WB IR ROM</u>

All subjects performed six trials on each side, with the mean of three used for analysis. There were no statistically significant differences for the group x side interaction ($p = 0.155$), main group effect ($p = 0.509$), or main side effect ($p = 0.733$).

These results are shown graphically in Figures 15, 16, and 17. The means and standard deviations are presented in Tables 10 and 11, with the statistical summary in Table 12.

Figure 15. Group x Side Interaction for WB Hip IR ROM

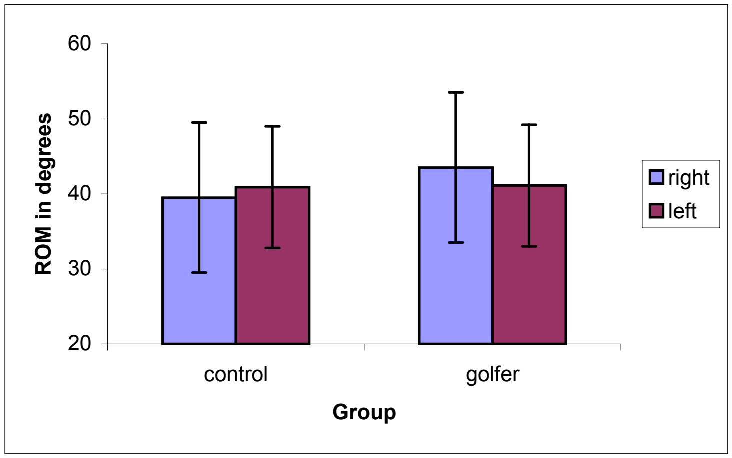


Figure 16. Group Effect for WB Hip IR ROM

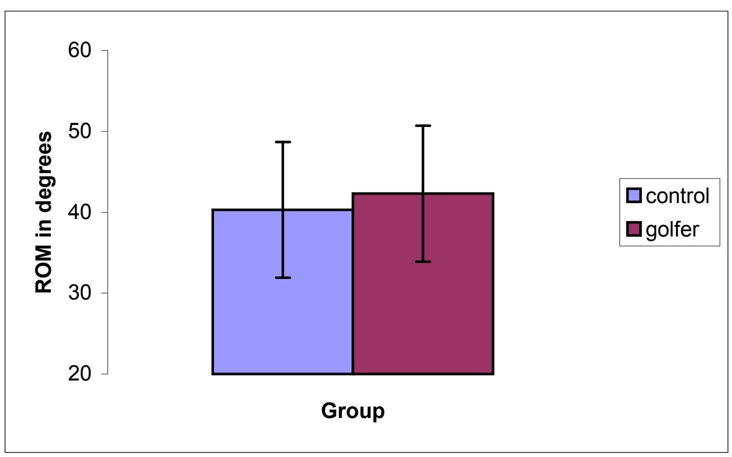


Figure 17. Side Effect for WB Hip IR ROM

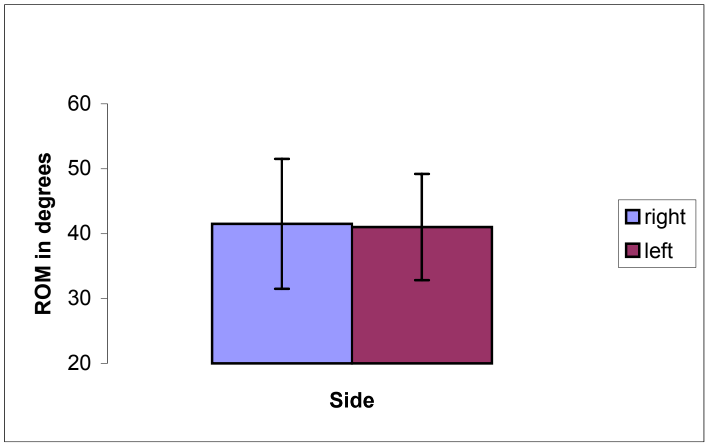


Table 10. Means and Standard Deviations for WB Hip IR ROM

	Means and Standard Deviations (deg.)	
Group	Right	Left
Control (n = 15)	39.5 ± 8.9	40.9 ± 7.9
Golfer (n = 15)	43.5 ± 10.9	41.1 ± 8.4

Table 11. Means and Standard Deviations for Main Effects WB Hip IR ROM

Main Effect	Means and Standard Deviations (deg.)	
Group	Control	Golfer
	40.3 ± 8.4	42.3 ± 8.4
Side	Right	Left
	41.5 ± 10.0	41.1 ± 8.2

Table 12. Statistical Summary for WB Hip IR ROM

Interaction	$F_{(1,28)}$	p-value
Group x side	2.136	0.155
Group main effect	0.447	0.509
Side main effect	0.119	0.733

WB ER ROM

All subjects performed six trials on each side, with the mean of three used for analysis. There were no statistically significant differences for the group x side interaction (p = 0.893), main group effect (p = 0.897), or main side effect (p = 0.385). These are shown graphically in Figures 18, 19, and 20. The means and standard deviations are illustrated in Tables 13 and 14, with the statistical summary shown in Table 15. The WB ROM summary for each group is shown graphically in Figure 21 and 22, with the means and standard deviations shown in Table 16.

Figure 18. Group x Side Interaction for WB Hip ER ROM

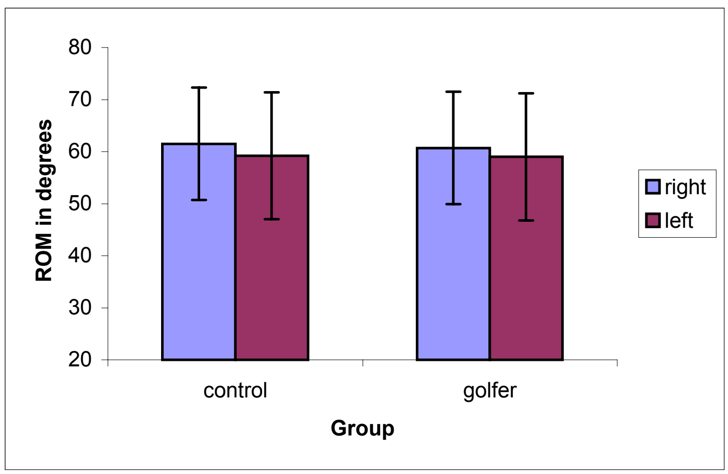


Figure 19. Group Effect for WB Hip ER ROM

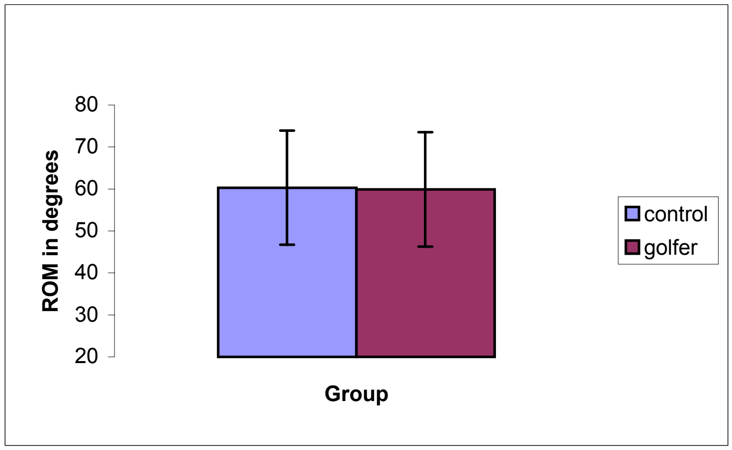


Figure 20. Side Effect for WB Hip ER ROM

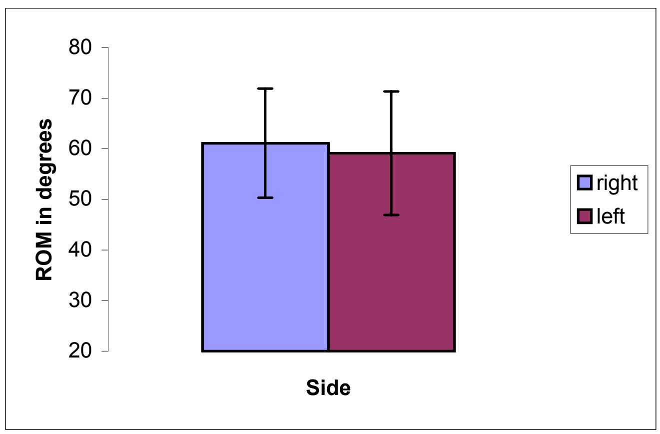


Table 13. Means and Standard Deviations for WB Hip ER ROM

	Means and Standard Deviations (deg.)	
Group	Right	Left
Control (n = 15)	61.5 ± 12.6	59.2 ± 13.2
Golfer (n = 15)	60.7 ± 8.6	59.0 ± 11.1

Table 14. Means and Standard Deviations for Main Effects in WB Hip ER ROM

Main Effect	Means and Standard Deviations (deg.)	
Group	Control	Golfer
	60.3 ± 13.6	59.9 ± 13.6
Side	Right	Left
	61.1 ± 10.8	59.1 ± 12.2

Table 15. Statistical Summary for WB Hip ER ROM

Interaction	$F_{(1,28)}$	p-value
Group x side	0.019	0.893
Group main effect	0.017	0.897
Side main effect	0.780	0.385

Figure 21. Control Group R-L Differences in WB Hip ROM

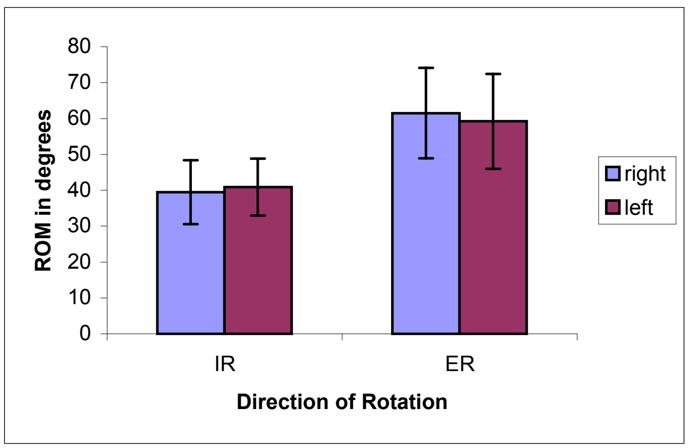


Figure 22. Golfer Group R-L Differences in WB Hip ROM

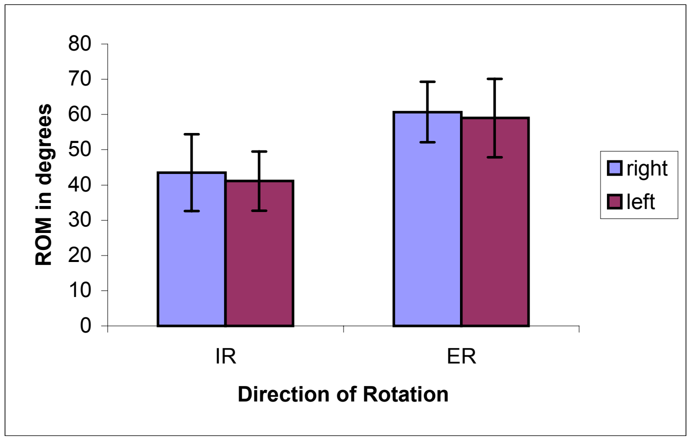


Table 16. Summary of Means and Standard Deviations for WB Hip ROM

	Means and Standard Deviations (deg.)			
Rotation	Control Group (n = 15)		Golfer Group (n = 15)	
	Right	Left	Right	Left
IR	39.5 ± 8.9	40.9 ± 7.9	43.5 ± 10.9	41.1 ± 8.4
ER	61.5 ± 12.6	59.2 ± 13.2	60.7 ± 8.6	59.0 ± 11.1

Hip Rotation ROM During the Golf Swing (Golfers Only)

A 3-D Motion Analysis System was used to capture the golfers hip rotation ROM during the golf swing. Data was then exported into Kintrac Software, which was able to identify each hip's pelvic-on-femoral movement during the duration of the golf swing.

Golfer Background Information

Fifteen female collegiate golfers from two separate Universities were measured for hip rotation ROM during the golf swing. The golfer's background experience is presented in Table 17.

Table 17. Golfer's Background Experience Descriptives

	Means and Standard Deviations for Golfer Descriptives				
	Handicap	Age started (yrs.)	Yrs.played	Hrs. pract/wk	Hrs. play/wk
Golfers	5.2 ± 3.3	9.3 ± 3.3	7.5 ± 1.7	7.6 ± 2.9	13.7 ± 3.5

Backswing and Downswing Hip Rotation ROM

Each phase of the golf swing was identified by specific markers set in the Kintrac Software (see Appendix J) prior to quantifying the amount of hip rotation that occurs. During the backswing phase, right hip (pelvic-on-femoral) IR was significantly less than that of the left hip ER ($p = 0.000$). During the downswing, the subjects demonstrated the same pattern, as right hip ER was significantly less than left IR ($p = 0.00$). Figure 23 represents the pathway of golfer's hip rotation motion during the golf swing.

In addition, Figure 24 illustrates the actual values graphically. The means and standard deviations are reported in Table 18, with the statistical summary in Table 19. Thus, the left hip experienced more rotation than the right hip during the full golf swing. In addition, there was a strong downswing effect size between the right and left hip (1.7).

Figure 23. Hip Rotation ROM During the Golf Swing Relative to the Initial Hip Position

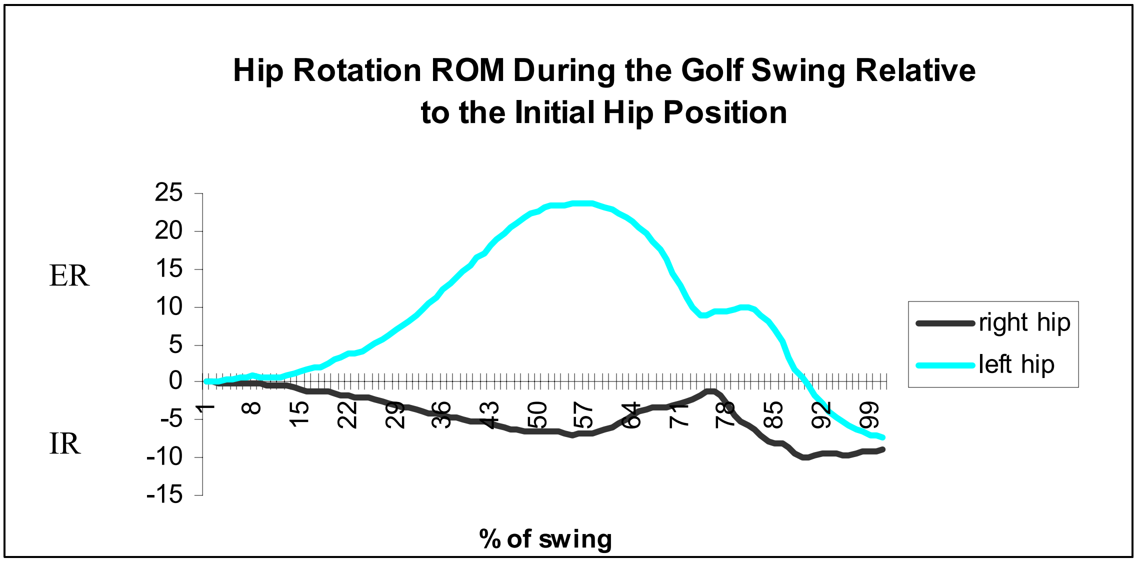
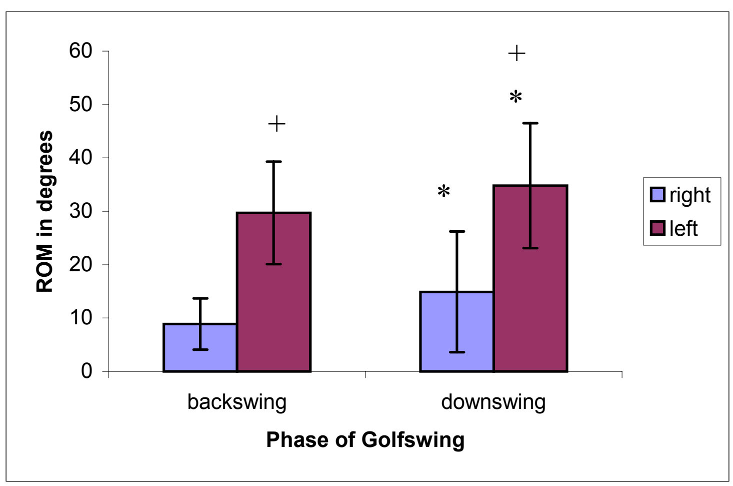


Figure 24. Golf Swing Hip Rotation ROM



* indicates significance between phase of swing at the 0.05 level
\+ indicates significance between right and left at the 0.05 level

Table 18. Means and Standard Deviations for Golf Swing Hip Rotation ROM

Hip Rotation	Means and Standard Deviations (deg.) Right	Left
Backswing (R IR, L ER)	8.9 ± 4.8	29.7 ± 11.3^{+}
Downswing (R ER, L IR)	14.9 ± 9.6*	34.8 ± 11.7*$^{+}$

* indicates significance between phase of swing at the 0.05 level
+ indicates significance between right and left hip at the 0.05 level

Table 19. Statistical Summary of 2 x 2 (rotation x side) Repeated Measures for Golf Swing Hip Rotation ROM

Interaction	$F_{(0,14)}$	p-value
Main effect for Rotation	27.127	0.000*
Main effect for Side	32.397	0.000*
Rotation x Side	0.097	0.760

* indicates significance at $p < 0.01$

Golfers WB ROM vs. Golf Swing Hip Rotation

In order to determine if the golfer's exceeded their anatomical limit in the WB condition, the amount of hip rotation during the golf swing is shown as a percent of the WB ROM limit. As illustrated previously, the golfers experienced much more hip ROM during the downswing. Thus, the hip rotation during this phase was compared to the golfer's WB ROM limit. For example, right hip ER during the downswing was 14.9 ± 9.6°, which equates to 25.4 ± 18.6 % of the ER available on the right hip in a WB status. In addition, the left hip IR during downswing was 34.8 ± 11.7°, which equates to 87.1 ± 33.5 % of the IR available at the left hip in a WB status. The means and standard deviations for these values are shown in Table 20.

Table 20. Means and Standard Deviations for Golfer's Hip Rotation Used During a Golf Swing as a Percent of their WB ROM

	Means and Standard Deviations		
Hip Rotation	WB limit (deg.)	Golf Swing (deg.)	Golf Swing ROM as % of WB limit
Right hip ER	60.7 ± 8.6	14.9 ± 9.6	25.4 ± 18.6
Left hip IR	41.1 ± 8.4	34.8 ± 11.7	87.1 ± 33.5

Hip Rotational Velocities During the Full Golf Swing (Golfers Only)

Peak rotational velocities were calculated for both hips. Since the velocities were the highest during the downswing movement, the important velocities considered for analysis were the right hip ER velocity and the left hip IR velocity, as both of these describe the hips during the downswing phase. In Table 21, the means and standard deviations for the hip rotational velocities from the golfer's swing data are presented. The left hip IR velocity is significantly greater than the right side ER velocity. The statistical summary is shown in Table 22.

Table 21. Means and Standard Deviations for Hip Rotational Velocities

Golf Swing Variable	n	Mean ± Standard Deviation
Peak R hip ER vel (deg/sec)	15	-145.3 ± 68.0
Peak L hip IR vel (deg/sec)	15	-227.8 ± 96.6
% of downswing where peak R hip ER vel occurs	15	85.2 ± 16.8
% of downswing where peak L hip IR vel occurs	15	89.1 ± 19.1

Downswing = top of swing to impact

Table 22. Statistical Summary for Left IR vs. Right ER Hip Rotation Velocity

Paired t-test Comparison	df	t-value	p-value
Left IR vs. Right ER	14	3.655	0.003*

* indicates significance at the 0.05 level

Golf Swing Descriptives of Various Phases

Each phase of the golf swing (backswing, downswing, impact) was identified for each golfer, and the mean of all 15 golfers was used for presentation of the data. Table 23 illustrates the descriptives for each phase of the golf swing.

Table 23. Golf Swing Phase Descriptives

Golf Swing Descriptive	N	Mean ± Standard Deviation
Total swing time (sec.)	15	1.666 ± 0.184
Backswing time as % of total	15	67.0 ± 2.8
Downswing time as % of total	15	16.1 ± 2.4
Time of impact as % of total	15	82.9 ± 3.4

Chapter Five

DISCUSSION

This section is organized by the order of the various hypotheses of the study. First, the results of hip rotation ROM between the two groups will be discussed. Secondly, the results of the second hypothesis regarding side-to-side asymmetry will be discussed. Third, the comparison of the golfer's WB ROM and hip rotation ROM achieved during the golf swing will be discussed. And, the last section will focus on the hip rotational velocities that the golfer experiences during the full golf swing motion.

Results of Hypotheses

Group Differences in Hip Rotation ROM

When ROM is assessed passively, there is no involvement influencing the assessment by the subject. In contrast, active ROM may be influenced by the motivation and strength of the subject. Thus, when trying to determine a subject's true anatomical limit, passive ROM may be the more appropriate measure.

The norms for hip ROM in healthy adults have previously been reported (see Appendix K). For passive hip rotation ROM measured in a prone position (the most reliable measurement position), the normal range for both IR and ER is approximately 32° to 53°, depending on the source (see Appendix K). Since both groups of subjects used in this study were healthy individuals and free from low back and hip pathology, it was expected that both of the groups would demonstrate hip rotation ROM values within the norms. Thus, the first hypothesis stated that the hip rotation ROM would not differ significantly between the two groups (golfer and control).

The results partially supported this hypothesis. The ER means of the two groups, for both the left and right sides were within the normal range and did not differ significantly, as indicated in Tables 5 and 7. Similarly, the IR means on the left side did not differ significantly between the two groups, as shown in Tables 2 and 4. These results are consistent with previous unpublished data[32] that compared LPGA golfers passive (prone) hip rotation ROM with that of age-matched controls. Gulgin[32] found no statistically significant differences between the LPGA golfers and controls for both IR and ER hip rotation ROM. Thus, the results of the current study appear to support the previous data on LPGA golfers.

However, the golfers demonstrated significantly more passive IR on the right side than the controls (50.8 ± 9.3 vs. 47.9 ± 7.5). It may be speculated that this is due to the chronic effect of the IR motion that occurs during the backswing phase of the golf swing. However, based on the kinematic data of the golf swing in the current study, the explanation for the golfer's greater ROM on the right hip may not be due to the effects of swinging the club. The current data have shown that the right hip IR during the golf swing (8.9 ±4.8 deg.) does not come close to exceeding the golfer's passive anatomical limit (50.8 ± 9.3 deg.). Thus, in spite of the degree to which this motion is repeated, it seems unlikely that it would influence the participant's hip rotation ROM. As an alternative explanation, the observed differences may be related to the abduction the hip goes through during the approach into ball contact. Although, the amount of abduction in the trail hip hasn't been measured, it can clearly be observed. It may be that the adductors experience strain over time, and adapt to the repetitive strain by shortening. Since the adductors have a role in hip internal rotation, this shortening of the adductors may pull the hip into IR. This subtle effect may account for the small but significant difference in this parameter between the golfers and controls. Regardless of any explanation, both groups passive ROM fell within the normal limits, and overall the golfers passive hip rotation ROM does not differ from the control group.

For the present study, another type of measurement for hip rotation ROM was of interest. Since the golf swing requires hip rotation ROM in a weight-bearing condition, both groups were assessed in this more functional weight-bearing position. The stance width in which measurements were recorded was equivalent to the stance width a subject would assume at the set-up position (with a driver) of the golf swing. The subjects also assumed a more flexed hip position (equivalent to the amount of hip flexion in the set-up posture), so that this would be similar to the ROM needed or used during the golf swing.

The results of the current study indicated that the groups did not differ statistically for both IR and ER WB ROM, as shown in Tables 12 and 15. Interestingly, the trend for golfers to have more right side IR than the controls, was similar to the passive ROM. However, regardless of the type of measurement, it appears that the golfers hip rotation ROM does not differ significantly from the controls.

<u>Side-to-Side Hip Joint Rotation ROM in Golfers</u>

The observation of a side-to-side ROM asymmetry, occurring over time, is based on the assumption that there is one side of the body serving as a control. In other words, the contra-lateral limb serves as the control for comparison to the involved limb. For example, most research that has measured joint ROM asymmetry in overhead athletes alludes to the dominant vs. the non-dominant side.[22, 38, 56] Essentially, in golf, the lead (left) hip would be the dominant hip (for a right-handed golfer), and the trail (right) hip would be the non-dominant. The kinematic analysis of the golf swing that was conducted in this study did show that there was a significant difference in the amount of rotation experienced at each hip, with the lead (left) hip achieving more than the trail (right) hip, thus providing evidence of a dominant and non-dominant side. Further statistical evidence of this was provided by the strong downswing effect size between the right and left hips (1.7) in the current study. The second hypothesis stated there would be side-to-side differences in the golfer's hip rotation ROM. This hypothesis was based on the previous results of the Vad et al.[68] study on PGA players, which found a significant decrease in the amount of lead (left) hip IR compared to the trail (right) hip when measured prone.

Given that a golfer makes repetitive rotations at each hip during the golf swing, it may be inferred that the hip joint ROM will adapt to the level of function that is imposed. This is similar to the bilateral adaptation of decreased hip extension that has been observed in hockey players.[67] Where the hockey players demonstrated this change in ROM equally bilaterally, participants in sports that require unilateral rotation (such as overhead throwers/servers), have also demonstrated this accommodation in joint ROM when comparing dominant vs. non-dominant limb.[22] Thus, if there are differences between the two hips in the amount of IR or ER achieved during the golf swing (the left hip experiences more ROM than the right hip, Tables 17 and 18), then it may be possible to find asymmetrical hip rotation ROM in elite golfers with accumulated years of playing experience.

The results support the hypothesis that golfers will evidence a hip rotation ROM asymmetry. In the present study, the golfer's left side IR (47.4 ± 11.2) was significantly less than the right side (50.8 ± 9), as shown in Table 2 and Figure 8. This finding in the current study also supports previous findings in PGA golfers.[68] Vad et al. (2004)[68] found that a sample of PGA golfers (with low back pain) demonstrated significantly less left (lead) hip prone IR (11.8 ± 1.2 deg.) when compared with the right (trail) hip (19.9 ± 1.7 deg.). Similarly, those players without low back pain also demonstrated a decrease in the lead hip (16.9 ± 1.3) ROM compared to the trail hip (19.7 ± 1.6), although this difference was not statistically significant. Since the previous study involved golfers both with and without low back pain, it is not known whether back pain was the cause of the golfer's asymmetry, or the result of the golf swing motion. However, based on the trend for the healthy PGA golfer's decreased left (lead) hip IR relative to the right (trail) hip, it may be inferred that this accommodation is due to the influence of the golf swing motion.

Although Vad et al. (2004)[68] measured prone ROM actively, and the current study measured prone ROM passively, the same phenomenon of decreased IR on the lead hip is present. The previous authors suggested that repetitive stress to the soft-tissue leads to micro-trauma and scar tissue formation, thus shortening the joint ROM. Thus, measuring the golfer in a prone position (neutral hip) where the capsule and ligaments are more taut, may be the best indicator of any shortening adaptation to those soft-tissue structures.

In addition, there may be another explanation for the change in hip rotation ROM, which relates to muscle length changes. It has been found in the current study that the left hip experiences significantly more rotational velocity than the right hip, as shown in Tables 21 and 22. Thus, the left hip musculature must control that velocity at the end of the swing. In order to control this velocity, the piriformis and other small external rotators are acting eccentrically, and thus being lengthened quite often. It has been suggested that repetitive micro-trauma from repetitive strain may shorten the involved soft-tissue[68], and thus internal rotation would be limited. However, since the capsule and ligaments of the hip are more taut when the hip is in a neutral position, a decrease in prone ROM may be more indicative of capsular/ligament shortening as opposed to a passive insufficiency of the muscle.

Although it is not known specifically how much time or how many repetitive motions are required for soft-tissue adaptation, a recent study on elite tennis players (mean age 18 yrs.) examined this question. Kibler et al. (1996)[38] found that tennis players with less than six years of playing experience evidenced significantly less IR deficits than those who had been playing for six to nine years. Based on the Kibler[38] study, if the soft-tissue at the hip responds in a similar fashion, then the elite female golfers in the current study should have had enough years (7.5 ± 1.7) of competitive participation in the sport to observe changes in joint ROM if they were to occur.

Another consideration relating to adaptation in the joint ROM as a result of sport participation, is whether the athlete begins to place the repetitive stresses on the joint prior to, or after skeletal maturation. A recent study by Mair et al.[45] examined youth baseball players (age 8-15 years) and observed a significant increase in the ER ROM in the dominant arm relative to the non-dominant. This suggests that adaptation, as a result of a sport related skill may occur early, and may be more likely when a young athlete has not yet achieved skeletal maturation. In the present study, the age when the golfers started playing golf was 9.3 ± 3.3 yrs., which is well before skeletal maturation.

Even though a person may have hip rotation ROM within normal limits, asymmetrical (side-to-side) hip rotation has been associated with low back pain (specifically sacroiliac joint dysfunction).[16] Furthermore, previous investigators have also found that when the available ER hip ROM exceeds IR hip ROM, subjects were more likely to have low back pain.[15, 53] Thus, although the subjects in this study demonstrated passive ER side-to-side symmetry, the loss of lead hip IR (passive) may be quite important clinically. Not only has limited hip IR ROM been linked to back pain, but has also been linked with early arthrosis of the hip.[17] Thus, it appears that a loss in hip IR ROM is not an insignificant problem, as this may contribute to more severe orthopedic consequences.

Based on the kinetic chain principle, if one segment of the chain is hypomobile (or dysfunctional), the rest of the kinetic chain must accommodate to complete some desired motion. For example, patients that undergo a fusion of the lumbar spine lose mobility, but gain stability. However, this trade-off places more stress on the surrounding lumbar vertebrae, which must provide for the lack of motion in the adjacent region. Similarly, it may be that a lack of available hip rotation ROM, may place increased stress on the back, as the body attempts to complete the rotation motion of the golf swing, thus compounding the loading effects to the back (reportedly eight times body weight[35]).

Much of the previous discussion thus far regarding side-to-side differences has focused on passive hip rotation ROM, which was taken in a non-weightbearing condition. However, since the golf swing requires hip rotation ROM in a weight-bearing condition, the current study also examined this motion in both groups to determine if the available hip ROM evidenced side-to-side differences. The results of the current study found no statistical difference for main side effect in the participant's WB hip rotation ROM (IR, $p = 0.733$; ER, $p = 0.385$), as shown in Tables 12 and 15. Thus, regardless of the group, the left side IR was equivalent to the right side IR, and likewise for ER. Although the WB ROM was not statistically different, there appears to be a trend similar to the passive ROM, where golfers demonstrate a decrease in the lead (left) hip.

Golfer's Anatomical Limit (WB ROM) vs. Hip Rotation During the Golf Swing

Golf is a sport that requires both internal and external rotation of each hip to complete the golf swing motion. During the backswing (cw rotation), the golfer experiences IR on the right hip and ER on the left hip. During the downswing (ccw rotation) and follow-through phases, the golfer experiences ER on the right hip and IR on the left hip. The lower extremities are predominantly a closed kinetic chain during the golf swing when this hip rotation occurs, with the exception of when the right heel lifts off the ground as the golfer approaches ball impact. Thus, it was important to compare the golfer's anatomical WB ROM (in a closed kinetic chain), to the ROM the golfer experiences during the golf swing.

Although there have been several studies on the kinematics of the golf motion, the hip movement that has been measured and described has examined pelvic rotation rather than actual hip rotation.[14, 21, 52] Thus, the literature provides information about the entire amount of pelvic rotation during a golf swing, but evidence of separate right and left hip (pelvic-on-femoral) rotation has been lacking. Separating out each hip for kinematic analysis allows one to determine how much pelvic-on-femoral rotation occurs, which may be more indicative of how much rotational ROM a golfer may need to safely make a full golf-swing. In addition, once this is known, then clinical measurements of the golfer's anatomical hip rotation limits would be useful for addressing clinical concerns or performance limitations.

Without knowing exactly how much hip rotation occurs at each hip during the golf swing, but with the recent awareness of labral pathology in elite golfers, it was hypothesized that during the golf swing the golfers would actually exceed their anatomical limit of available hip rotation.

In the current study, the comparison with WB hip rotation ROM was chosen due to the similarity to the golf swing, as both require loading of the body weight on the hip joint. In addition, the WB ROM measurement was taken with the same amount of hip and knee flexion that the golfer assumed in the address position of the golf swing. Keeping the same amount of hip and knee flexion that would be used in the golf swing was important so that any differences observed may not be attributed to the changes in hip joint laxity in the capsule or ligaments. Although, it was not the purpose of the current study to compare the effects of hip joint position on available ROM, this may contribute to the measurement, and thus was controlled for by keeping the hip joint position the same as during the golf swing. Thus, a more functional comparison between the golfer's available hip joint ROM could be made with that used during the golf swing.

In this study, it was found that the during the backswing, IR ROM on the right hip (8.9 ± 4.8) was significantly less than the ER ROM of the downswing on the right hip (14.9 ± 9.6). In other words, a golfer does not internally rotate the right hip as much during the backswing as they externally rotate the same hip for the downswing. Furthermore, the subject's mean left hip ER ROM (29.7 ± 11.3) during the backswing was significantly less than the left hip mean IR ROM (34.8 ± 11.7) during the downswing. Again, the golfer does not externally rotate the hip as much during the backswing, as they internally rotate the same hip for the downswing. Thus, it appears that more hip rotation occurs during the downswing, and that regardless of the phase of the swing (backswing or downswing), the left hip experiences more motion than the right hip during the entire golf swing (see Table 18 and Figure 24).

These hip rotation values measured during the golf swing are less than the anatomical limits that were measured in a WB condition. Thus, it appears that the golfers do not exceed their WB anatomical ROM limit of hip rotation during the golf swing. If this is the case, it is unlikely that the motion the golfer experiences during the golf swing is a contributor to any adaptation in hip joint ROM. Thus, it may be that the velocity of the hip rotation may provide more insight into the phenomenon of the golfer's IR ROM asymmetry.

Hip Rotation Velocities During the Golf Swing

Of the studies that have examined hip kinematics during the golf swing, the hip motion that has been examined is actually describing entire pelvic motion.[14, 21, 52] Clockwise (cw) rotational velocity and counter-clockwise (ccw) rotational velocity have been used to describe the rate of pelvic rotation during the golf swing.[18] However, prior to the present study, there has not been a kinematic analysis of separate right and left hip rotational velocities. It was hypothesized that there would be a difference between the IR and ER velocities of the hip during the golf swing.

Previous literature has shown that the downswing time is much shorter than the backswing time.[14, 52] Since the downswing occurs much more rapidly, the rotational velocities of the hip during this phase are of specific interest. The backswing phase, which was identified in the current study, as the time period between the start of swing until top of swing (based on clubhead path), lasted approximately 67% of the total swing time (Table 23). The downswing phase, which was identified as the time period between the top of the swing until ball impact, took approximately 16% of the total swing time (Table 23). Thus, the lower body returns to the initial hip position in a short amount of time during the downswing phase. In particular, during the downswing phase, the right hip experiences an ER velocity, and the left hip experiences an IR velocity.

In the present study it was determined that the mean peak hip rotational velocities were –227.8 ± 96.6 (deg/sec) for IR of the left (lead) hip, and –145.3 ± 68.0 (deg/sec) for ER of the right (trail) hip. The peak left hip IR velocity occurred at 89.1 % of the downswing (from top of swing to impact), and the right hip ER velocity occurred at 85.2% of the downswing. Both of these events occurred just slightly prior to impact, which is similar to what was reported in a study by Welch[71], who found that peak pelvic rotational velocity occurred just prior (0.075 seconds) to ball contact during the hitting motion of a baseball swing.

The golfer desires to produce the greatest possible clubhead velocity at ball impact, and the body uses transfer of momentum to achieve this. The data indicates that the hips reach a peak velocity just prior to impact, which means that the hips actually begin to slow down at impact. As a result of a decreased velocity in these body segments, the other segments gain velocity. The end result of this is that the clubhead achieves maximum velocity at impact, and thus is able to effectively transfer maximum momentum to the ball.

Hip Rotational Velocities and Injury Risk

Although an athlete may exhibit an appropriate amount of joint ROM for a given sport movement, this does not assure them that an injury will not occur. Another factor that may play a role in joint injuries is the velocity of the movement. Thus, even though the golfers may not exceed their WB anatomical limit for available joint ROM, the rate of loading of the soft-tissue may have more of an influence on incidence of injury. For example, Race et al. (2000)[58] found that the mechanical properties of the intervertebral disc are significantly dependent on the loading rate. In another study, Wang et al. (2000)[69] examined the viscoelastic behavior of the lumbar vertebrae and found that the distribution of stress and strain was markedly affected by the loading rate. Thus, the mechanical properties of the ligament and capsule may be at risk for failure at some critical loading rate, which has not yet been determined in the existing literature. Regardless of the existing gap, Davis (2000)[19] points out that due to various tensile strength of the ligaments between individuals, the amount of muscle activation and inhibition, and excitability of the nervous system, identifying one specific threshold to failure is not possible.[19]

It is a known principle in viscoelastic mechanics that if the loading rate increases, the tissue stiffness increases. This means that a tissue becomes less elastic, and will fail at lower levels of loading. The study of PGA golfers, previously reported IR deficits on the lead hip. Thus, it may be inferred that the soft-tissue had become stiffer, and may possibly have been at a higher risk for failure. Furthermore, this change in soft-tissue viscoelastic properties over time may be a predisposing factor contributing to the labral tears that have been reported in some elite athletes. Currently in the literature, there has been no documentation of the necessary velocity of movement to reach the failure point of the acetabular labrum. Such information would be valuable in providing insight for the injury risk of labral tears in the golfer's hip.

Long-term Effects of Repetitive Loading

Golf is a popular game worldwide that is enjoyed by people from various age ranges. Although golf is considered a low-risk sport for exercise, there is some risk of injury with all sports. The literature regarding golf injuries has shown that low back pain/pathology is the leading injury area associated with golf.[7, 31, 43, 47, 66] Knowing that there is a correlation between low back pain and hip rotation ROM asymmetry, the finding of a significant side-to-side difference in the golfer's IR ROM is concerning. Furthermore, since golfers execute the same movement pattern repetitively over time, the accumulative effects of repetitive loading may predispose athletes to more serious consequences at the hip joint. For example, it has been found that the frequency of hip arthrosis in elite javelin throwers was higher than in the general population.[62] Thus, although sports are enjoyed by many, the long-term effects of such participation are not without consequences to the body.

Limitations

One limitation in comparing WB ROM with the golf swing ROM, is that the right foot begins to lift off as the golfer approaches ball impact, and is thus no longer a closed kinetic chain, or similar to the WB measurements. In addition, this lift off of the right foot would also affect the hip rotation velocities, and were thus calculated from the top of the swing up to the point of ball contact, when the right foot begins to lift off the ground.

Conclusions

Overall, the golfer's hip rotation ROM does not differ significantly from age-matched controls, as there were non-significant group differences in passive ROM or WB ROM, with one exception in passive IR on the right side (golfers demonstrated more ROM than controls). In addition, golfers perform repetitive rotational movements (with more stress placed on the lead hip) over time, which appears to alter their hip rotation ROM symmetry, as was shown by the significant side-to-side differences in passive IR. The amount of ROM that the joint goes through during some sport task is not the only factor that may alter joint ROM. The velocity of the sport movement (and resulting forces) may be the culprit for the changes in joint ROM that have been observed in this study as well as others. Thus, although golf is considered a low-intensity sport, it is not without the risk for long-term consequences.

Future Research

Future research may focus on 3-D analysis measuring elite golfers (males and females) to establish normal hip rotation ROM and rotational velocities experienced on each hip during the golf swing. Until these norms are established on healthy golfers, little may be concluded about golfers with hip or low back pain, and whether their hip rotation ROM led to their pathology, or that the pathology is altering their hip rotation ROM. Another area of future research may focus on measuring active hip rotation ROM, as well as the golfers strength in the surrounding hip musculature, in order to have a more complete picture of the golfer's hip and the risk of injury.

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APPENDIX A

IRB Form

University of Toledo
Applied Biomechanics Laboratory
Informed Consent for Research Involving Human Subjects

Title of Project: Hip rotation measurement comparison among golfers and non-golfers

Principal Investigator: Heather Gulgin, Applied Biomechanics Lab
Phone# 419-530-2753

Purpose: You are being invited to participate in a research study that will examine the passive anatomical limits of hip rotation in a non weight-bearing (NWB) and weight-bearing (WB) status. You are eligible to participate if you are a female and have not had a back or hip injury in the past 6 months, are physically active, within the age range of 18-35 years old, and are right-hand dominant. If you do not participate in golf or tennis frequently you are eligible to participate in the control group (excluding any hip or low back pain that has required medical attention).

If you decide to participate you will be asked to visit the Applied Biomechanics Laboratory for one testing session lasting approximately one hour in duration. You will be asked to bring shorts so that the measuring instrument (goniometer) can be positioned correctly on your hip and lower leg, and a tank top for access to apply the necessary markers. First, a series of measurements will be made on both hips while you are in a seated position and again with you in a lying position (on stomach). Following the range of motion measurements, you will be asked to have several retroflective markers (attached by Velcro) at various anatomical landmarks. Then another set of hip rotation measurements will be done in a standing (weight-bearing) position. The golfers will be asked to perform approximately 10 full golf swings (after adequate warm-up), and the non-golfer group will be dismissed.

There are minimal risks associated with participation in this study. You are free to stop the study at any point if you are uncomfortable with any of the procedures.

Your participation in this study is strictly confidential. Information obtained in this study will be identified by code, and not by your name. Only the investigators will have access to the data, and any personal information will only be disclosed with your permission.

In the unlikely event of physical injury resulting from your participation, the investigators will assist in obtaining medical care. However, payment for the medical care is the responsibility of the subject. The University of Toledo will not provide financial compensation for the medical care.

Participation in this study is voluntary. If you decide to participate, it is important for you to understand that you may withdraw your consent at any time. This will not affect your future relations with the University of Toledo, your coach or team, or any individual involved with the research.

Please feel free to ask any questions pertaining to this study before signing this form.

I fully understand that I may withdraw from this project at any time. I also understand that I am free to ask questions about any procedure that will be done.

Finally, I understand that the information obtained during this study will be kept confidential.

Authorization: Your signature indicates that you have read and understand the information provided above, have had all your questions answered, and have decided to participate.

___________________________________ ________________
Participant's name (please print) Date

___________________________________ ________________
Participant's signature Date

___________________________________ ________________
Principal Investigator Date

___________________________________ ________________
Witness Date

APPENDIX B

Marker Placement

Marker Placement

Marker Placement for Subjects During the Golf Swing

1. R ASIS
2. L ASIS
3. sacrum
4. R greater trochanter
5. L greater trochanter
6. R anterior thigh
7. L anterior thigh'
8. R lateral femoral condyle
9. L lateral femoral condyle
10. R patella
11. L patella
12. R tibial tuberosity
13. L tibial tuberosity
14. R mid-tibia
15. L mid-tibia
16. R low tibia
17. L low tibia
18. R lateral malleolus
19. L lateral malleolus
20. R calcaneus
21. L calcaneus
22. R 5^{th} metatarsal
23. L 5^{th} metatarsal
24. R 3^{rd} toe
25. L 3^{rd} toe
26. Club head
27. Club grip
28. Ball
29. R acromion
30. L acromion
31. R elbow
32. L elbow
33. R wrist
34. L wrist
35. C7
36. Anterior head

Marker Placement for the WB ROM testing

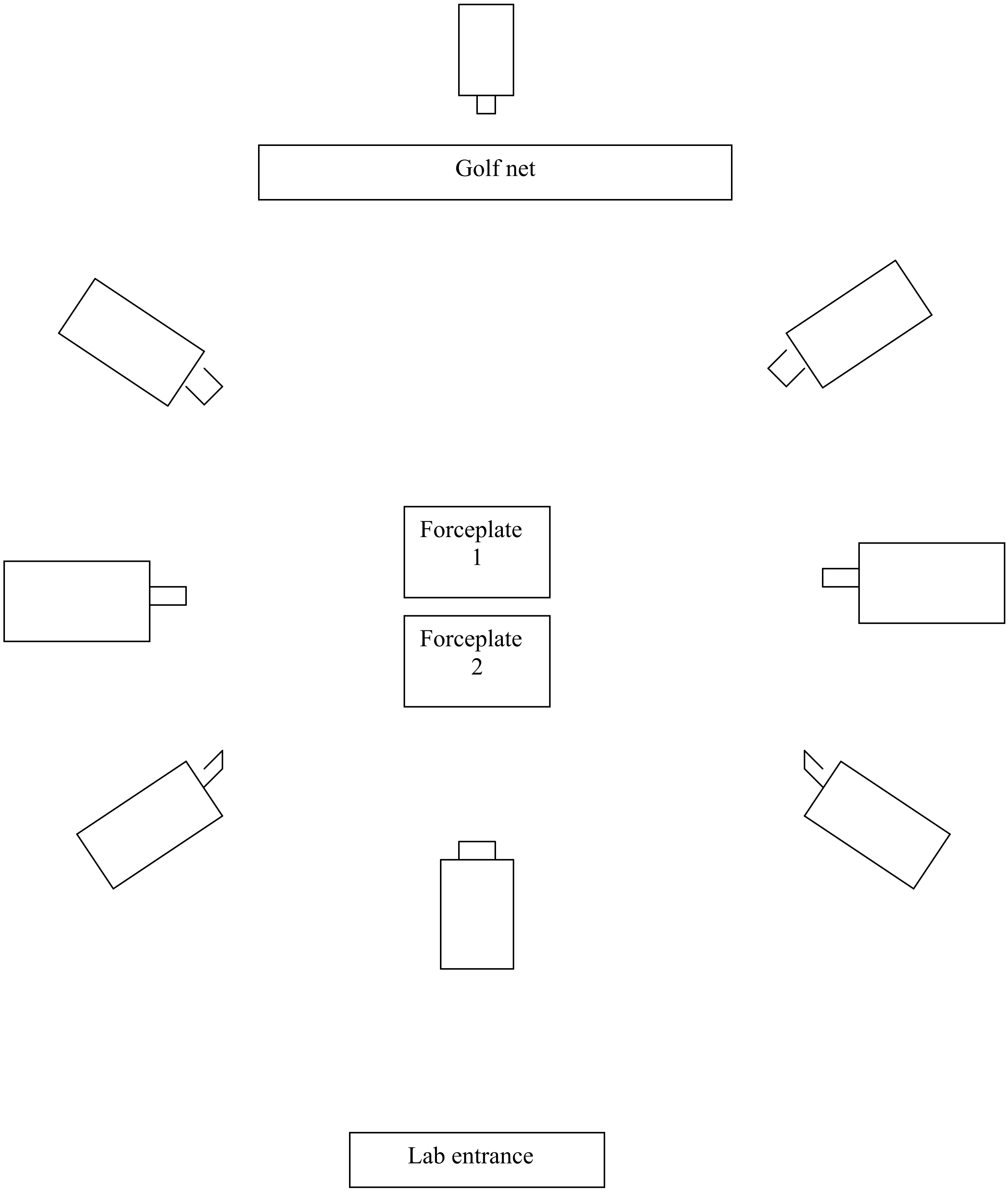
Same as previous marker set, using only #1-25

*All markers were custom built using Styrofoam balls (1/2 inch width), covered with retroflective tape and placed on a plastic ball mark. Adhesive backings with Velcro were applied to secure the markers to the anatomical landmarks on subjects.

APPENDIX C

Lab Set-up

Lab Set-up



APPENDIX D

Intra-rater Reliability for Prone ROM

Intra-rater reliability (ICC's) for passive range of motion
(n = 20)

	Right	Left
Prone IR	0.984	0.961
Prone ER	0.905	0.968

APPENDIX E

Passive ROM Data Collection Sheet

Passive ROM Data Collection Sheet

Prone Hip rotation	Right hip	Left hip
Internal rotation		
Measure one	________	________
Measure two	________	________
Measure three	________	________
External rotation		
Measure one	________	________
Measure two	________	________
Measure three	________	________

APPENDIX F

WB ROM Data Collection Sheet

WB ROM Data Collection Sheet

Ht_____ Wt______ Age_____ Dominant hand______

Golf stance: ______hip flexion(deg) _____knee flexion(deg) ______feet width(cm)

rer1__________________________	rir1_____________________
rer2__________________________	rir2_____________________
rer3__________________________	rir3_____________________
rer4__________________________	rir4_____________________
rer5__________________________	rir5_____________________
rer6__________________________	rir6_____________________
ler1__________________________	lir1_____________________
ler2__________________________	lir2_____________________
ler3__________________________	lir3_____________________
ler4__________________________	lir4_____________________
ler5__________________________	lir5_____________________
ler6__________________________	lir6_____________________

<u>For Golfer subjects only</u>:

Golfswings (Trial name)	Swingspeed
___________________________	__________
___________________________	__________
___________________________	__________
___________________________	__________
___________________________	__________
___________________________	__________
___________________________	__________
___________________________	__________

APPENDIX G

Golfer Questionnaire

Golfer Questionnaire

Which way do you play golf? _________Right-hand __________ Left-hand

What is your dominate hand? _________Right __________ Left

How many years have you been playing competitive tournament golf? ____________

At what age did you start playing golf? ____________

What is your current handicap? ____________

Approximately how many hours per week do you spend actually playing golf? ________

Approximately how many hours per week do you spend practicing golf (i.e. on the range)? ___________

Have you had any low back or hip pain in the recent 6 months that has kept you from playing or required medical attention? _______________ If yes, explain____
____

APPENDIX H

Abbreviations Used

Abbreviations Used

range of motion = ROM
weight-bearing = WB
non-weight-bearing = NWB
external rotation = ER
internal rotation = IR
clockwise = cw
counterclockwise = ccw

For Passive Measurements
rirp = prone internal rotation on right side
lirp = prone internal rotation on left side
rerp = prone external rotation on right side
lerp = prone external rotation on left side

For WB Measurements
rer = right external rotation
rir = right internal rotation
ler = left external rotation
lir = left internal rotation

APPENDIX I

Calculations of WB ROM (Kintrac Software)

Calculation of WB ROM
(Kintrac software)

Each subject had 3 trials imported into the Kintrac software, and the mean of those 3 trials was used for statistical analysis. Markers defining the ROM were set as follows:

Initial pelvis position – manually placed instantaneously prior to movement
Initial Right foot position – manually placed instantaneously prior to movement
Initial Left foot position – manually placed instantaneously prior to movement
Maximal R Foot ER – set at maximum between initial foot position and end of data
Maximal R Foot IR – set at maximum between initial foot position and end of data
Maximal L Foot ER – set at maximum between initial foot position and end of data
Maximal L Foot IR – set at maximum between initial foot position and end of data
Total R Foot ER – calculation of difference between initial foot position and maximal ER
Total R Foot IR – calculation of difference between initial foot position and maximal IR
Total L Foot ER – calculation of difference between initial foot position and maximal ER
Total L Foot IR – calculation of difference between initial foot position and maximal IR
R lateral pelvis movement – set at point of maximal R foot ER
R medial pelvis movement – set at point of maximal R foot IR
L lateral pelvis movement – set at point of maximal L foot ER
L medial pelvis movement – set at point of maximal L foot IR
Total R lateral pelvis movement – calculation of difference between R lateral pelvis movement and initial pelvis position
Total R medial pelvis movement – calculation of difference between R medial pelvis movement and initial pelvis position
Total L lateral pelvis movement – calculation of difference between L lateral pelvis movement and initial pelvis position
Total L medial pelvis movement – calculation of difference between L medial pelvis movement and initial pelvis position
Total R hip ER – calculation of difference between Total R lateral pelvis movement and total R Foot ER
Total R hip IR – calculation of difference between Total R medial pelvis movement and total R foot IR
Total L hip ER – calculation of difference between Total L lateral pelvis movement and total L foot ER
Total L hip IR – calculation of difference between Total L medial pelvis movement and total L foot IR

APPENDIX J

Calculation of Golf Swing Variables (Kintrac Software)

Calculation of Golf Swing Variables
(Kintrac software)

clubhead path (z) at impact - set manually when club reaches minimum in z-direction
clubhead at top of swing - set manually when club reaches maximum in y-direction
clubhead start - set manually when club starts movement in y-direction
end of swing - set manually when club reaches last minimum in y-direction
initial right hip position - value at marker at clubhead start
initial left hip position - value at marker at clubhead start
max right hip IR - minimum between initial hip position and clubhead at top of swing
max right hip ER – maximum between clubhead at top of swing and end of swing
max left hip ER - minimum between initial hip position and clubhead at top of swing
max left hip IR - maximum between clubhead at top of swing and end of swing
total right hip IR – difference between initial right hip position and max right hip IR
total right hip ER – difference between max right hip IR and max right hip ER
total left hip ER – difference between initial left hip position and max left hip ER
total left hip IR – difference between max left hip ER and max left hip IR
right hip peak ER velocity – minimum between clubhead at top of swing to clubhead path (z) at impact
NOTE: right hip ER velocity was calculated up to the point of impact due to the right foot lifting off the ground, which then becomes an internal rotational velocity
left hip peak IR velocity – minimum between clubhead at top of swing to end of swing

APPENDIX K

Summary of Norms for Hip Rotation ROM

Summary of Norms for Hip Rotation ROM

Normal Passive Hip Rotation Values

	AAOS[29] (prone)	AMA[1] (supine)
Internal rotation	45	40
External rotation	45	50

Normal Active Hip rotation values

	Kendall[37]	Hoppenfeld[34]
Internal rotation	45	35
External rotation	45	45

Summary of Passive Hip Rotation Measures in the Literature

Author	Motion	Position		
		Seated	Prone	Supine
		Mean (SD)	Mean (SD)	Mean (SD)
Svenningsen[65] (Males)	Internal rotation	--	38	--
(mean age 23 yrs)	External rotation	--	43	--
(Females)	Internal rotation	--	52	--
	External rotation	--	41	--
Bierma-Zeinstra et al[8]	Internal rotation	38.8	53.2	39.9
(M-F, age 21-43)	External rotation	37.6	51.9	34.2
Roaas & Andersson[60]			R-L	
(M-F, age 30-40)	Internal rotation		32.6-32.5	
	External rotation		33.6-33.7	

Summary of Active Hip Rotation Measures in the Literature

Author		Motion	Position		
			Seated	Prone	Supine
			Mean (SD)	Mean (SD)	Mean(SD)
Simoneau et al[1]	Male	Internal rotation	30(7)	32(9)	--
(age 18-27)		External rotation	35(8)	44(7)	--
	Fem.	Internal rotation	35(6)	38(9)	--
		External rotation	37(8)	46(13)	--
Bierma-Zeinstra[2]		Internal rotation	33.6	46.3	36
(M-F, age 21-43 yrs)		External rotation	33.9	47	33.1
Roach & Miles[61]		Internal rotation	33(7)	--	--
(M-F, age 25-39 yrs)		External rotation	34(8)	--	--

PGA Golfers Active Hip Rotation Measures (Healthy vs. Low back pain subjects)

Author	Motion (prone)	Symptomatic Mean(SD)	Asymptomatic Mean(SD)
Vad et al.[68]	Internal rotation		
	Lead hip	11.8(1.2)	16.9(1.3)
	Trail hip	19.9(1.7)	19.7(1.6)
	FABRE's (cm)		
	Lead hip	16.8(1.3)	9.3(1.5)
	Trail hip	6.7(1.3)	6.8(1.2)

Hip rotation range of motion symmetry summary on adults

Author	Internal-External symmetry	Right-left symmetry
Boone & Azen[11]	yes	undetermined
Barbee-Ellison et al.[6]	(healthy and low back pain subjects)	
Type IA	yes	yes
Type IB	no	yes
Type II	external<internal	undetermined
Type III	internal<external	undetermined
Chesworth[15]	undetermined	yes
Svenningsen[65]	no	yes
Ahlberg et al.[2]	no	yes
Roaas & Andersson[60]	yes	yes