# A Comparison of Golf Swing Kinematics Among Non injured, Rotator Cuff Injury-repaired, and Rotator Cuff Injury-non repaired Golfers

by

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# A COMPARISON OF GOLF SWING KINEMATICS AMONG NONINJURED, ROTATOR CUFF INJURY-REPAIRED, AND ROTATOR CUFF INJURY-NONREPAIRED GOLFERS

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## TABLE OF CONTENTS

# ABSTRACT

The ability of golfers experiencing shoulder pain to continue to play golf is often decreased, although how severely the shoulder pain compromises the technique of the golf swing is questionable. The specific injury site of shoulder pain in golfers is the supraspinatus tendon of the shoulder of the lead arm. Golfers with a supraspinatus injury tend to have discomfort at the top of their backswing associated with the impingement of the supraspinatus tendon underneath the acromion process of the scapula.

The purpose of this proposed study was to develop a filming configuration that enabled acquisition of video film data to determine the 3D coordinates of the glenohumeral joint during a golf swing. The same filming configuration was then used to film golfers with either a current rotator cuff tear, or a recent surgically repaired rotator cuff. Video film data was collected on all three groups - 10 non injured, 4 current rotator cuff tear, and 6 recent surgical repair. An ANOVA was completed to test for significant differences between the swing mechanics of each group of golfers. Post-hoc testing determined where the differences occurred.

The subjects for the study were low-handicap (handicap $\leq$ 15) male golfers born in 1972 or earlier. The golfers were filmed using three video cameras which filmed six swings of each golfer using their driver. Once collected, the video film data was entered and analyzed using Peak5 Motion Analysis Software that configured a 27 point spatial model representing the segments of the golfer.

Horizontal adduction of the lead shoulder was the only variable tested that showed significant differences between groups. The RCR group demonstrated a reduced range of motion in lead shoulder horizontal adduction when compared to the non injured group of golfers ($p=.03$).

Correlations between variables tested indicated several relationships, with the strongest being shoulder flexion and shoulder adduction of the lead shoulder at the top of the backswing. These two variables showed strong relationships in all groups both together and individually.

Sequencing of segmental rotation of body segments was examined by observing the linear velocity profiles of the distal points of active lead arm joints and of the club head during the swing. Graphing each profile on the same graph indicated that sequencing of joints appeared to occur, although the club head reached a peak linear velocity prior to the distal point of the lead wrist in all cases. From the results of this study, it was concluded that the camera configuration was successful in capturing accurate 3D measurements, and that the RCR group had a reduced range of motion in lead shoulder horizontal adduction compared to the non injured group. It was further concluded that rotator cuff injury does not severely affect shoulder joint range of motion or golf swing kinematics.

# ACKNOWLEDGEMENTS

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Most of all, I would like to thank my grandmother, Mary Vicars, and my nephew, Matthew Chalker. You two gave me strength that I'm sure neither of you realized. Being so many miles away as you both grow older helped me finally decide to finish what I left home to do.

## LIST OF FIGURES

## LIST OF TABLES

# I. INTRODUCTION

Golf has been played for years by everyone from the recreational athlete to the seasoned veteran. With the wide variety and number of people playing, numerous variations exist in the techniques used to strike a golf ball. Golf is the subject of many discussions, both scientifically in biomechanics literature (Maddalozzo, 1987; Milburn, 1982; Neal & Wilson, 1985), and informally amongst professionals in golf literature (Flick, 1990; Haney & Tomasi, 1992; Kite, 1985), which is aimed more at the recreational golf community than the academic golf enthusiasts.

The golf swing is not the most aggressive of actions typically seen in sports (Meister & Andrews, 1993). The movements used to successfully contact a golf ball require control and accuracy which tend to promote consistent, relaxed swings. However, the repetitive nature of hitting balls and the acceleration experienced throughout a large range of motion is physically demanding, especially at the shoulder joint. The shoulder is the most intricate joint complex in the body. The combined and coordinated movements of four distinct articulations- glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic- allow the arm to be positioned in space for efficient function (Zuckerman & Masten III, 1989). The multi-axial range of motion capabilities of the shoulder are evident in the golf swing. The more axes that a joint utilizes in movement, the more complex the muscle, tendon and ligament network must be to facilitate the required movement.

The muscles of the shoulder function in a specific sequence to produce an activity such as a golf swing. The sequence of the muscle function during a golf swing can be examined using electromyography

(EMG) (Bradley & Tibone, 1991; Glousman, 1993; Jobe, Perry, & Pink, 1989; Moynes, Perry, Antonelli, & Jobe, 1986; Pink, Jobe, & Perry, 1990). However, the natural variation in golf swings would affect the ability to define any swing as normal or typical. EMG may assess the typical sequence of the muscles, although even EMG cannot perfectly describe the subtle differences that may occur in a golf swing. With the variety of golf swings making description of a typical swing difficult, addition of further variables such as impaired or altered muscular function make this description of normality even more complex. Therefore, any attempt at addressing the description of typical golf swing parameters would be useful to golfers, rehabilitation professionals, instructors, and any others interested in the movements required to swing a golf club skillfully. Differences between golfers with altered anatomical function, and those with a typical swing, if they exist, may be described using kinematics, the scientific description of motion.

Kinematic analysis of golf swings are readily available in golf literature. EMG studies utilized their findings to describe golf kinematics, with the majority of the studies highlighting the muscle activity at the shoulder (Bradley & Tibone, 1991; Glousman, 1993; Jobe, Moynes, & Antonelli, 1986; Jobe, et al., 1989; Kao, Pink, Jobe, & Perry, 1995; Moynes, et al., 1986; Pink, et al., 1990). EMG analysis has also been utilized to describe the golf kinematics during the swing with respect to trunk musculature (Pink, Perry, & Jobe, 1993; Watkins, Uppal, Perry, Pink, & Dinsay, 1996). There have also been studies that have combined kinematic and kinetic analysis to describe golf swings (Koenig, Tamres, & Mann, 1993; Neal & Wilson, 1985), although this study focussed on the kinematic analysis of the golf swing.

Studies examining shoulder dysfunction and the golf swing are not abundant. Orthopaedic and rehabilitative journals often address shoulder pain in overhand activities, including golf (Batt, 1993; Jobe & Pink, 1993; Jobe & Pink, 1996; Mallon, 1996; Mallon, 1997; Meister & Andrews, 1993). Studies including specific comparison between the swing kinematics of golfers diagnosed with shoulder dysfunction, and golfers considered normal were not found. Shoulder injuries were found to contribute only 7.7% of the total injury count seen in new injuries on the Senior PGA Tour (Jobe & Pink, 1996). Results of a recent study by Mallon et. al (1995) reported over 97% (34/35) of the golfers studied experienced pain in the contralateral shoulder. Of the 97% found with shoulder pain in the study, 53% of the golfers experienced pain due to an acromioclavicular joint problem. Obviously, a specific shoulder injury, such as a rotator cuff injury affecting the contralateral shoulder, would be seen less often. Despite the apparently low reported incidence of shoulder injury in the recent study by Jobe et. al (1996), the study by Mallon et. al (1995) suggests a more positive relationship between poor swing mechanics and shoulder dysfunction.

The shoulder of the nondominant arm (lead arm) appears to be affected more often by injury related to the golf swing. Occasionally, shoulder problems occur in the dominant extremity (trailing arm), but these problems are much less likely to correlate to the swing mechanics (Jobe & Pink, 1996). Kinematic comparison of golf swings between golfers with a shoulder dysfunction, and golfers with no shoulder dysfunction may assist in greater awareness of altered golf swing biomechanics due to injury. In addition, kinematic comparison may indicate technique modifications that have been altered to compensate for shoulder discomfort during the execution of a golf swing.

Comparison of golf swing patterns, timing of the components of the swing, velocities of the club, and other parameters can be used to describe the kinematics of the golf swings and may demonstrate similarities in the swing kinematics. Consistency in swing kinematics may be present with a group of golfers diagnosed with shoulder dysfunction. The kinematic variables that may be altered most noticeably are the degree of shoulder range of motion seen, specifically at the top of the backswing. A decrease in shoulder range of motion may be accompanied by an increase in elbow flexion in an attempt to gain a higher backswing. Swing velocities may also indicate altered swing kinematics. Golfers with shoulder discomfort may attempt to decelerate the club as they approach the top of their backswing earlier than golfers with no pain present at the top of their backswing.

## Purpose of the Study

The purposes of the study were:

1) To develop a filming configuration that will enable acquisition of video film data to determine the three dimensional coordinates of the glenohumeral joint during a golf swing.
2) To use the filming technique to acquire kinematic data for low-handicap golfers that have had either a recent surgically repaired rotator cuff, or have a currently injured rotator cuff.
3) To determine if differences exist in selected golf swing mechanics between non injured golfers, golfers with a dysfunctional rotator cuff, and golfers with a surgically repaired rotator cuff.

## Hypothesis

The hypothesis for this study was that there would be a significant decrease in glenohumeral range of motion at the top of the backswing seen in the golfers with the previously or currently injured rotator cuff when compared to the non injured golfers. It was further hypothesized that other differences in swing kinematics may also be present among the three groups.

## Rationale for the Study

Comparison made between golfers with a repaired rotator cuff, currently injured rotator cuff and non injured, may suggest differences between the swings of the groups. Reduced range of motion, especially in the back swing, is likely to be the most recognizable difference. Golfers with repaired rotator cuffs may exhibit less range of motion in the glenohumeral joint during execution of the swing. The reduction in range of motion may be more noticeable in groups of golfers with current rotator cuff dysfunction. The decreased range of motion in either group of golfers with rotator cuff injury history may be most noticeable in shoulder flexion/extension, and horizontal abduction and horizontal adduction. The two rotator cuff groups may also display differences in other measured parameters of the swing. Reduced peak velocities of the club, or altered velocity profiles of the club, will possibly be evident in the rotator cuff groups during the swing. Comparisons would determine if any differences exist with the occurence of the peak velocity during the swing, or in a pattern that differs from the velocity profiles of the non injured golfers.

Golfing literature often addresses methods to improve a golf swing (Flick, 1990; Haney & Tomasi, 1992; Kelley, 1983; Kite, 1985), or discusses muscle activity during the swing (Bradley & Tibone, 1991; Glousman, 1993; Jobe, et al., 1986; Jobe, et al., 1989; Moynes, et al., 1986; Pink, et al., 1990; Pink, et al., 1993; Watkins, et al., 1996), but rarely focuses on minimal and maximal range of motion values at the shoulder during golf swings. This study examined maximal ranges of motion for shoulder flexion/extension, horizontal abduction/horizontal adduction, and abduction/adduction as seen at the top of the backswing. One recent study has presented values measured from professional golfers during the backswing for horizontal adduction and what appeared to be a combination of shoulder flexion and scapular elevation (Mallon, 1996). Low-handicap golfers were used in an attempt to minimize error associated with natural variation typical of golf swings often seen in less-skilled golfers.

The ability to assess injured golfers may be possible with a successful filming and data collection method established to determine golf swing variables for the normal golfers. Golfers with altered swing mechanics may be assessed using the techniques utilized for the non injured golfer assessment.

The specific athletic injury examined in this study is a tear or strain of the rotator cuff musculature of the glenohumeral joint. There are a number of golfers that still manage to maintain a low handicap while having experienced a rotator cuff injury, especially following surgical repair of the torn muscle. Determining if surgical repair permits the golfer to swing a golf club with the same range of motion as the golfer without previous history of shoulder dysfunction would be valuable in developing successful rehabilitative programs for golfers requiring surgical intervention. This study attempted to compare specific glenohumeral dysfunction during a golf swing with typical golf swing kinematics for the shoulder. Comparison between healthy rotator cuff golfers and golfers with previous or current rotator cuff dysfunction may provide evidence of specific compensatory movements. Additional movements may be used to produce reasonable clubhead velocities and golf swing consistency, despite shoulder dysfunction. An attempt was made to describe compensatory movements evident in the groups studied.

## Limitations

1) The injured golfers may not have had a swing that would be considered typical, as compared with the non injured golfers, before injury.
2) The subjects with rotator cuff tears or strains had varying degrees of injury. There was also a variation in the rate of recovery from surgery and exact location of the rotator cuff tear. All the golfers in the rotator cuff repair group had different lengths of times since their surgical repair was completed. The variations in recovery from injury may have complicated the normalization of the kinematic data for the golfers with rotator cuff history.
3) Kinematic description of internal and external rotation range of motion at the glenohumeral joint was not possible with the spatial model and camera configuration used since the field of view was too large to accurately assess the range of motion occurring.
4) With range of motion likely decreasing with age, it was not possible to determine if decreases in range of motion during golf swings were related to shoulder dysfunction from injury or simply from age of the golfer. Variability between the range of motion seen in subjects may have been partially due to differences in age.

## Delimitations

1) The results were based on data collection from low-handicap, male golfers, at least 26 years old.
2) The data collection for the swings was obtained on only one occasion for each golfer. These results may not have been reliable in producing data that was representative of a typical swing of the golfer filmed.
3) Configuration of cameras and joint markers, as well as the parameters studied, attempted to provide kinematic description of joint movements and the characteristics of the swing that were important for analysis. Variation in swings from subjects may have restricted consistent data collection for all subjects from all three camera views chosen to be effective.

## Definition of Terms

**Address:** The "ready" position prior to initiating the start of the takeaway and backswing of the golf club (Adlington, 1996; Kelley, 1983). The frontal plane of the body is parallel to the intended line of flight of the golf ball. There is trunk and hip flexion evident, with the arms hanging approximately straight down allowing the proximal end of the golf club to point towards the belt buckle area of the golfer.

**Clubhead velocity:** The displacement of the clubhead with respect to time. Clubhead velocity for a golf swing with a driver has been reported to be up to 50 m/s at impact (Hay, 1985; Mallon, 1996).

**Direct Linear Transformation (DLT):** A method of obtaining three dimensional data from multiple two dimensional views using a calibration frame (Peak Performance Technologies, 1994).

**Handicap:** the number of strokes included or excluded from the strokes of a golfer to adjust scoring to a common level of scratch for a zero handicap score (RCGA manual, 1996).

**Hertz (Hz.):** The unit for describing frequency. It indicates the number of times data is collected and displayed per second, (e.g. the standard video camera films at 30 Hz, or 30 frames per second).

**Rotator cuff injury-non repaired (RCN):** Descriptor of the subjects in the study that have current dysfunction in the rotator cuff as diagnosed by an orthopaedic surgeon or physiotherapist.

**Rotator cuff injury-repair (RCR):** Descriptor of the subjects in the study that have received surgical repair for a torn rotator cuff muscle.

**Swing plane:** The plane along which the golf swing occurs and is perpendicular to the axis of rotation of the swing (see Figure 1-1).

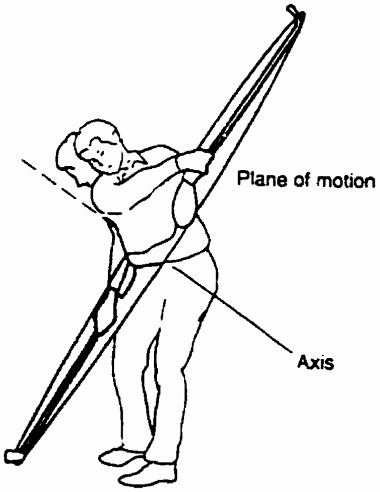


**Figure 1-1.** Plane of the golf swing (Kreighbaum & Barthels, 1996), p. 33.

**Torque:** The turning effect produced when a force is applied at a distance from an axis of rotation and is also known as a moment (Hay, 1985). The turning effect that muscle torque produces is seen as movement at a joint.

# II. REVIEW OF LITERATURE

## ANATOMY

### Glenohumeral Joint

The true shoulder joint is a ball and socket joint consisting of the glenoid fossa of the scapula and the round head of the proximal humerus. A fibrocartilage rim, the glenoid labrum, surrounds the glenoid fossa to deepen the socket and provide stability to the joint (Hay & Reid, 1988).

The shoulder joint is surrounded by a loose synovial capsule with one strong ligament. The coracohumeral ligament is attached to the coracoid process of the scapula and the greater tuberosity of the humerus. The main purpose of this ligament is to prevent the downward dislocation of the humeral head. There are thickenings of the anterior capsule called the glenohumeral ligaments which may assist in reducing anterior dislocation of the shoulder. However the laxity of the glenohumeral ligaments suggests that they are poor stabilizers of the humerus in the glenoid fossa and therefore of no real significance (Basmajian, 1985). The majority of the stabilization for the shoulder is provided by a group of muscles referred to as the rotator cuff muscles. These muscles are subscapularis, supraspinatus, infraspinatus, and teres minor and can be seen in Figures 2-1a and 2-1b.

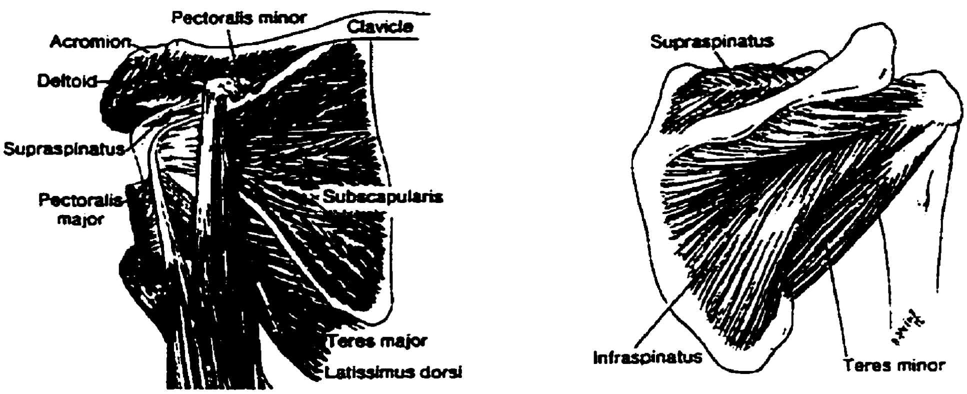


**Figure 2-1a)** Subscapularis and other internal rotator muscles of the humerus (Basmajian, 1985), p. 149.

**b)** supraspinatus, infraspinatus, and teres minor; the external rotators of the humerus (Basmajian, 1985), p. 147.

The movements that occur at the glenohumeral joint are shoulder flexion and extension (Figure 2-2), shoulder abduction and adduction (Figure 2-2), and horizontal adduction and abduction (Figure 2-3). Internal and external rotation also occur, and are illustrated in Figure 2-4.

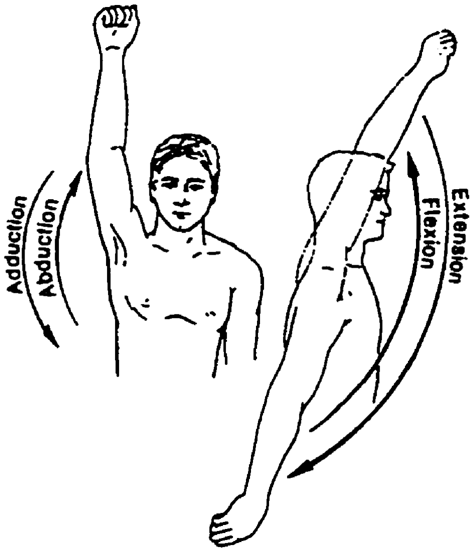


**Figure 2-2.** Movements at the shoulder joint: flexion/extension and adduction/abduction (Basmajian, 1985), p. 88.

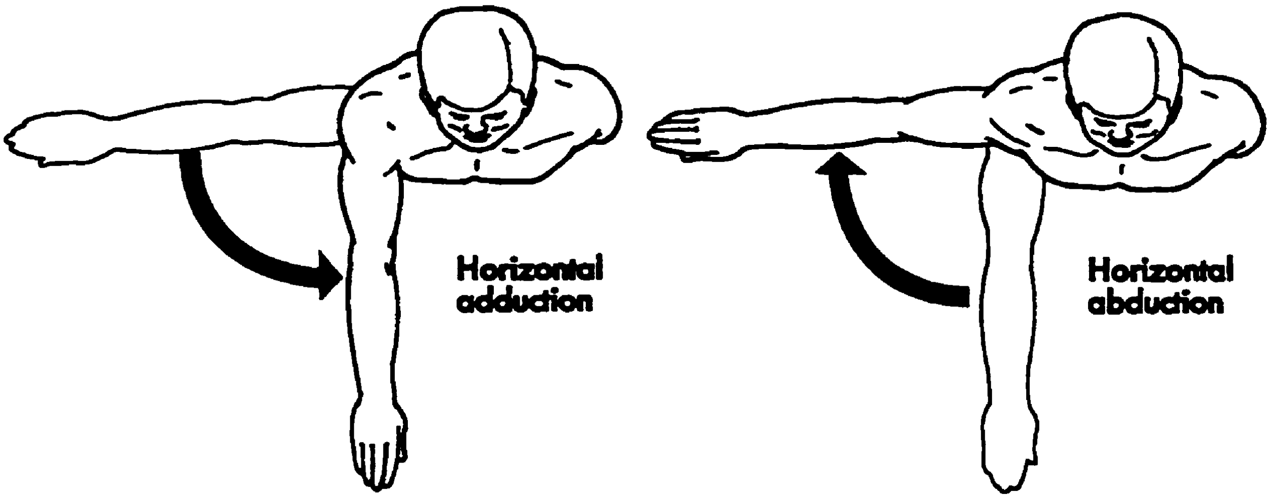


Figure 2-3. Horizontal adduction and abduction of the shoulder (Hall, 1995), p. 42.

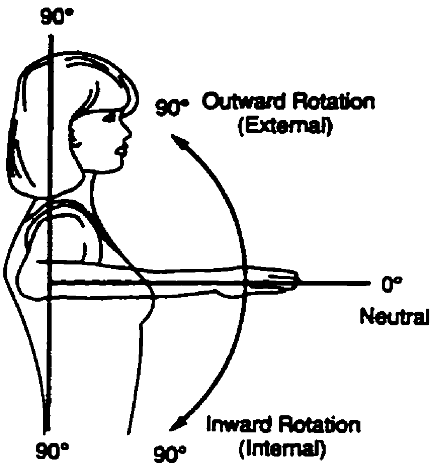


Figure 2-4. External and internal rotation of the humerus about the shoulder (Luttgens, Deutsch, & Hamilton, 1992), p. 630.

## Prime Mover Muscles of the Glenohumeral Joint

### Shoulder flexion

The main muscles that produce shoulder flexion are the clavicular head of pectoralis major and the anterior deltoid. The flexion of the shoulder can also be aided by the coracobrachialis and the short head of the biceps (Hay & Reid, 1988). The clavicular head of the pectoralis major is the upper one quarter of the pectoralis major muscle. The muscle originates on the medial portion of the clavicle and inserts on the lateral lip of the bicipital groove of the humerus. The anterior deltoid is composed of the anterior fibers of the deltoid muscle, with their origin on the distal third of the clavicle. The deltoid muscle originates from the lateral third of the clavicle, the lateral border of the acromion, and the spine of the scapula. The deltoid inserts on the deltoid tuberosity of the humerus. The coracobrachialis originates on the coracoid process and inserts on the medial shaft of the humerus. The short head of biceps originates on the coracoid process of the scapula and inserts on the radial tuberosity and the deep fascia of the forearm (Basmajian, 1985).

### Shoulder extension

The main shoulder extensor muscles are the sternocostal head of pectoralis major, latissimus dorsi, and teres major. The posterior deltoid and the long head of the triceps can also assist in shoulder extension (Hay & Reid, 1988). The sternocostal head of pectoralis major is the lower portion of the pectoralis major muscle and originates from the sternum and the upper six ribs to insert on the bicipital groove of the humerus. The latissimus dorsi lies on the posterior aspect of the trunk and originates from the posterior half of the iliac crest, the lower six thoracic spines, the lumbar spines, and the upper sacral spines. The latissimus dorsi inserts on the floor of the bicipital groove of the humerus. The teres major muscle originates from the inferior angle of the scapula and inserts on the medial lip of the bicipital groove of the humerus. The deltoid muscle and its origins and insertions were described above, however, only the posterior fibers of the deltoid assist with extension. The long head of triceps originates from the infraglenoid tubercle and inserts on the upper surface of the olecranon process (Basmajian, 1985).

## Shoulder abduction

The prime movers for shoulder abduction are the deltoid and the supraspinatus. The abduction may be assisted by the anterior deltoid, clavicular head of pectoralis major, and the long head of biceps (Hay & Reid, 1988). The origin and insertion of the deltoid muscle has been described previously, but for abduction, the middle fibers of the muscle are most active. The supraspinatus originates from the fossa above the scapular spine and inserts on the greater tubercle of the humerus. The clavicular head of pectoralis and the long head of biceps have both been described (Basmajian, 1985). There is also research that suggests an increased role of supraspinatus in generating concentric muscle torque in the early range of abduction (Basmajian, 1985; Tortora, 1995). This belief in supraspinatus as an initiator of abduction is contradicted by the literature that looks specifically at supraspinatus function (Howell, Imobersteg, Seger, & Marone, 1986; Sharkey, Marder, & Hanson, 1994; Wuelker, Plitz, Roetman, & Wirth, 1994).

Howell et al. (1986) observed in shoulders with a paralyzed supraspinatus muscle, that the deltoid could initiate and generate a significant torque from zero to 30 degrees in the plane of the scapula. Lack of force in the supraspinatus muscle reduces the position of abduction in the shoulder, however the deltoid can compensate for the loss of force needed for abduction, and with less force than is seen with supraspinatus (Wuelker, et al., 1994).

Concerning the golf swing, if the deltoid is capable of compensating for lost function of supraspinatus, then individuals with an injured rotator cuff should still be able to generate the muscle force needed to abduct the arm during the golf swing. While this may be the case, the supraspinatus may play a greater role in stability of the humeral head during the golf swing that the deltoid muscle may not be capable of. The fact that the deltoid was shown to abduct the arm using less force than supraspinatus demonstrates the greater moment arm for the deltoid, although Howell et al. (1986) described the moment arm for supraspinatus to be only slightly shorter than the moment arm for the deltoid.

Wuelker et al. (1994) reiterates this statement from the Howell et al. (1986) article, with neither researcher explaining how the deltoid can produce the same torque, with less force, and a slightly longer moment arm. The anatomical position of the shoulder at which the moment arm was measured and reported remained relatively constant within the $120^0$ arc of motion. The unchanging length of the moment arm is surprising and may suggest inadequacies in the measurement procedures. It would appear that the function of supraspinatus in glenohumeral movement is controversial.

The rotator cuff muscles and their angles of pull in anatomical position are shown in Figure 2-5. The diagram illustrates the significant role that the rotator cuff musculature plays in stabilization of the humeral head in the glenoid fossa. This stabilization role is evident from the large horizontal vectors for each muscle. The angle of pull of supraspinatus as it occurs specifically throughout the golf swing was not found, but would be an asset in understanding the role that supraspinatus plays in the execution of a golf swing.

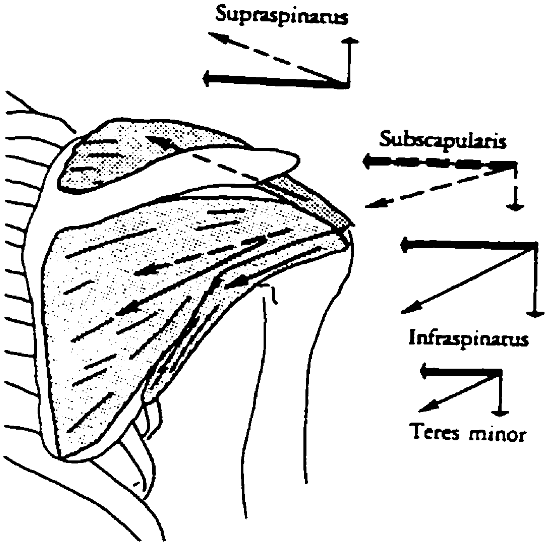


**Figure 2-5.** Rotator cuff muscles showing the angle of pull of each muscle (Kreighbaum & Barthels, 1996), p 174.

## Shoulder adduction

The muscles most responsible for shoulder adduction are the sternocostal head of pectoralis major, latissimus dorsi, and teres major, assisted by the short head of biceps and the long head of triceps, all described previously. The coracobrachialis and subscapularis can assist in adduction when the arm is adducted from a position greater than $90^0$ (Hay & Reid, 1988). The subscapularis originates from the subscapular fossa on the anterior side of the scapula and inserts on the lesser tubercle of the humerus (Basmajian, 1985).

## Horizontal adduction

The motion of horizontal adduction, also known as horizontal flexion, is achieved by the contraction of both heads of pectoralis major, anterior deltoid, and coracobrachialis (Figure 2-3). Horizontal adduction can also be assisted by the short head of biceps brachii (Hay & Reid, 1988). Horizontal adduction occurs as an anterior movement of an abducted humerus in the horizontal plane (Luttgens, et al., 1992).

### Horizontal abduction

The motion of horizontal abduction, also known as horizontal extension, is achieved by the contraction of the middle and posterior fibers of deltoid, infraspinatus, and teres minor (Figure 2-3). Assistance may come from latissimus dorsi and teres major (Hay & Reid, 1988). Horizontal abduction is the opposite movement to horizontal adduction with the humerus moving posteriorly in the horizontal plane (Luttgens, et al., 1992).

## COMPONENTS OF THE GOLF SWING

Figure 2-6 (a-l) shows a photo sequence of a low-handicap golfer completing a golf swing. The sequence shows the overhead view of the golfer on the left, and the frontal view for the same instant of the swing on the right. Photos shown in a) indicate the golfer in the address position preparing to start the golf swing. The golfer has the feet close to shoulder width apart with the weight evenly distributed on both feet. The knees are slightly flexed enabling the golfer to assume a comfortable stance. The hip and trunk are flexed providing a trunk lean angle of approximately $140^0$ in the sagittal plane. The frontal plane through the trunk is parallel to the desired flight path of the ball. The shoulder of the lead arm, in this case the left, is flexed to approximately $40^0$ and partially adducted across the body. The right shoulder shows a similar amount of flexion as the left at close to $40^0$, although there is a greater degree of cross-body adduction of the right shoulder since the club is shifted slightly towards the ball which is positioned closer to the left foot. The left elbow is near full extension at $180^0$, while the right elbow is about $15^0$ flexed at $165^0$. The head is positioned to ensure eye focus on the ball.

Photos in b) show the golfer beginning the take-away. The foot position is maintained at shoulder width, although the weight has marginally shifted towards the right foot. The remaining weight on the left foot should be distributed on the medial side of the entire foot and not on the ball of the left foot as is often done with inexperienced golfers. The golfer shown in this photo sequence appears to properly maintain contact of the medial edge of the left foot. The knees remain flexed about the same amount as they were at address. The left hip begins to abduct and the right hip begins to adduct as the weight is laterally shifted in the frontal plane. The hips have started to rotate clockwise in the transverse plane about $10^0$ from their original position at address. A degree of clockwise trunk rotation of $60^0$ is evident by the shoulder turn observed. The left shoulder maintains an angle of $40^0$ of flexion, although the amount of cross-body adduction increases to $25^0$. The right shoulder also maintains an angle of $40^0$ of shoulder flexion from address, although the right humerus has assumed a position approximately equal to anatomical position. Both the left and right elbows are near full extension. The wrists have maintained a relatively neutral position from the address at this point in the swing. The head remains in position to keep the eye focus on the position of the ball.

Photos in c) show the golfer in the early portion of the backswing. The weight continues to shift laterally to the right as the club is drawn back. The knees do not flex to any greater degree than was evident earlier in the swing. The left hip continues to abduct, while the right hip continues to adduct. The hips continue to rotate clockwise to an angle of about 20$^0$. The trunk has also increased clockwise rotation in the tranverse plane about a longitudinal axis through spine to an angle of about 50$^0$. The left and right shoulders extend as the club is drawn back and the golfer keeps the humerus of both arms closer to the trunk. The left shoulder is cross-body adducted to about 45$^0$. The right shoulder begins to abduct and illustrates an angle of about 10$^0$. Both arms remain near full extension at this portion of the swing. The left wrist remains close to a neutral position, although the right wrist has cocked slightly illustrating an angle on the lateral side of about 30$^0$. The head continues to be positioned to allow eye focus on the ball.

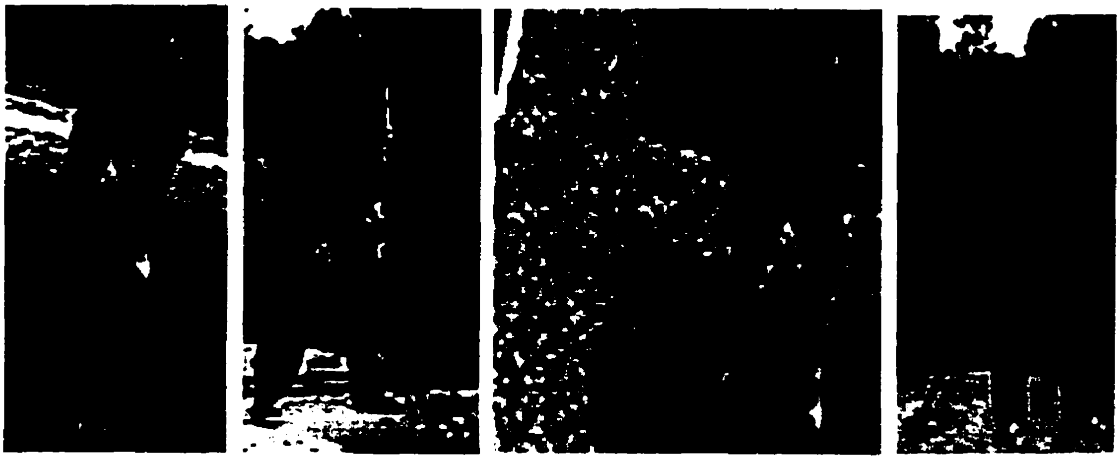
Photos in d) and e) show the continuation of the backswing of the golfer. The foot position remains relatively constant for both d) and e) with the weight continuing to shift laterally towards the right. The frontal view in e) shows a small increase in the degree of knee flexion in the left knee. The hips continue to rotate clockwise in both d) and e) showing the hips rotating from 20$^0$ in d) to about 25$^0$ in e). The trunk rotates clockwise from about 55$^0$ in d) to about 70$^0$ in e). The left shoulder is flexed continuously to allow clearance of the humerus in cross-body adduction to a degree of 50$^0$ in d) to about 70$^0$ in e). The right shoulder is only marginally abducted any further to an angle of about 20$^0$ for both d) and e). The left arm remains near full extension in d) and e), although the right elbow is flexed about 45$^0$ and can be observed in the frontal view of e). The wrists continue to cock away from the ball and illustrate angles of about 35$^0$ in d) and 40$^0$ in e). The head remains in a position to allow eye focus to be maintained on the ball.

Photos f) and g) show the golfer in the final stage of the backswing and at the top of the backswing. The weight continues to laterally shift towards the right in f) to a point in g) where the line of gravity of the golfer should pass through the medial side of the right foot of the golfer. This should be the furthest lateral position of the line of gravity since this is the top of the backswing. The knee of the left knee continues to flex to a slightly greater degree assisting the left hip to abduct to a greater degree as well. The hips rotate from about $40^0$ in f) to almost $50^0$ in g). The trunk rotates from $80^0$ in f) to $90^0$ in g) at the top of the backswing. The left shoulder remains flexed from earlier in the swing, while the right shoulder maintains the position of about $20^0$ of abduction. The left shoulder further increases in cross-body adduction from $80^0$ in f) to $90^0$ in g). The left elbow appears to be flexed to $40^0$ in g) from the near full extension seen in f). The right elbow flexes from about $90^0$ seen in f) to a position of $120^0$ in g). The wrists significantly increase their clockwise rotation (abduction in the transverse plane) away from the ball from about $50^0$ in f) to over $60^0$ in g). The large range of wrist rotation, along with the greater degree of hip and trunk rotation, and the large range of motion at the shoulder joint, position the shaft of the club just above horizontal at the top of the backswing in g). A horizontal club shaft would be parallel to the ground.

Photos h) and i) show the golfer move into the downswing as the reverse sequence of movement demonstrated in the backswing. The center of mass has been abruptly shifted medially towards the left foot by utilizing a forceful adduction of the left hip and a forceful abduction of the right hip. Counterclockwise hip rotation in the transverse plane is quite rapid, moving from an angle of $20^0$ in h) to near $0^0$ in i) as was seen at address. Trunk rotation is equally as dynamic, rotating from about $35^0$ in h) to about $20^0$ in i). Forceful abduction of the left shoulder is the most significant contribution of the shoulders at this point in the swing, moving from about $70^0$ in h) to almost $0^0$ in i). The wrists have not yet rotated counterclockwise towards the target and have therefore remained at about a $60^0$ angle. The head is positioned to enable eye focus to remain on the ball.

Photos j) and k) shows the golfer late in his downswing and at the instant of ball contact. The weight continues to shift towards the left foot to a point where the line of gravity passes through the left foot of the golfer at ball contact in k). The left hip illustrates the adduction that has occurred during the downswing and into ball contact, while the right hip shows the abduction that has occurred. The hip and trunk rotation has returned to positions approximately equal to the initial positions seen at address. The left and right shoulders resume the same positions as they were in at address, assisting to center the position of the club head behind the ball as it was at address. Another significant movement that has occurred at this stage in the swing is external rotation of the left humerus and internal rotation of the right humerus. Rotation of both shoulders contribute to increasing the acceleration of the club and square up the club face in preparation for ball contact. The forearms provide a similar role of accelerating the club and squaring the club face to the ball seen as supinatation of the left forearm and pronation of the right forearm. The wrists contribute to the acceleration of the club by rotating towards the ball from about $40^0$ in j) to near neutral ($0^0$) at ball contact.

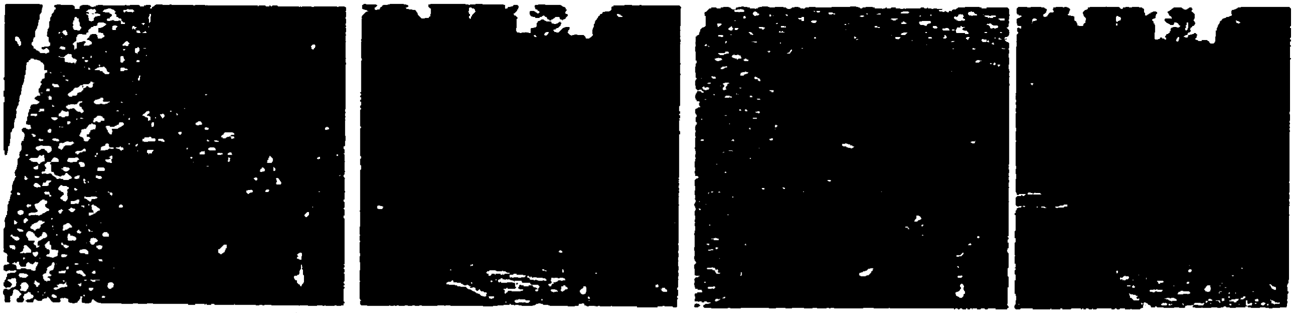
Photo l) shows the golfer completing the swing and gradually decelerating the swing of the golf club with the follow through. The line of gravity of the golfer is over the left foot with only the toe of the right foot remaining in contact with the ground. The left knee of the golfer should be extended at this stage of the golf swing as is shown in l). The hips and trunk continue to rotate in the direction of the downswing and have now rotated past the $0^0$ position at address to an angle of about $-90^0$ allowing the hips to rotate through with the shoulders. The right shoulder is flexed to about $120^0$, while the left shoulder should not flex to any great degree as the humerus should remain close to the trunk. The right shoulder is adducted across the body about $90^0$. The elbow of the right arm remains near full extension, while the left elbow flexes to allow the humerus to remain close to the trunk and the left forearm to continue supinating as the right forearm pronates during the final stages of the follow through. The pronation/supination of the two arms can be seen in the overhead view of l) where the left wrist and hand is clearly shown under the right wrist. The head position has now come up with the follow through to track the flight of the ball.



a. address

b. early take-away

**Figure 2-6.** Overhead and frontal views of the golf swing (a - b). Left-hand pictures are overhead, right-hand pictures are frontal.



c. early backswing

d. mid backswing (1)

e. mid backswing (2)

f. late backswing

g. top of the backswing

h. early downswing

i. mid downswing

j. late downswing

Figure 2-6. Overhead and frontal views of the golf swing (c - j). Left-hand pictures are overhead, right-hand pictures are frontal.

k. ball contact l. nearing follow through completion

**Figure 2-6.** Overhead and frontal views of the golf swing (k-l). Left-hand pictures are overhead, right-hand pictures are frontal.

The nomenclature describing the components of the swing may vary depending on the source. The swing is commonly described by golf professionals as beginning with the backswing. The backswing is the action of the club being drawn away from the ball at address in an arc to a position above the head of the golfer (Haney & Tomasi, 1992; Maddalozzo, 1987) (Figure 2-6a to g). Following the backswing, there is a transition in which the club head changes direction and begins to follow an arc towards the ball (Figure 2-6g). The action once the club head changes direction and moves towards the ball is referred to as the downswing (Adlington, 1996; Maddalozzo, 1987) (Figure 2-6g to j). Several authors also indicate an instant during the swing where the ball is impacted by the club, known as ball contact (Adrian & Cooper, 1995; Hay, 1985) (Figure 2-6k). Following ball contact, the golf swing concludes with a gradual deceleration of the club and limbs referred to as the follow through (Bradley & Tibone, 1991; Glousman, 1993; Mallon, 1996) (Figure 2-6l).

These descriptors provide a full account of the components of the golf swing, although they are not standardized since the same components are described using different terminology. One study using electromyography referred to the components as the takeaway, the forward swing, acceleration, and follow through (Jobe, et al., 1989). These coincide with the backswing, the downswing (forward swing and acceleration), and maintaining the follow through, respectively. These phases, with the exception of ball contact, are illustrated in Figure 2-7. Ball contact would occur ideally at the end of the acceleration phase.

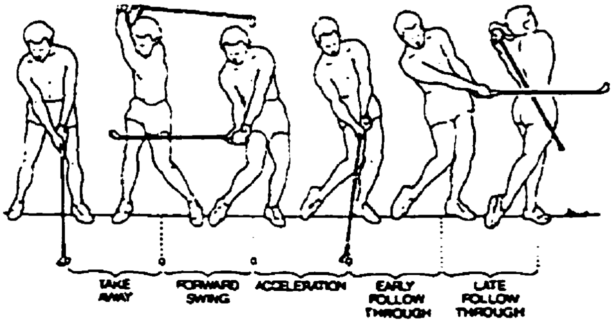


**Figure 2-7.** Phases of the golf swing (Glousman, 1993), p. 33.

Research presented by Adrian & Cooper (1995) indicate the downswing of a highly skilled college male to be twice as fast as the backswing. Films of professional golfer Bobby Jones indicate that his downswing was two-and-one-third times faster than his backswing. Cochran & Stobbs (1968) found the downswing to be from .23 - .25 seconds, more than two and one-half times as fast as the backswing. Milburn (1982) found values of .23 seconds for the downswing, consistent with the range reported by Cochran & Stobbs (1982). Other reported values specifically looking at amateur golfers indicate the duration of the downswing to be longer, averaging .38 seconds (McTeigue, Lamb, Mottram, & Pirozzolo, 1994).

## BIOMECHANICS OF THE GOLF SWING

Perfect execution of all phases of the golf swing highlighted in the previous section will produce a skilled drive. It is often unclear why a particular technique is effective in accomplishing the task of making contact with a golf ball. In addition, simply making contact with a golf ball will not necessarily be effective in driving a golf ball any great distance. Considerable rotation of the hips, trunk, shoulders, and wrists is utilized in swinging a golf club. Examining the system in terms of moment arms provides a rationale why experts advocate one particular body position over another when executing the skill. A golfer in the address position can be seen in Figure 2-8. The illustration includes the longitudinal axis of rotation of the swing as indicated by the dotted line passing through the trunk of the golfer. Figure 2-8 differs from the golfer shown in Figure 1-1, in that Figure 2-8 illustrates clearly the length of the moment arm of the club at the critical instant of ball contact. The axes in the two figures are different since Figure 2-8 is highlighting the axis of rotation through the trunk relative to the position of the trunk at ball contact. Figure 1-1 shows the plane of the golf swing, and indicates the axis for that plane as being perpendicular to the swing plane. The swing plane in Figure 1-1 is slightly more vertical than seen with golf swings using a driver. The use of the driver would tend to shift the swing plane towards the horizontal which would also cause the axis to shift and therefore pass more through the trunk as shown in Figure 2-8. The moment arm for the club and golfer, about the longitudinal axis, is the dotted line labeled 'd' that runs perpendicular to the axis of rotation.

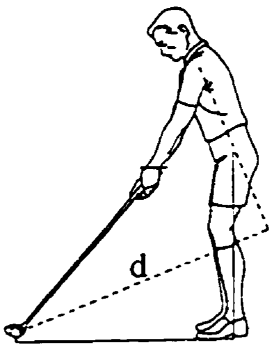


**Figure 2-8.** A golfer in the address position showing the moment arm (d) and axis of rotation of the system (Adrian & Cooper, 1995), p. 380.

The torque value could be determined from the equation $T = I\alpha$ , by finding, from previous research, the product of the moment of inertia (I) of the rotating body about the axis of rotation, and the angular acceleration ($\alpha$) of the club. Moment of inertia values will not be reported here since they will not be included in the analysis of the golfers involved in this study. Angular acceleration of the club could be determined from video film directly, or by using the Peak motion analysis software, although this will not be included since accelerations are not required in the analysis of the golfers in this study. Once the torque value is determined it can be divided by the moment arm distance to determine the force at ball impact.

From the golfer's perspective, an angular acceleration that reaches a maximum immediately prior to ball contact indicates a peak angular velocity provided both the acceleration and velocity were in the same direction. The angular velocity of a club, when multiplied by the radius of the swing about the axis of rotation as its center, gives the linear velocity value. It is the linear velocity value that is critical in determining the velocity of the ball following impact from the club. A study by Milburn (1982) measured linear velocity of the clubhead which ranged from 43.45m/s - 53.56m/s. These values seem high when compared to more recent research which measured a range of linear velocity of the clubhead from 33.52m/s - 39.27m/s, for amateur and PGA professionals, respectively. Even when the standard deviation (± 2.70) is considered with the 39.27m/s value for the professional golfers, the maximum linear value seen is 41.97m/s (Barrentine, Fleisig, & Johnson, 1994). Therefore, while the minimal range reported by Milburn (1982) appears possible, the maximal value in the range given seems excessive. Ball velocity is a primary determinant in the range that the golf ball will travel.

The velocity of the ball immediately after impact is taken from film data and used in the impulse - momentum relationship, $\mathbf{Ft=(mv)_2-(mv)_1}$, to estimate the force at impact (F), combined with t (time) to give the impulse, $(mv)_2$ is the final velocity and mass of the ball immediately after impact, and $(mv)_1$ is the mass and velocity of the ball before impact (Hall, 1995). The product of mass and velocity gives momentum. The greater the impulse, the greater the change in momentum which results in a higher ball velocity after impact since the mass of the ball remains constant (Hall, 1995; Luttgens, et al., 1992).

A system with more rigidity is produced when the club is gripped firmly and the muscles of the limbs are contracted to stabilize extraneous movements. Less kinetic energy (KE) loss would result from a more rigid system and promote a better transfer of KE to the ball from the club. If the system is not rigid, energy is more likely to be conserved as heat energy in the muscles and other anatomical structures of the body. A small portion of the energy is inevitably lost as sound energy when the collision between the ball and club occurs (Luttgens, et al., 1992). Kinetic energy analysis of the golf swing and other sport skills is not typically done due to inaccuracies associated with following where energy is transferred within the system. Kinetic energy of the club increases from close to zero at the top of the backswing to a maximal value at ball contact or at the point where linear velocity of the club head reaches a maximum. The higher level of kinetic energy after ball impact, the greater the amount of work will be done during collision between the club and ball. The amount of work done is equivalent to the product of the force applied and the distance over which the force is applied (Hay & Reid, 1988; Luttgens, et al., 1992). The short distance that the club does work on the ball remains relatively constant. Therefore an increase in the total amount of work done would result from an increase in the force applied at ball contact (Jorgensen, 1994). The amount of work done could be analysed by applying the formula, $\mathbf{Fd = 1/2\ mv_f^2 - 1/2\ mv_i^2}$, where Fd is the work, m is the mass of the ball, $v_f$ is the velocity that the ball is travelling after contact from the club, and $v_i$ is the velocity of the ball before contact with the club, which would be zero.

The conservation of momentum applied to the collision between a golf club and a golf ball would be described with a similar formula to the impulse - momentum formula, except this formula implies an isolated system in which no impulse acts upon the system during the collision. The formula, $\mathbf{m_b u_b + m_c u_c = m_b v_b + m_c v_c}$, replaces the impulse (Ft) with mass and velocity measurements for the club. In the conservation of momentum equation, the b and c subscripts are for the ball and club, respectively. The v symbol denotes velocity after impact, and the u symbol denotes velocity before impact. The m symbol represents the mass (Luttgens, et al., 1992). The equation used is dependent on what the investigator intends to observe. If investigators are looking at the forces acting upon the ball, then impulse - momentum analysis is used. If investigators are more concerned with the collision between the club and ball, then a conservation of momentum analysis is used.

## UPPER BODY KINEMATICS

Since the golf club is grasped with both hands, it is expected that the majority of the movement of the club results from upper body movements. Beginner golfers tend to rely almost entirely upon a swing that involves arm action only. The result is a swing that lacks power and consistency when the larger muscles of the trunk and legs are not included in sequence with the swing. Jorgensen (1994) used an interesting estimate concerning the amount of muscle required to produce the magnitude of power seen in the golf swing and concluded that the large muscles of the trunk and legs must be responsible. Jorgensen (1994) based his conclusions on the fact that a minimum of 32 lbs. of muscle is needed to generate the estimated two horsepower required to execute the golf swing. The smaller muscles of the arms and shoulders do not contain this amount of muscle mass.

Golf swing mechanics tend to emphasize either a swing of the club (Haney & Tomasi, 1992; Kelley, 1983) or a turn of the torso (Adlington, 1996) in developing a consistent and efficient golf swing. Both consistency and power is the likely result when the two techniques are combined and utilize both a swing and turn in a golf swing (Flick, 1990). The literature that emphasizes the swing is not describing the golf swing differently, it is focusing on the movements of the club and upper limbs during the swing.

Since the movements of the club and upper limbs should be a result of trunk and hip rotation, describing the golf swing with reference to a sequence would seem to address the entire golf swing. The sequence would involve a swing of the club about a system of links rotating about an anterior-posterior axis primarily through the lead shoulder, and a turn involving trunk and hip rotation Examination of each joint involved in swinging a golf club illustrates the action required, with the trunk being the link between the movements from the lower and upper limbs. Studies are often focused on individual segments or specific regions of the body to simplify analysis (Glousman, 1993; Moynes, et al., 1986). Break down of skills in the simplified manner employed in these studies is often useful but may be misleading or not representative of the entire skill. Looking at the contribution of different joints and the segments they connect during a swing is useful, provided these movements are then combined to describe the entire skill of the golf swing.

A rough approximation of the linear contributions from the joints to the final club velocity is 70% at the wrist, 20% at the shoulder, and 5% each at the hip and spine (Adrian & Cooper, 1995). These values reported by Adrian & Cooper (1995) fail to explain the actual movements responsible to produce the suggested 70% contribution from the wrist. To understand the large contribution from the wrist, the mechanics of movements that occurred at joints more proximal to the body, and from the trunk, must first be examined. Sequential rotation is the timed contributions from body segments and is one fundamental characteristic seen in the skillful execution of sport skills, especially striking and throwing skills (Adrian & Cooper, 1995; Kreighbaum & Barthels, 1996).

Sequential rotation utilizes as many joints as possible in order from largest to smallest which may also be seen as proximal to distal. The result is a coordinated movement in which each proximal segment reaches or approaches a maximal velocity prior to the more distal segment beginning independent movement (Kreighbaum & Barthels, 1996; Putnam, 1993). A distal segment movement may be only the result of being attached to the segment above, therefore, observing the relative angle between the two segments and how and when it changes is needed to properly describe the movement actually occurring between segments. Immature or inexperienced golfers may change a sequential movement into a simultaneous pattern by ordering the initiation of two or more links at the same, or nearly the same time (Kreighbaum & Barthels, 1996). Proficient golfers maximize the use of sequential rotation when striking a golf ball. The sequence of joint involvement in the downswing is hip and trunk rotation, humeral movement in an arc towards the ball - combined movement of shoulder flexion/extension, horizontal abduction/adduction, abduction/adduction, and internal and external rotation - with the forearm supination/pronation, wrist flexion/extension and wrist adduction being last (Adrian & Cooper, 1995). The elbow joint was not listed in the sequence of action provided by Adrian and Cooper (1995), but it would occur after shoulder joint action and prior to any wrist joint action.

A segmental rotation pattern includes the lagging of more distal segments. As proximal segments are accelerated, the distal end of the proximal segment should be moved ahead of the more distal segment below (Kreighbaum & Barthels, 1996; Putnam, 1993). The result that is seen as the more distal segments trailing behind the proximal segments is known as inertial lag. Utilizing inertial lag of segments characterizes experienced, smooth movement from skilled athletes. The inertial lag of the segments allows stretching of the muscle tissue responsible for acceleration of distal segment. This stretching occurs prior to the acceleration of the distal segment allowing a greater torque applied to the segment by utilizing the elastic characteristics of the muscle fibers. Figure

2-9 illustrates the increasing angular velocity of the club during the golf swing as the angular velocity of the arm starts to decrease. In the graph, angle $\theta$ indicates the angle of the left humerus in the swing plane as it rotates about a longitudinal axis shifted to the left to pass through the shoulder which is the origin of the coordinate system. Angle $\beta$ on the graph indicates the angle of the club relative to the arm, allowing the angular displacement of the club to be measured (Milburn, 1982). Ball contact would optimally occur when the most distal segment reaches a peak angular velocity. However, one study looking at five low handicap golfers measured peak linear velocity of the club head occurring up to 0.003 s prior to impact for four out of the five golfers. One golfer did approximate maximum linear velocity with ball impact. Since linear velocity ($\mathbf{v}$) is the product of angular velocity ($\omega$) and the radius of rotation ($\mathbf{r}$), then a peak angular velocity would also indicate a peak linear velocity providing $r$ does not change. Radius of rotation would be the length of the segment - in this case the club - from the axis of rotation through to the distal end of the segment. The axis of rotation for the swing would be located in the mid-thoracic region running longitudinally through the trunk (McTeigue, et al., 1994). It is likely that the axis of rotation for the golf swing does not necessarily remain fixed in one place. However, keeping the axis in the region of the spine avoids the incorrect assumption that the rotation occurs about an axis through either shoulder.

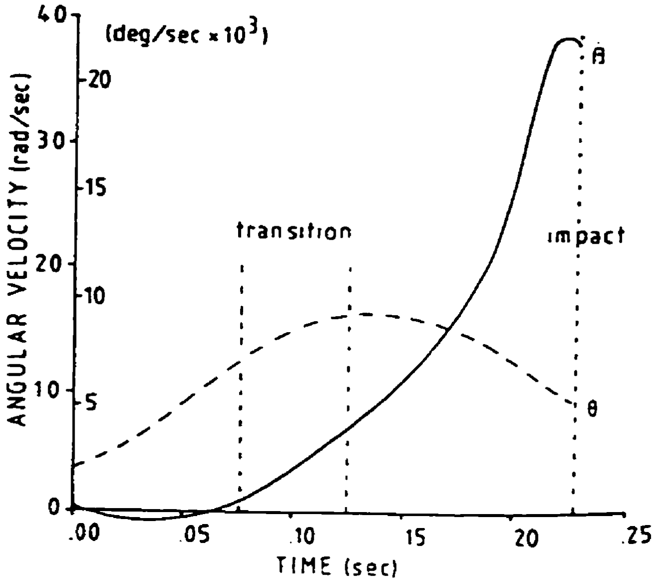


**Figure 2-9.** Angular velocity of the arm (θ) and club relative to the arm (β) during the downswing (Milburn, 1982), p. 62.

Each of the following sections will address the contribution of each segment in the execution of a golf swing with reference made to the description of inertial lag and segmental rotation. All descriptions of the golf kinematics in this study refer to a right-handed golf swing.

## Trunk

The contribution of the trunk to the golf swing is considerable. From the address to the top of the backswing the shoulders rotate approximately $90^0$ about an axis through the spine (Figure 2-6a to g). The angular displacement seen at the shoulders is known as the shoulder turn, but is actually a combination of trunk and hip rotation. Trunk and hip rotation that produce the shoulder turn, and the amount each contribute to the rotation, will be discussed in their respective sections. EMG studies examining the musculature on the trunk or upper torso indicate substantial muscle activity during the entire golf swing that produces recognizable patterns despite a variety of swings (Pink, et al., 1993; Watkins, et al., 1996). The study by Watkins et. al (1996) recorded EMG activity from both left and right sides of: erector spinae, abdominal obliques, and rectus abdominus. Gluteus maximus was included in this study, but does not act on the trunk despite its origin located at the mass of ligaments that bind the sacrum and ilium together. Gluteus maximus acts to powerfully extend and externally rotate the hip (Basmajian, 1985). It was likely included due to its stabilizing role on the hip which would reduce the need for additional trunk muscle stabilization, although the Watkins et. al study did not differentiate the action of gluteus maximus as producing iliofemoral movement rather than vertebral movement. Therefore, the distinction between iliofemoral joint movement and vertebral movement was not made.

The erector spinae muscles have been shown to be approximately 30% active during the takeaway phase of the golf swing, with the left side having slightly more muscle activity than the right. The start of the downswing shows a vast increase in right side erector spinae activity of up to 75% of maximal muscle tension (MMT), while the left side increases only marginally. MMT was determined from recording EMG activity during a maximal level isometric contraction. During the acceleration phase of the club in the late downswing, the activity in the right erector spinae decreases to about 58%, and the left erector spinae increases to around 50%. Both the right and left erector spinae muscles demonstrated a reduction to similar percentages during the follow-through as was seen during the takeaway (Pink, et al., 1993). The amount of muscle activity in the erector spinae musculature reached a peak during acceleration of the club when stabilization of the trunk is important for increasing the angular velocity of the club while maintaining good balance. Stabilizing the trunk would promote more consistency between swings and encourage torques generated to be only about the axis of the swing. Torques produced that cause rotation about secondary axes, not required for skillful golf swing execution function only to alter mechanics of the golf swing and are likely to produce erratic technique.

The abdominal oblique musculature was similar for both right and left sides at about 20% of maximal values during the takeaway. Both sides increased substantially during the downswing, averaging about 58%, with the right side slightly higher than the left. The right oblique activity increased only marginally during the acceleration phase, while the left oblique decreased to about 40%. During the early follow-through, both sides decreased slightly, with the right showing about 20% higher levels of activity. The late stages of the follow-through showed both the right and left sides leveling out at about 42% of maximal activity (Pink, et al., 1993). The percentage values in the EMG study by Watkins et. al (1996) were supportive of the values and trends shown in the study by Pink et al. (1993). Unfortunately, despite the detailed nature of this EMG data, no relationship between the reported muscle activity and trunk range of motion was included in these or any other EMG studies reviewed. Without reference to quantitative range of motion values related to the EMG activity, the data has limited usefulness in its application to the golf swing.

The amount of trunk lean in the sagittal plane is of importance in determining the length of the moment arm of the system with the golfer rotating about a longitudinal axis through the spine. The longitudinal axis indicates the trunk position since the two points that describe the axis are located on the spine. The moment arm for the system is the length of a line at an angle of $90^0$ from the extended longitudinal axis through the trunk to the point of ball contact on the club. Adrian & Cooper (1995) illustrated the amount of trunk lean of $134^0$ occurring primarily as a result of hip flexion indicating the internal angle between the thigh and trunk.

The amount of trunk lean tends to decrease as shorter clubs are used. The longer the club, the greater the amount of trunk lean, and the greater the amount of shoulder flexion at address. The increased shoulder flexion that results from the increased trunk lean tends to cause a swing plane that is recognizable as being more horizontal, or "flatter" in orientation. An increase in trunk lean may cause a decrease in the moment arm of the system if the golfer uses a shorter club or moves their grip towards the clubhead on a longer club as their body is moved over the ball with the increased trunk lean. Therefore, if shorter clubs are used, a more upright posture with less trunk lean is demonstrated (Adrian & Cooper, 1995).

Another consideration is the decreased trunk and hip rotation that occurs as a result of increased trunk and hip flexion with an excessive trunk lean. With decreased trunk and hip rotation, the amount of angular displacement seen in the shoulder turn of the golfer would also be decreased. One study suggests that bending over more at the waist may also help golfers with shoulder problems. Mallon (1996) explained that the increased steepness of the shoulder plane associated with the increased trunk lean allows the golfer to elevate the left arm less and still achieve a reasonably upright swing plane. The "elevation" described appeared to refer to shoulder flexion. The decreased elevation of the left arm may reduce the stress on the left shoulder on the backswing. Increasing the trunk lean in the sagittal plane would also tend to place a greater strain on the lower back by increasing the moment arm of the weight of the upper body and club about L4/L5 as the left/right axis of rotation. The moment arm of the weight is the length from the center of mass of the golf club and all segments superior to L4/L5 to the axis of rotation at L4/L5.

## Shoulder Movements and Kinematics

### Shoulder girdle

The glenohumeral joint is an important joint in the production of a skilled golf swing. In addition to the muscular contribution of the shoulders to the golf swing, rotation of the shoulder girdle about an axis through the spine plays an important role in accelerating more distal segments. The shoulders rotate approximately twice as much as the hips in long hitters. Quantitatively, this would indicate about $90^0$ of shoulder angular displacement from the position at address seen for $45^0$ of hip angular displacement. This shoulder to hip ratio of rotation and the difference in angular displacement between the shoulders and hips becomes less in golfers that hit balls shorter distances with a ratio of 1: 0.7, which equates to about $63^0$ of hip rotation for $90^0$ of trunk rotation, seen as the shoulder turn (Adrian & Cooper, 1995). A reduction in the magnitude of the shoulder turn is likely in golfers that hit balls shorter distances, therefore the amount of hip rotation would be less than $63^0$. One study reported the magnitude of angular displacement for several positions of the trunk and hips through out the golf swing and reported $87^0$ of "upper body" rotation and $53^0$ of hip rotation. Upper body rotation referred to the amount of rotation of the upper body about a longitudinal axis through the mid-thoracic region. Hip rotation referred to the amount of rotation, also about a longitudinal axis, but through the pelvis which was determined by a line connecting the anterior-superior iliac spines (ASIS) (McTeigue, et al., 1994).

### Shoulder muscles

Electromyography studies indicate that the muscles that produce torque about the shoulder are quite active, but not in causing abduction as is often seen in developmental golfers (Bradley & Tibone, 1991; Jobe, et al., 1989). Activity of rotator cuff muscles throughout the entire golf swing function to stabilize the head of the humerus in the glenoid fossa and position the humeral head for rotation within the glenoid fossa. Karlsson & Peterson (1991) suggested that it is difficult, if not impossible, to measure the EMG in all shoulder muscles or regions at the same time. The right humerus should not abduct during the backswing as seen in many inexperienced golfers, but rather remain close to the right side until after ball contact and into the follow through (Kelley, 1983).

In elite golfers, the deltoid muscles of the shoulder are minimally active bilaterally, illustrating little or no shoulder adduction/abduction (Batt, 1993; Bradley & Tibone, 1991; Jobe, et al., 1989; Moynes, et al., 1986). The low range of motion in the right shoulder during the backswing was supported in a study by Mallon (1996) and can be seen in Figure 2-10. While the range of shoulder abduction and adduction are not frequently discussed in the literature, this study by Mallon (1996) stated that the right arm of a right-handed golfer does not abduct more than $60^0$, which was referred to in extreme cases as "winging" of the arm. The study by Jobe et al. (1986), did not show increased deltoid activity throughout the swing, even during the follow-through. However, Moynes et al. (1986)

mentioned eccentric right deltoid activity as a possible deceleration mechanism during the follow-through. The left deltoid may act eccentrically in changing the direction of the golf swing at the top of the backswing and offering a small contribution to the forward swing with a concentric torque action causing abduction of the left shoulder (Pink, et al., 1990). With the apparent quiescence of the deltoids, the range of abduction and adduction seen in the left shoulder during the swing must be produced by other muscles. Supraspinatus activity in the left shoulder does increase during the forward swing and acceleration phases of the swing. The increase in activity may be beyond the capability of the supraspinatus muscle, especially during situations of fatigue or overuse, although these possibilities were not discussed by the EMG researchers studied (Bradley & Tibone, 1991; Jobe, et al., 1989; Jobe & Pink, 1996; Moynes, et al., 1986; Pink, et al., 1990). The activity of supraspinatus during the full golf swing appears relatively constant with minimal increase or decrease in activity throughout the golf swing. The muscle activity recorded is smaller in magnitude for supraspinatus in relation to other muscles of the shoulder girdle. Supraspinatus activity would appear to be difficult to measure accurately with EMG, or perhaps minimal contractions of a torn supraspinatus is sufficient to elicit a painful response during the golf swing.

The right deltoid activity was minimal throughout the majority of the golf swing as reported by Jobe et al. (1986), showing only a slight increase during the forward swing and acceleration phases. This would suggest that the "winging" of the right arm reported by Mallon (1996) is not due to right deltoid activity. The mechanics of the golfers involved in the different studies may have varied which would also explain discrepancies between the two studies. Any right humeral movement that did occur may have been due to the momentum of the backswing which caused the right humerus to abduct away from the body.

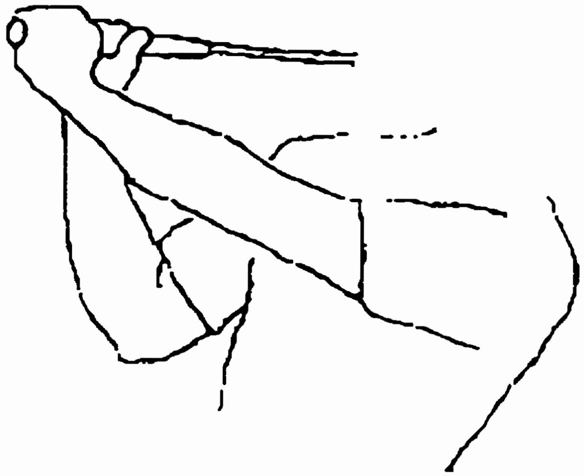


**Figure 2-10.** Arm position at the top of the backswing of a professional golfer illustrating the low range of motion in the right shoulder (Mallon, 1996), p. 429.

### Shoulder movements

Horizontal abduction/adduction range of motion values during the golf swing are more prevalent in the literature. The lead arm, or left arm for a right-handed golfer, reaches an angle of $38^0$ of horizontal adduction at the top of the backswing. This angle was based on an overhead photograph taken of a professional golfer and describes the internal angle that the left arm makes with the frontal plane through the shoulders (Mallon, 1996). The angle description of horizontal adduction that Mallon (1996) used would describe an angle that increases as the humerus is horizontally abducted. Mallon (1996) also defined another angle for glenohumeral range of motion at the top of the backswing which was shoulder "elevation". The amount of elevation was reported as $30^0$ above the shoulder plane ($120^0$ of elevation). While the value of $30^0$ appears accurate, the description of elevation actually seems to be describing a combination of shoulder flexion and adduction, which was referred to as cross-body adduction. Glenohumeral range of motion is complex to describe, especially when movements occur in oblique planes. Such complexity often causes researchers to generate terminology unique to a particular study to describe glenohumeral movement. The use of the term elevation by Mallon (1996) provides further ambiguity since "elevation" usually refers to scapular movement in the frontal plane in anatomical and biomechanical literature (Basmajian, 1985; Kreighbaum & Barthels, 1996). Failure to describe the angles with respect to any particular plane makes interpretation more difficult. Therefore, when researchers incorporate their own terminology into the description of movements they should avoid terms that are currently used to describe other movements, and should also include reference planes to increase the clarity of their description. Both the diagrams from the article by Mallon (1996) illustrating horizontal adduction and shoulder elevation (i.e. shoulder flexion) are shown in Figures 2-11a and 2-11b, respectively.

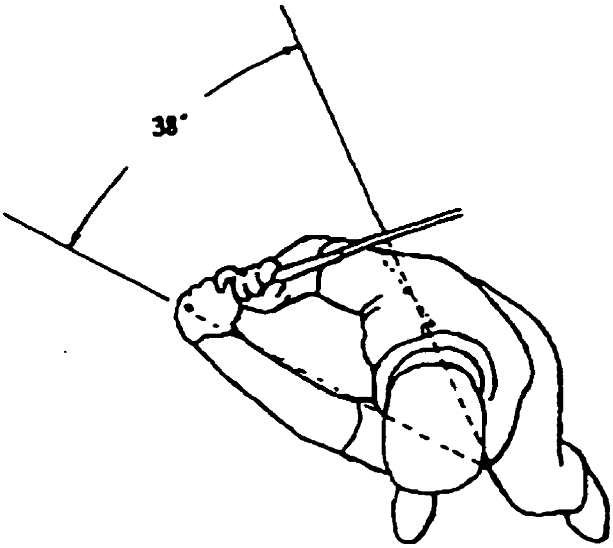
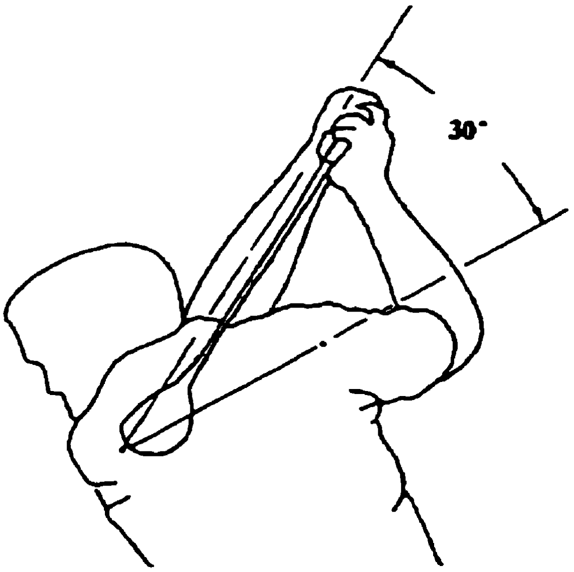


**Figure 2-11a)** Horizontal adduction at the top of the backswing (Mallon, 1996), p. 430.



**b)** Shoulder elevation at the top of the backswing (Mallon, 1996), p. 430.

Internal and external rotation of the humerus is an integral movement utilized in the golf swing. During the backswing the humerus of the lead arm internally rotates as the humerus of the opposite arm externally rotates. The humerus of the lead arm and the humerus of the opposite arm reach maximal range of motion at the top of the backswing. During the downswing, forceful external rotation of the lead arm generates a significant portion of the club head acceleration. The trailing arm internally rotates, also contributing to the torque causing forceful rotation of the golf club, although the external rotation of the lead arm is the primary contributor. Despite the importance of internal and external rotation to the execution of the golf swing, neither measurement will be included in this study due to difficulty in obtaining accurate data with the large field of view needed to observe the entire swing.

### Supraspinatus muscle in golf

The nature of the supraspinatus muscle and its tendon likely predisposes the muscle to chronic injury. There is a significant portion of the supraspinatus tendon that is avascular (Rathbun & MacNab, 1970). Rathbun et al. (1970) indicated that supraspinatus demonstrated an avascular region of its tendon near the insertion point that was not seen in other muscles of the rotator cuff. The only other exception to this was a small avascular area in the superior region of the infraspinatus muscle. Large tears of supraspinatus often extend to include upper portions of infraspinatus (MacDonald, 1997). This fact would support the presence of the avascular region seen in both muscles.

Since blood supply is critical for regeneration of soft tissue following injury, a diminished blood supply to the supraspinatus tendon may be responsible, in part, for injury sustained during golfing or injury that presents the golfer with discomfort during a golf swing (Jobe & Pink, 1996). A cross-sectional representation of the glenohumeral joint showing the supraspinatus muscle and its tendon can be seen in Figure 2-12. Figure 2-13 is a superior view of supraspinatus and its tendon. The facet for articulation with the clavicle can be seen as the darker colored area on the upper edge of the acromion angle. The acromion passes directly superior to the supraspinatus muscle and tendon as it articulates with the scapula. The arch created by the acromion and coracoacromional ligament that the tendon of supraspinatus passes under is known as the supraspinous outlet.

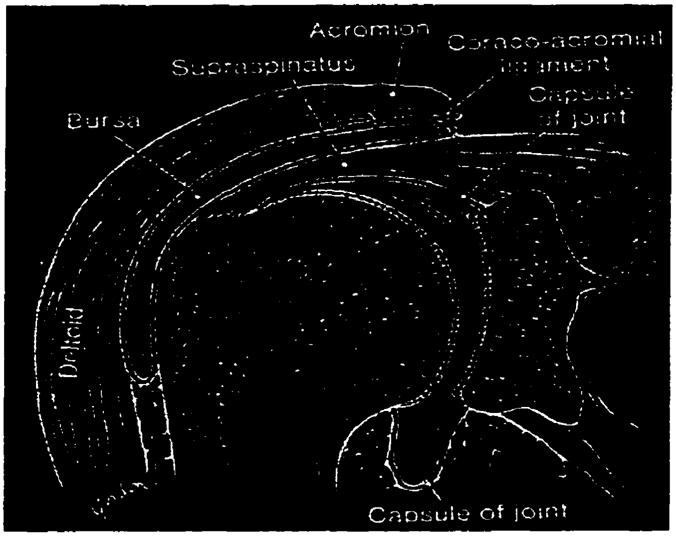


**Figure 2-12.** Cross-section of the glenohumeral joint in the frontal plane (Basmajian, 1985), p. 147.

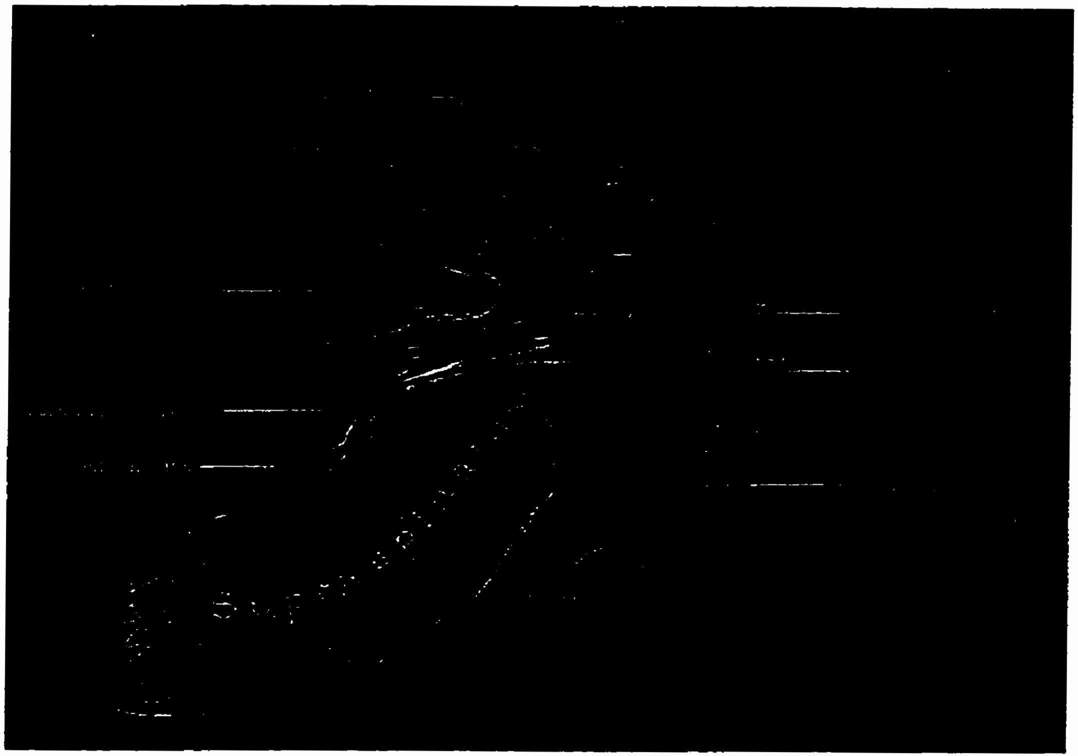


Figure 2-13. Superior view of the shoulder showing the deep structures (clavicle removed) (Agur, 1991), p.386.

The left supraspinatus tendon may experience tension from a rapid eccentric contraction of the muscle at the top of the backswing as it assists in deceleration of internal rotation and horizontal adduction of the humerus (Hay, 1985). During this already stressful eccentric contraction, impingement of the tendon from the inferior side of the acromion is also probable (Jobe & Pink, 1993). While under the stressful impingement and eccentric contraction, the supraspinatus muscle may be required to forcefully contract concentrically to assist in abducting the left arm segments and golf club through the downswing. The role of supraspinatus is controversial, however possible actions are abduction of the arm, and elevation/compression of the humeral head in the glenoid fossa. Whether supraspinatus can assist in abduction of the left humerus is questionable given conflicting studies cited previously concerning its role (Basmajian, 1985; Howell, et al., 1986; Otis, Jiang, Wickiewicz, Peterson, Warren, & Santner, 1994; Sharkey, et al., 1994; Tortora, 1995; Wuelker, et al., 1994). However the compression and elevation role of supraspinatus during glenohumeral movement would cause the muscle to be constantly active. At the top of the backswing and into the start of the downswing, the humerus is moving through a combination of shoulder flexion and abduction (horizontal abduction), and the humeral head is elevated. It is the possible eccentric - concentric firing pattern of the supraspinatus muscle, and potential of impingement against the acromion within the supraspinatus outlet, that suggest problematic rotator cuff injuries (Mallon, 1996). Jobe et al. (1993), illustrates how trauma due to overstress and tendon impingement in the cycle shown in Figure 2-14 inevitably leads to tearing. Weakness in the muscles, either from fatigue or overuse, that act to cause humeral movement, allow subtle instabilities to develop during motion of the shoulder. Instability present during activity such as a golf swing may predispose the subluxation or movement of the humerus through a range of motion that places the person at risk of impingement. Once structures are impinged, in this case the supraspinatus muscle and tendon, continuation of movement is likely to cause tearing of the muscle.

**INSTABILITY ---> SUBLUXATION --->**
**IMPINGEMENT---> ROTATOR CUFF TEAR**

**Figure 2-14.** Progression of joint instability to muscle tear (Jobe & Pink, 1993), p. 428.

Further complications occur once the cycle suggested by Jobe et al. (1993) proceeds. Rathbun et al. (1970) indicated that once initial degeneration occurred in the supraspinatus, further increase in the avascular region of the tendon was soon to follow, leading to greater degenerative changes.

## Elbow

Less research has been focused on the elbow action during the golf swing than has been reported on the shoulder. It was previously mentioned that the right elbow should remain close to the torso for the golfer, at least until ball contact is made. The left elbow crosses the torso to some extent, especially during the backswing, and is the result of humeral adduction and internal rotation of the shoulder (Haney & Tomasi, 1992). The extent of the movement would depend on the height of the backswing. The higher the backswing, the greater range of motion is needed at the shoulder which causes a greater displacement seen in the position of the left elbow across the torso.

The elbow joint is a uniaxial joint which has muscles acting at the joint that can be more easily recorded using EMG than shoulder musculature (Moynes, et al., 1986). The muscles acting on the elbow are more superficial and easier to locate which explains the simplified description of the movements at the elbow during a golf swing. Unfortunately, the range of motion seen at the elbow during a skilled golf swing is not large, especially at the left elbow. Muscle activity of the elbow extensors and flexors is required to stabilize the elbow joint and minimize unwanted flexion of the left elbow, as well as control of the swing. The line of action of the muscle is easier to determine at the elbow due to the uniaxial construction (Adrian & Cooper, 1995).

During the backswing, the right elbow is initially flexed more than the left since the left elbow is thought to provide better swing mechanics when kept as straight as possible during the backswing (Haney & Tomasi, 1992). Keeping the left arm as straight as possible functions to maximize the radius of rotation which would equate to a greater linear velocity of the club head at ball contact. The radius of rotation would be maximized by increasing the distance between the axis of rotation at the shoulder and the club head. Straightening of the arms during ball contact functions well to increase the distance indicated as the radius of rotation from the shoulder joint to the club head. Keeping the left arm near maximal elbow extension during the backswing and downswing tends to encourage straight arms at contact, promoting improved accuracy and control of the golf swing. Flexion of the elbows during ball contact would be difficult to reproduce consistently as opposed to a position with no elbow flexion at ball contact. In addition, bending the elbows during ball contact would require a greater trunk lean in order to keep the clubhead at a height that would contact the ball. However, Adlington (1996) suggests that too rigid an elbow of the left arm during the backswing may have a hindering effect on the swing due to increased muscle tension.

The average range of motion in the elbow joints during execution of a golf swing were not reported quantitatively in the literature. The descriptions were qualitative statements that consistently referred to "minimal elbow flexion". The right elbow must flex early in the swing to enable the elbow to remain in proximity to the torso while the club completes the backswing. The elbow flexors of the right arm are therefore active primarily as a stabilizer of the humerus and elbow later in the backswing, allowing supination of the forearm during the backswing, and rapid pronation during the late downswing. If the right elbow flexors were to be used as a significant force producer, greater velocity of the club and arm segments during the backswing would likely be the result. This would cause a swing that was more difficult to control than a slow, controlled backswing. The greater velocities may also increase the risk of injury as the shoulder joint experiences a rapid change in the direction of movement at the top of the backswing. These actions are rarely recorded during a golf swing as most EMG activity of interest typically occurs at the shoulder as seen with previous studies (Bradley & Tibone, 1991; Jobe, et al., 1986; Jobe, et al., 1989; Pink, et al., 1990). None of the studies reviewed researched any EMG activity of the muscles involved in flexion of the elbow.

During the final portion of the backswing, the left elbow extensors produce an eccentric torque to avoid excessive flexion of the elbow (Moynes, et al., 1986). This torque assists in avoiding initiation of the downswing in a poor position and perhaps protects the elbow and shoulder from injury caused from excessive range of motion (Batt, 1993). The elbow extensors are triceps brachii, with a marginal contribution from anconeus (Tortora, 1995). These extensors, especially from the right side, rapidly fire concentrically to extend the elbow and cause the hands grasping the club to travel in a path that is more linear than was seen in the larger arc during the backswing. The path of the hands travelling more linear as opposed to the curvilinear arc seen during the backswing allows quicker rotation of the arm segments and a lag in the golf club which has to accelerate greatly to catch up to the hands for ball contact (Dante & Elliot, 1962).

The elbow extension is likely assisted as well by a resultant joint moment caused by the forces of gravity and acceleration acting on the segment of the forearm and club at a distance from the axis of rotation of the joint (Chaffin & Andersson, 1984; Putnam, 1993). This resultant joint moment that occurs at the elbow is characteristic of rapid swinging and striking skills and is similar in concept to a whip having its end segment accelerated as the more proximal segments reach the end of their range of motion (Jorgensen, 1994). For inertial lag of the distal segments to be effective in increasing the acceleration distally, these distal segments must initiate independent rotation about the proximal joint as the proximal segment reaches its maximal velocity (Kreighbaum & Barthels, 1996). With the more distal segment suddenly accelerating past the proximal segment, the proximal segment appears to be stopping. While the proximal segment is decelerating, it maintains movement in the same direction as the more distal segment. Elbow and shoulder actions do not account entirely for the range of motion of the club seen during a golf swing. A significant amount of the range of motion occurs because of motion facilitated by the wrist.

The range of motion expected to be seen at the left and right elbow joints is variable. The left elbow will likely move from an angle of $180^0$ at address to a lesser angle as it flexes during the backswing. The left elbow should return to an angle of approximately $180^0$ at ball contact. The right elbow is expected to show greater variability when measured during the backswing and downswing of the golfers. The angle measured at the elbow is expected to decrease early in the backswing indicating significant elbow flexion. The magnitude of the right elbow range of motion will not be measured as a variable since it is rarely discussed quantitatively and would not necessarily reflect any dysfunction in the left shoulder.

### Lower arm and wrist

The wrist is a difficult joint to describe anatomically, especially when describing a range of motion as seen in skill analysis. Figure 2-15 illustrates the motions of ulnar and radial deviation as one role of wrist range of motion required in executing a golf swing. The proximal and distal radioulnar joints of the forearm allow the movements of pronation and supination to occur. The distal radioulnar joint allows the radius to rotate freely around the distal head of the ulna which is fixed. From anatomical position, pronation rotates the palm of the hand to face posteriorly as a result of the radius rotating medially around the ulna (Basmajian, 1985). The opposite movement is referred to as supination as the radius rotates laterally around the ulna (Basmajian, 1985). Pronation and supination can be seen in Figure 2-16.

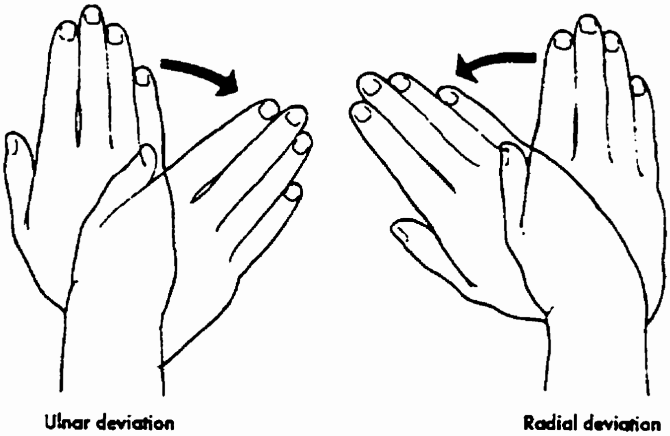


**Figure 2-15.** Ulnar (adduction) and radial deviation (abduction) seen at the wrist (Hall, 1995), p. 40.

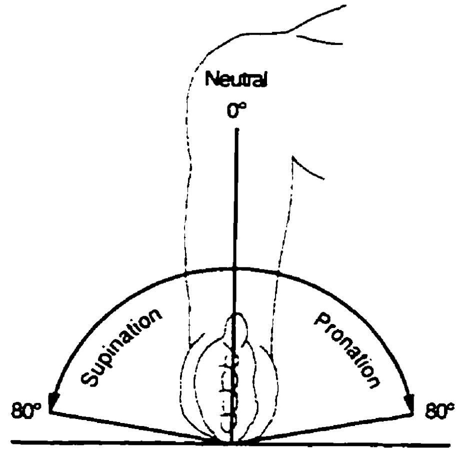


**Figure 2.16-** Pronation/Supination of the forearm (Luttgens, et al., 1992), p. 627.

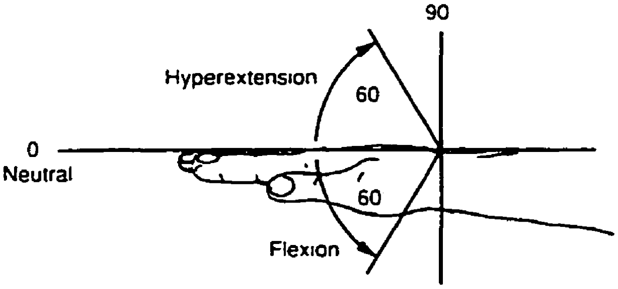


**Figure 2.17-** Flexion and extension at the wrist (Luttgens, et al., 1992) p. 628.

During the downswing, the right and left wrists adduct to provide rotation in the direction of the rotating club head and assist in maximal acceleration through ball contact. The "uncocking" action is a very natural movement which occurs as a result of the angular momentum of club head catching up to the hands for ball contact (Dante & Elliot, 1962). In addition to the ulnar deviation of the wrists known as "uncocking", a combination of pronation/supination (Figure 2-16) at the proximal radioulnar joints, and flexion/extension at the wrist joints (Figure 2-17) is utilized in swinging a golf club. Golf literature terminology has referred to these additional lower arm actions as "hinging" in reference to wrist flexion and extension, and "rolling of the wrists" in reference to pronation and supination of the forearms (Cochran & Stobbs, 1968). The hinging of the wrists is timed to occur at the same time as the uncocking of the wrists. The rolling of the wrists occurs during the entire swing and is most recognizable initially as pronation in the left arm and supination in the right arm near the top of the backswing to bring the club into the swing plane. The movement is reversed after ball contact into the follow through as the left arm supinates and the right arm pronates (Cochran & Stobbs, 1968). It is the rolling of the wrists during the late downswing and through ball contact that is the movement completed at a high level in great golfers, and usually executed unconciously, if at all, by unskilled golfers. Pronation of the trailing forearm, and supination of the lead forearm as seen in the golf swing are seen in other skills, such as accelerating through the underhand release in softball (fastball) for the similarity to the pronation of the non-lead or trail arm in the golf swing (Alexander & Haddow, 1982). A skill that very closely follows the pattern of the lead arm in golf is the downstroke of the throwing arm in releasing a frisbee. Unfortunately, the recent popularity of ultimate frisbee has not extended into research describing arm action in terms of mechanics, but more focussing on the dynamics of the frisbee after release. The great accelerations capable during pronation and supination of the forearms allow huge increases in angular velocity of the club through transfer of angular momentum, thereby greatly increasing the linear velocity of the club head at ball impact (Dante & Elliot, 1962).

The cocking of the wrists would occur during the backswing and be maintained until late in the acceleration of the club when the uncocking or ulnar deviation occurs (Kite, 1985). The uncocking would occur after the rolling of the wrists was initiated if timing was precise enough to follow the proximal to distal pattern considered optimal. The uncocking of the wrists is thought to be a significant factor in the ability to hit a ball with power since the acceleration of the club is increased immediately prior to ball impact with the contribution from the delayed action of the wrists (Kelley, 1983). The difference between developmental and elite golfers is often seen in the elite golfer and their ability to maximize the range of motion and speed of movement in the cocking-uncocking action of the wrists (Kite, 1985). Often, recreational golfers do not possess the timing and skill needed to facilitate the acceleration of the club that the delayed wrist uncocking allows. It would appear that the actual uncocking action of the wrists is likely a natural result of the properly executed rolling of the wrists which the majority of unskilled golfers lack during their swing. Therefore, despite the effectiveness of the movement, the delayed wrist uncocking is suggested to be emphasized for the professionals, and not stressed for beginners (Kite, 1985). By emphasizing the uncocking action of the wrists, unskilled golfers may avoid initiating an aggressive rolling action of the forearms which is likely the dominant movement allowing the wrist uncocking to occur naturally with greater acceleration and effectiveness.

The uncocking of the wrists depends heavily on timing of the swing (Milburn, 1982). If the golfer's wrists uncock too early, the club accelerates too much in the early portion of the downswing, but decelerates or travels at a constant velocity through ball contact (Neal & Wilson, 1985). One study reported wrist uncocking began approximately 0.075 s from the start of the downswing, although the greatest change in the angular displacement of the club in relation to the arms (i.e., wrist uncocking) occurred after 0.125 s from the start of the downswing (Milburn, 1982). The illustration of the wrist uncocking can be seen in the graph of club and arm angular velocities in Figure 2-9. The β angle indicates the angle of the club relative to the lower arm and shows the wrist movement prior to ball contact. While uncocking or ulnar deviation of the wrists is likely the predominant movement illustrated by the graph curve β in Figure 2-9, it is impossible to eliminate the presence of flexion/extension and pronation/supination in the recorded movement. Focussing on ulnar deviation may actually prevent the capture of the necessary movements of flexion and extension of the wrist, and especially pronation and supination of the forearms. The transition period indicated by the vertical dotted lines from 0.075 - 0.125 s is where the wrist movement begins, with the region of the graph after the transition zone showing the greatest change as indicated by the increased slope. The goal of any striking skill is to contact the ball with the striking implement accelerating to a point of maximum velocity immediately prior to contact (Hay, 1985; Putnam, 1993). To accomplish this task in a golf swing, the wrists uncock as the club head approaches the ball in order to allow natural acceleration of the club at the end of the downswing into the instant of ball contact (Kite, 1985).

## LOWER BODY

Golf literature found in golf journals that is concerned with swing mechanics typically includes discussion on the role of the lower body during the swing (Flick, 1990; Jorgensen, 1994; Kite, 1985; Milburn, 1982; Neal & Wilson, 1985). Research studies examining the golf swing usually include minimal discussion of the lower body and its' contribution to the golf swing. Of particular importance to this discussion is the role of the hips in the contribution and timing to the segmental rotation necessary to swing a golf club skillfully. The trunk to hip range of motion ratio was already reported in a previous section as 1: 0.5 for long hitters, and 1: 0.7 for golfers that tend to hit the ball shorter distances. Concerning timing, the hips actually start to rotate towards the target prior to the club reaching the top of the backswing in better golfers (Adrian & Cooper, 1995;

Hay, 1985). Cochran and Stobbs (1968) timed the hip rotation initiating the downswing as beginning approximately 0.1 seconds before the clubhead reaches the limit of its backswing.

From the address position, in which the weight of the body is evenly distributed towards the balls of both feet and the knees are relaxed with a slight bend, there is a shift of weight as the club initiates the takeaway into the backswing. The weight of the body gradually shifts onto the right foot during the backswing and at completion of the backswing, the center of gravity of the golfer is behind the ball, with the weight on the inside of the right foot (Adlington, 1996; Ballard, 1984). From the top of the backswing the line of gravity is shifted from the inside right foot position to the left foot. The left knee is slightly flexed at impact, and has the knee extended very soon after impact. The extended knee of the left leg assists the arms to straighten at ball contact by keeping the center of mass near the level it was at address when the arms were straight. A left leg that remains flexed and driving toward the target tends to lower the entire body, making full release of the club head and hands difficult (Kite, 1985). As the weight is shifted laterally from the right to the left foot, the right hip forcefully abducts to continue the segmental movement in sequence from the ground up through the trunk. With the emphasis not on lateral hip movement, the downswing is likely to cause the golfer considerable problems at ball contact with consistency and with the quality of the drive. The focus on hip rotation versus lateral hip movement has been summarized by stating, "the hips will turn if they are moved laterally, but they are very liable not to move laterally if they are merely turned" (Dante & Elliot, 1962, p. 92).

The right hip abduction, in combination with hip rotation, is supported in an EMG study that demonstrated significant increase in gluteus maximus activity that was 84% of the value measured for a maximal contraction (Watkins, et al., 1996). This increase in gluteal activity occurred prior to club movement seen in the downswing to allow the hips to precede the trunk, shoulders, and arms. This suggested pattern of movement functions to pre-stretch the muscles of the trunk and shoulders which enables a greater acceleration of the club prior to ball contact. The pre-stretch of the muscles recruits the stretch-shortening cycle which uses the elastic properties inherent in the sarcomeres of muscle to contract with a greater velocity and force after being stretched. The principle that this segmental movement illustrates is the summation of joint forces and is a fundamental movement pattern in nearly all sport skills (Luttgens, et al., 1992).

## VIDEO ANALYSIS

Cinematographic analysis of sport skills has been conducted using either high speed film methods at 294 Hz. (Neal & Wilson, 1985), and 300 Hz. (Milburn, 1982) or video taping methods (Abraham, 1987; Kennedy, Wright, & Smith, 1989). High speed movie film capable of filming at rates of 1000 Hz. and greater have been used but are becoming less popular due to the cost involved in processing the film, the time spent to manually digitize film, and the difficulty in finding outlets that sell and process 16-mm movie film. Video taping methods use video cameras that record a video image at a rate of 30 Hz. for most typical video cameras. High speed video cameras are also available that are capable of capturing video film at a higher frequency of 200-300 Hz with the advantage of not having to wait for the processing time as with the high speed movie film.

The video taping method may be advantageous because of the lower cost involved (Abraham, 1987; Kennedy, et al., 1989), easier use, and a shorter processing time (Kennedy, et al., 1989). The resolution of the video image produced was found to be acceptable but limited by the number of pixels, which are the minute divisions of the picture on the video monitor (Abraham, 1987). The number of pixels on the video monitor used in most manual digitization studies is 512 x 512 (Peak Performance Technologies, 1994).

The main drawback to video taping methods is that standard video cameras film at a rate of 30 frames per second, which is then enhanced to 60 fields per second with motion analysis software (Peak Performance Technologies, 1994). One advantage of video analysis over the naked eye is that capture of skills on video enables slow motion and freeze-frame observation. The naked eye observes much less detail during analysis than can be accomplished using pictures captured every 1/60th of a second. These advantages are lessened when compared to high speed film analysis that utilizes 200 frames per second and greater (Milburn, 1982; Neal & Wilson, 1985). Higher filming speeds such as these are often needed in high speed sport skills in order to capture instances such as ball impact and accurate transitions from one phase of a skill to another. High speed video cameras are expensive, both for the actual camera and for the software required to read and analyze the data.

Kinematic data for a golf swing is adequately described by video analysis at a film rate of 60 frames per second. One other recent three-dimensional study of the golf swing used two video cameras capturing data and utilized a Peak motion analysis system to analyze the data at 50 fields per second (McLaughlin & Best, 1994). Studies examining other sport skills where high angular velocities are present have used 60 Hz. as the picture capturing frequency. A study by Rash & Shapiro (1995) used 60 Hz. as the filming frequency for analysis of a football quarterback throw in which angular velocities for internal and external rotation of the humerus reached values of 2,987 degrees per second. In this study, the only portion of the golf swing measured that will be likely to exceed 60 Hz. is the instant of ball contact. However, reasonable accuracy is available by observing the frame immediately prior to ball contact if skipping to the next frame is beyond the instant of actual ball contact.

Decreased accuracy of the video taping method compared to 16-mm film was shown by Angulo & Dapena (1992). The error values for coordinates from the video method was 10 millimeters, while the film method was 4 millimeters. The increased error in the video method was said to be increased by the use of larger fields of view but was also said to be sufficiently accurate for most applications. Kennedy et al. (1989) also calculated error values for coordinates from video analysis. The error values were 4.8mm for film data, and 5.8mm for video data. The difference of 1mm was found to be statistically significant ($p<.05$). The Kennedy et al. (1989) study did conclude however, that video techniques are comparable in accuracy to 16-mm filming methods since the video error was found to be .29% of the calibrated field, only .05% higher than the .24% error found using film.

Without the analysis of kinetic data, which requires acceleration data determined from video, video taping methods have produced data used for kinematic analysis of sport skills with negligible error (Rash & Shapiro, 1995). The acceleration data required for kinetic analysis was more likely to be inaccurate when compared with other kinematic data using video taping methods (Abraham, 1987; Angulo & Dapena, 1992).

## DATA SMOOTHING

Cubic spline functions are the preferred data smoothing technique for skills such as the swinging of a golf club (Peak Performance Technologies, 1994). Cubic spline functions have been used for other kinematic analyses of the golf swing (Milburn, 1982). Cubic spline applications for data smoothing should also include as many points as possible to reduce errors associated with using cubic spline algorithms when another method of data smoothing would be more appropriate. The minimum number of data points suggested was fifty (McLaughlin, Dillman, & Lardner, 1977).

The Peak5 Data Conditioner uses a cubic spline algorithm with a knot at every data point (Peak Performance Technologies, 1994). The cubic spline data conditioner smooths data by decreasing the slope of the lines connecting points or "knots" in the graph. The greater the number of passes that the spline function completes on the raw data, the smoother it becomes. For instance, zero passes of the function would not condition the raw data, resulting in data that was identical to the original. A cubic spline function that used ten passes, would indicate that the cubic spline function smoothed the raw data ten consecutive times resulting in data that would be much smoother than the original raw data.

# III. METHODS

## Pilot study

Prior to the collection of data for the project, the filming configuration was arranged and tested for accuracy in describing kinematic profiles of glenohumeral motion during a golf swing. The pilot filming session was organized with the protocol to be used for the actual data collection.

Three pilot filming sessions were completed, each with different subjects. The first session was conducted in December, 1996, and was primarily used to assess the suitability of the camera configuration for filming the golf swing and used a local golf professional as the subject. The location was an indoor driving range, and the subject used a five iron instead of the driver that was used for the actual study.

The second pilot session was conducted in June, 1997, and filmed three subjects that had a recent rotator cuff surgical repair. This second filming session occurred outdoors, and was used to help determine the golf swing variables that were analyzed in the study. The third filming session occurred in July, 1997, and was necessary since one of the three cameras in the second filming session failed to function correctly. During these three filming sessions, a shutter speed of 1/2000s was determined to be effective at capturing the swing without blurring of the club and limbs. This third pilot session also confirmed the suitability of the camera configuration to accurately capture the entire golf swing and specifically, the lead shoulder joint.

From the pilot data collected, sample measurements were taken of each of the calculated variables. These measurements served to determine the description of angles necessary to develop accurate representation of the actual range of motion of the golfer. This pilot data also was used to assess whether or not the spatial model chosen to represent the golfer described angles that were consistent with the golfing literature. A horizontal adduction measurement was also collected from all the pilot study subjects using a transparency tracing from a monitor screen of the interior angle at the top of the backswing between the humerus and the line of the shoulders. While this method was not likely to be as accurate as the Peak measurements, it allowed a faster method to measure angles for pilot study purposes only. The results obtained from the pilot study are included in the next chapter.

### Present study subjects

Low-handicap (handicap $\leq$ 15), male golfers, at least 26 years of age, were the subjects for this study. Handicap, age, and years of golf experience was collected as descriptive information on all subjects. Ten of the subjects were non injured subjects (N), with no history of rotator cuff injury that required surgery or prolonged therapy. Four additional subjects were diagnosed by a licensed physiotherapist or orthopaedic surgeon as having a rotator cuff injury to the shoulder of the lead arm in the golf swing, either chronic or acute (rotator cuff - not repaired; RCN). Six subjects were also included in the study that had surgical repair done within two years on the supraspinatus muscle of the shoulder of the lead arm in the golf swing (rotator cuff - repaired; RCR). RCR golfers also reported the duration since the repair of the rotator cuff which was included as descriptive information. Eighteen of the twenty golfers were right handed, leaving two left handed golfers that were part of the RCR group. The left handed golfers met the same criteria, although the lead shoulder was the right shoulder instead of the left as was seen with the right handed golfers.

All non injured subjects were free of shoulder complications, history of recent injury, or other conditions which may have altered the mechanics of the golf swing. RCR golfers were excluded from the study if shoulder dysfunction other than the rotator cuff tear was determined during pre-screening of the golfers. Pre-screening of the golfers was done over the telephone while recruiting potential subjects. A pain questionnaire was used to gather additional information from RCN golfers since they were the only subjects that reported discomfort which affected their golf swing. The information collected from the pain questionnaire was used to confirm that all RCN subjects experienced discomfort at the top of their backswing, which coincided with rotator cuff dysfunction diagnosed by an orthopaedic surgeon or physiotherapist. The pain questionnaire is included as Appendix I.

The non injured subjects were recruited from local golf clubs using posters to advertise the study. RCR and RCN golf subjects were recruited using rural and urban physiotherapy and athletic injury clinics. The golfers were pre-screened to ensure that they met the subject description of the study. The RCN subjects were confirmed by telephone after they were selected as suitable study subjects by the orthopaedic surgeon or physiotherapist. All subjects were required to complete an informed consent form before participating in the study. Copies of the two informed consent forms, one for non injured golfers, and one for the RCR and RCN golfers, are included in Appendices II and III.

## Camera configuration

Three video cameras filming at 30 Hz. were used to analyze the golfers. These cameras were genlocked with the use of cables connecting the three cameras which allowed synchronous data capture of the golf swing. The analysis system used a direct linear transformation (DLT) to create a three dimensional image from the three two dimensional images filmed during data collection (Peak Performance Technologies, 1994). Two of the cameras were placed approximately orthogonal to each other on the ground with one filming the sagittal plane of the golfer (camera 1), and the other filming a frontal plane (camera 2). The third camera was used to film an overhead view (camera 3) that captured an oblique view film of the plane of the swing similar to the swing plane shown in Figure 1-1. These three views allowed data collection that ensured all points of the spatial model were in view of at least two of the cameras at all times throughout the swing. This configuration was used to attempt to avoid the potential errors associated with estimating or extrapolating missing or hidden points (Peak Performance Technologies, 1994).

All three video films were encoded with a time code that enabled computer recognition of identical frame numbers of data for all three views during the entire data collection. A SMPTE time code signal was placed on the channel two audio track during recording. This signal was maintained at the necessary 1 volt level by using a Kramer 50A audio distribution amplifier (Kramer Electronics Ltd., Jerusaleum, Israel). The filming set up is illustrated in Figure 3.1, with the schematic of the filming configuration shown in Figure 3.2.

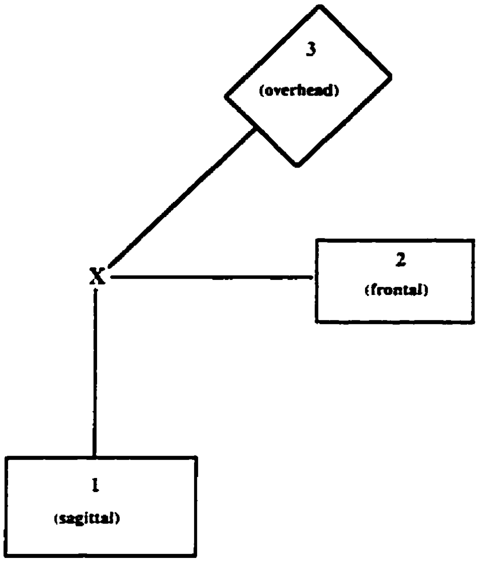


**Figure 3-1.** Camera configuration for video analysis

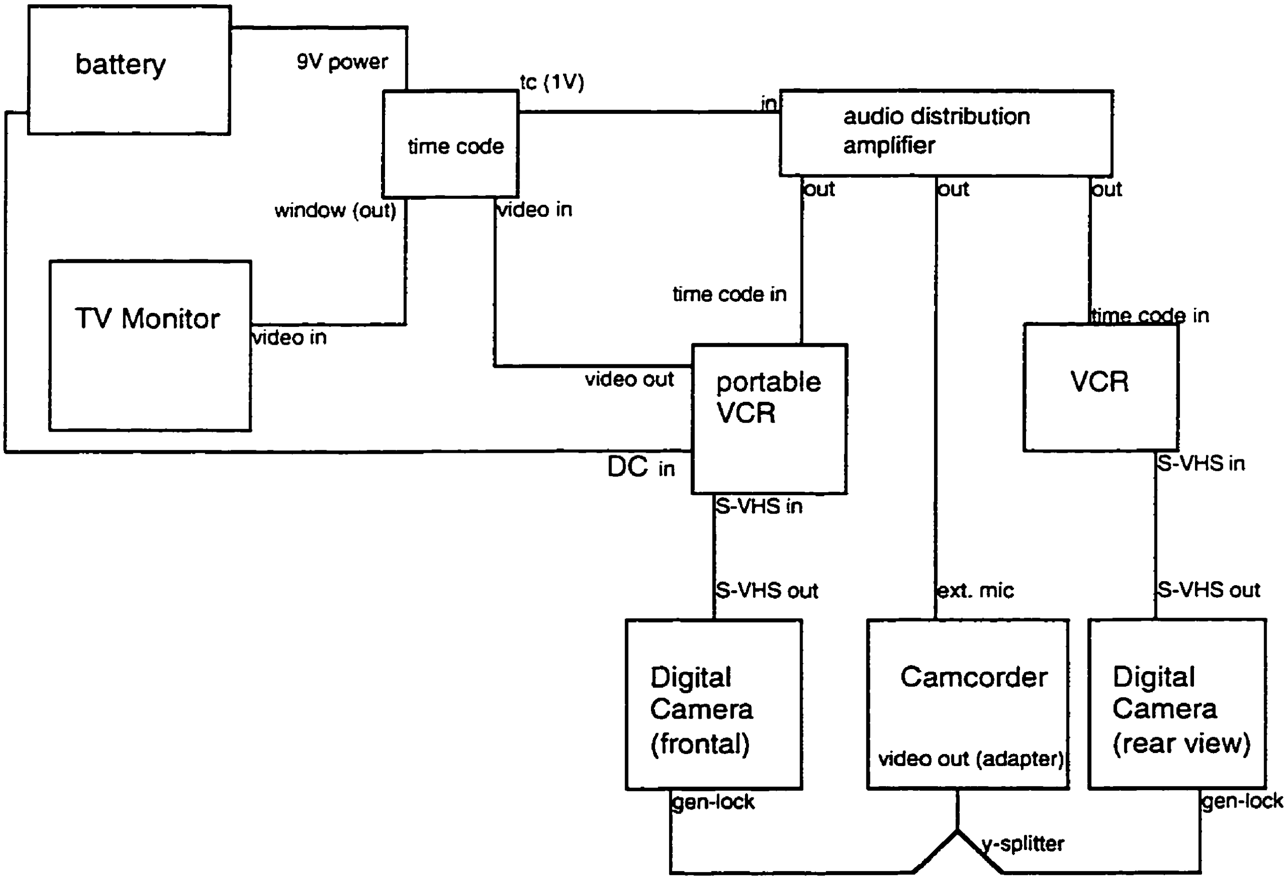


**Figure 3-2.** Schematic drawing of camera and equipment configuration

### Video filming considerations

Since all three cameras were located at different positions, the actual distance that each of the cameras view for each pixel may differ. To minimize differences, all cameras were configured to film approximately the same field of view. The field of view that was attempted to be kept consistent for all views was a 3 x 3 meter square. Given the size of each pixel on the video monitor was 512 x 512, the actual size that each pixel represents on the video was calculated. Since the horizontal and vertical measurements are the same at 3 meters, then the calculation would be:

$$300 \text{ cm} / 512 \text{ pixels}$$
$$= .586 \text{ cm/pixel.}$$

The lens of the three cameras had different aspect ratios (width to height ratio of the lens) which must be considered to give a true estimate of the actual size each pixel on the monitor represented for each view. The formula for determining the actual size that each pixel represented when considering the aspect ratio of each camera lens is shown below:

$$\text{actual cm/pixel} = \text{Calculated value} / \text{aspect ratio}$$

Using this formula, the actual cm/pixel calculation for each camera is 0.699 cm/pixel for camera 1, 0.684 cm/pixel for camera 2, and 0.688 cm/pixel for camera 3.

### Filming procedure

Once the cameras were configured as shown in Figure 3.1, four pylons were placed at the corners of the calibration frame to define the field of view of the cameras. The calibration frame was determined from the use of a calibration tree which consisted of a central block with eight metal arms attached at right angles to the corresponding arm in the next two dimensional quadrant. The calibration tree is illustrated in Figure 3.3. The arms each have three precisely situated points that have been calibrated using surveyor equipment. The calibration tree allowed the film analysis software to calculate a scaling factor in order to convert image distances seen on the film to real-life distances.

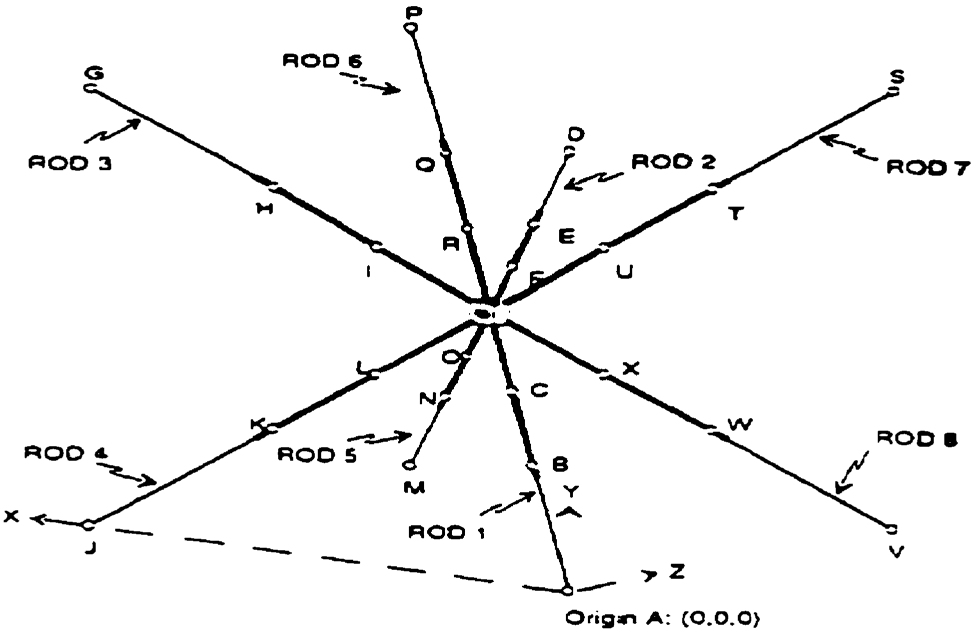


**Figure 3-3.** The calibration tree used for DLT calculations (Peak Performance Technologies, 1994, p. 5-37).

The cameras filmed the calibration frame prior to the data collection for a period of time adequate to ensure optimal data capture of the calibration frame. Once the calibration tree was captured on film, the tree was then removed for the collection of the golfing data. The calibration tree was replaced in the field of view following the filming of the golf swings to ensure that the field of view was captured by the points specified using the calibration tree.

## Test protocol

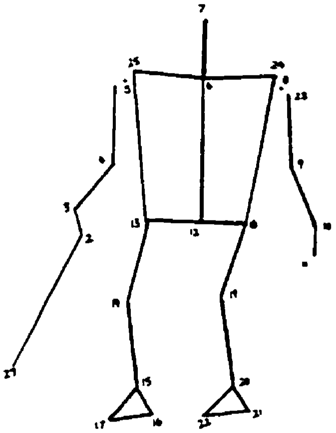
Each golfer completed six trials of the golf swing that were filmed following a general warm up. Prior to the actual six trials filmed for data collection, each golfer completed several warm up swings. All of the subjects used their own driver to complete the six filmed golf swings. The use of the driver was required in an attempt to have the golfers use a similar amount of trunk lean while executing a maximal swing. Although the amount of trunk lean was expected to be variable with all golfers, the golfers were encouraged to hit the ball with consistency, typical of their normal swing.

## Film analysis equipment

The film analysis was completed using a computerized video motion analysis system that utilized Peak5 software (version 5.2) supplied by Peak Performance Technologies (1994). The hardware of the analysis system consisted of a Sanyo GVR-S955 video cassette recorder (Sanyo, Compton, California), a Sony Trinitron PVM-1341 color video monitor (Sony Corporation, Ichinomiya, Japan), an ALR IBM compatible personal computer (ALR Technologies, California), a NEC MultiSync 2A computer monitor (NEC corporation, Tokyo, Japan), a Hewlett-Packard LaserJet series II printer and a Hewlett-Packard 7475A plotter printer (Hewlett-Packard Company, San Diego, California).

## Spatial model

A computer representation of the golfer, known as a spatial model, was used to analyse of the golfer using the Peak Performance Technologies digitizing software. The spatial model used for this study consisted of 27 points, with one reference point. The spatial model can be seen in Figure 3-4. The segmental weights and positions of the segment centers of mass in the three dimensional view for each segment were entered into the computer to calculate the golfer's center of mass. The segment values were average male values taken from Humanscale 1/2/3 (Diffrient, Tilley, & Bardagjy, 1978). The points of the spatial model were chosen to maximize the description of glenohumeral movement. These points were tested to be adequate using the pilot study.



**ANATOMICAL LANDMARKS IN THE SAGITTAL VIEW FROM ANATOMICAL POSITION**

2, 11) Head of the second proximal phalanx
3, 10) Styloid process of radius
4, 9) Center of lateral epicondyles
26, 23) A point on the humerus centered between the surface of the tricep and bicep
25, 24) Acromion process of the scapula
5, 8) Mid-point between humerus landmark and acromion process
6) Mid-point between the anterior and posterior walls of the thorax at the level of the sternal notch
7) Crown of the head
13, 18) Point 2 centimeters superior to the greater trocanter in line with ASIS
12) Mid-point between 13 and 18
14, 19) Center of the lateral condyle of the femur
15, 20) Center of lateral malleolus of the fibula
16, 21) Center of calcaneus
17, 22) Distal phalanx of great toe
27) Toe of the club

### ANATOMICAL LANDMARKS IN THE FRONTAL AND OVERHEAD VIEWS FROM ANATOMICAL POSITION

| | |
|---|---|
| 2, 11) | Head of the second proximal phalanx |
| 3, 10) | Mid-point between styloid processes of radius and ulna |
| 4, 9) | Mid-point between lateral and medial epicondyles |
| 26, 23) | A point centered between the medial and lateral edges of biceps brachii |
| 25, 24) | Acromion process of the scapula |
| 5, 8) | Mid-point between humerus landmark and acromion process |
| 6) | Sternal notch |
| 7) | Crown of the head |
| 13, 18) | Point 2 centimeters superior to the greater trocanter in line with ASIS |
| 12) | Mid-point between 13 and 18 |
| 14, 19) | Mid-point between medial and lateral condyles of femur |
| 15, 20) | Mid-point between malleoli of the tibia and fibula |
| 16, 21) | Center of calcaneus |
| 17, 22) | Distal phalanx of great toe |
| 27) | Toe of the club |

**Figure 3-4.** Spatial model points and drawing.

## Data reduction and analysis

From the six trials of each of the golfers, one trial was selected for analysis for each subject. The trial selected for analysis was smooth and balanced, representing a good swing by the golfer. The swing chosen also had to capture a frame that was near the instant of ball contact, which was successful for all subjects filmed. Whether the swing was considered a valid trial of a typical swing was decided based upon the approximate length and accuracy of the drive at the time of filming and noted for later comparison with appropriate trials that captured ball contact.

The selected trial for each golfer was manually digitized from the start of the take away to the end of the follow through. Once the trials were entered into the computer, each raw data file was smoothed using a cubic spline function to produce a conditioned data file. Smoothing the data removed artifact or unwanted signal from the raw data which left conditioned data that was more indicative of the actual movement of the golfer. The conditioned data minimized oscillations of digitized points during the golf swing that were apparent in the raw data likely resulting from digitizing error. For this study, each point in the spatial model for each trial was smoothed individually and the number of cubic spline function passes was selected through trial and error choosing the line of best fit; the number of passes ranged from 2 - 4. A greater number of passes (e.g., 4) was used for smoothing raw coordinate data that moved at a greater frequency such as the fingertips and club head, or for data points that required more estimation on location in the process of digitizing such as the hip joint and shoulder joint centers of rotation. Fewer passes were needed to smooth data that represented points moving at a lesser frequency or were clearly evident during the golf swing, such as the elbows and lower extremeties. The resulting graph of the x, y, z coordinates for all 26 points (exclusion of the reference point) of the spatial model were representative of the raw data. The number of passes was only large enough to smooth out digitizing error and to avoid removing critical movements that occurred during the golf swing.

With the original data conditioned, angular and linear measurements had minimal deviation from the actual position during the golf swing. With measurements reflecting the actual position, the first derivative of the linear displacement measurements were calculated automatically using the Peak motion analysis software to provide linear velocity values for the segments during the golf swing. Graphing the segment distal end point linear velocities for the active joints in relation to one another illustrated the proximal to distal principle utilized in striking skills.

## Calculated Variables

### Glenohumeral joint measurements

To assess the range of motion at the glenohumeral joint during the golf swing, the movements of shoulder flexion and extension, adduction and abduction, and horizontal adduction and abduction were analyzed. Shoulder flexion/extension was measured as the internal angle scribed by the humeral movement in the sagittal plane relative to the trunk. Positive values that increased in magnitude away from $0^0$ indicated flexion. Positive values that decreased in magnitude towards $0^0$ indicated extension, with zero being the midline of the trunk (Figure 3-5). Negative values indicated a hyperextended position of the humerus. Negative values that decreased towards zero also indicated the shoulder was being flexed toward the neutral position ($0^0$).

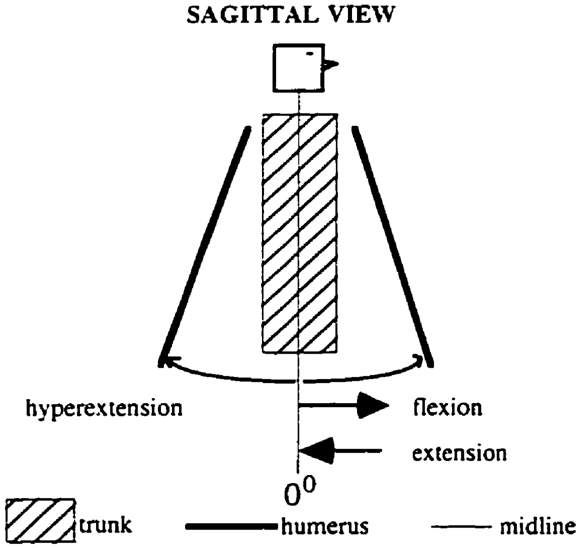


**Figure 3-5.** Shoulder flexion and extension measurement.

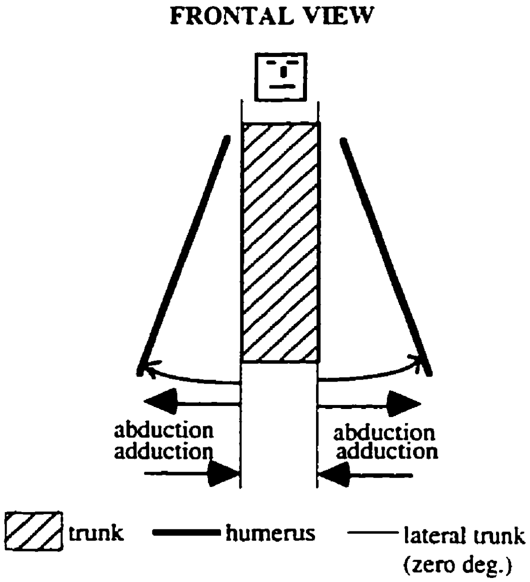


**Figure 3-6.** Shoulder adduction and abduction measurement.

Adduction and abduction were measured similar to the flexion and extension measurement, except the humeral movement was recorded in the frontal plane in relation to the trunk. Positive values that increased in magnitude away from $0^0$ indicated abduction. Positive values that decreased in magnitude towards $0^0$ indicated adduction, with zero being the lateral side of the trunk described by a segment connecting the acromion process with the hip on the same side (Figure 3-6). Negative values that increased away from $0^0$ indicated that the arm was being adducted across the body with what has been referred to as "cross-body adduction". Negative values that decreased towards $0^0$ indicated that the arm was being abducted from a cross-body adducted position.

Horizontal adduction and horizontal abduction of the left shoulder were measured as the internal angle between the left humerus and a segment connecting the left and right acromion processes (Figure 3-7). Zero degrees indicated that the humerus was horizontally adducted and in line with the shoulders medially, while $180^0$ indicated that the humerus was horizontally abducted and in line with the shoulders laterally. Joint positions indicated the humerus as horizontally adducting when the angle measurement was decreasing towards $0^0$. The humerus was moving through horizontal abduction when the angle measurement was increasing towards $180^0$.

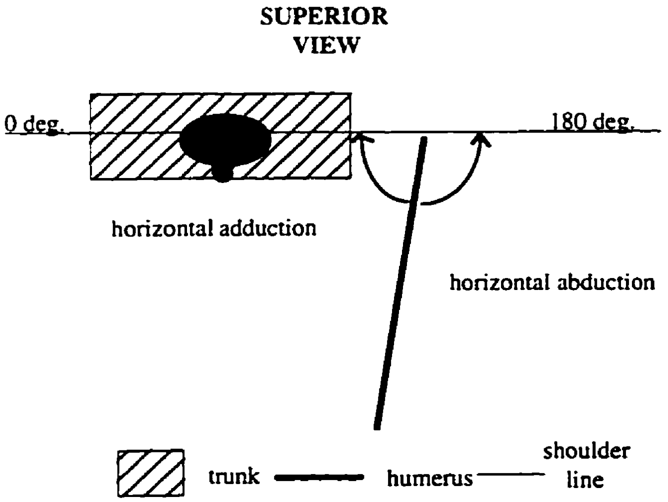


**Figure 3-7.** Shoulder horizontal adduction and horizontal abduction.

### Elbow joint measurements

Lead arm elbow range of motion was analyzed at the top of the backswing, and throughout the swing, to help determine whether any of the subjects were attempting to increase the angular displacement of the club head by flexion and extension of the lead elbow. Elbow flexion and extension were measured by taking the internal angle enclosed by the humerus and forearm, connected at the center of the elbow joint as the vertex (Figure 3-8).

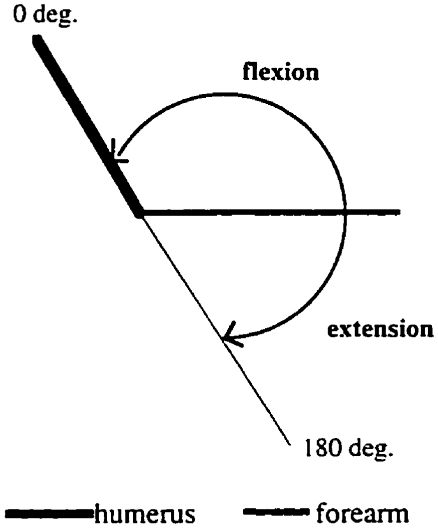


**Figure 3-8.** Elbow flexion and extension.

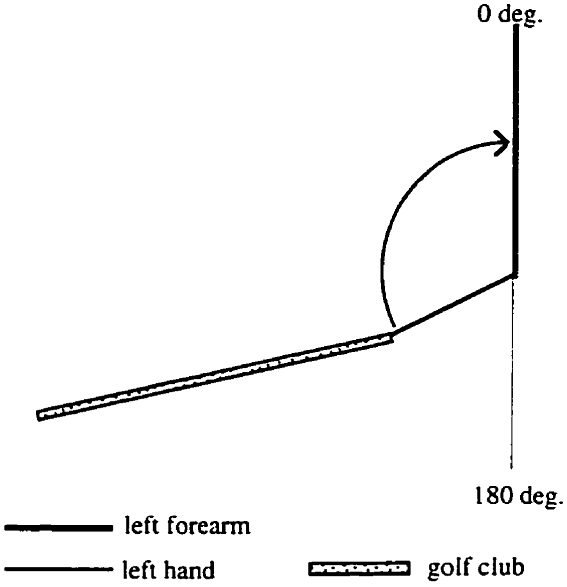


**Figure 3-9.** Wrist joint angle measurement.

### Wrist joint measurements

Range of motion of the wrist of the lead arm was also included in the analysis. The angle of the lateral side of the lead hand midline, in relation to the forearm was measured and reported as "wrist range of motion" (Figure 3-9). This motion was primarily wrist abduction (radial deviation), since the cocking action of the wrists occurred as the lead forearm pronated during the early backswing. This abduction of the lead wrist may have originated as minor wrist flexion at the start of the take away. The forearm segment was defined as the line connecting the center of the elbow joint with the center of the wrist joint. The hand segment was defined as the line connecting the center of the wrist joint with the head of the second proximal phalanx. The first derivative of the linear displacement measurements of these segment distal end points were automatically calculated from the Peak motion analysis software to provide linear velocity values for the segments during the golf swing. Graphing of the segment distal end point linear velocities in relation to one another will illustrate the sequence in the timing of joint peak linear velocities utilized in striking skills.

### Trunk and hip rotation

Determining angular displacement values of trunk and hip rotation allowed insight into the sequencing of movement during completion of the golf swing. The amount of trunk and hip rotation was measured by recording the angular displacement of a line through the shoulders, and a line through the hips as it deviated from the original position at address. The angle at address of each of the lines through the shoulders and hips was the zero line for each angle. The zero lines for the shoulders and hips were independent, indicating different angles if observed in relation to a common reference line. These zero lines are illustrated in Figure 3-10a. As the golfer began their backswing, positive angles indicated that their trunk and hips were rotating away from the ball. Once maximal trunk and hip rotation were reached, the magnitude of the angle measured decreased towards zero, with zero indicating the shoulders and hips of the golfer returned to their initial position seen at address. Any negative angle measurements recorded indicated that the shoulders and/or hips rotated beyond the initial position, in the direction of the downswing. Figure 3-10b shows how the angle measurements were measured at the top of the backswing. The range of trunk rotation was expected to be approximately twice the range of hip rotation during the golf swing.

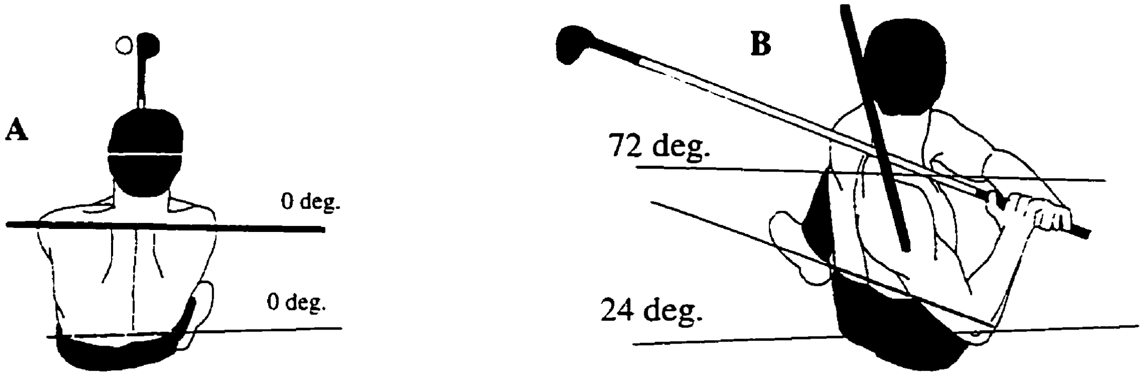


**Figure 3-10.** Hip (---) and trunk (——) rotation at **a)** the address and **b)** the top of the backswing (Plagenhoef, 1971), p. 149.

## Trunk lean

The degree of trunk lean in the sagittal plane at address was analyzed to determine if the suggestion by Mallon (1996) concerning increased trunk lean to allow more flexion at the shoulder was supported by the current study. If the arms were allowed to hang in a greater degree of shoulder flexion when the trunk lean increased, then a golfer may have been able to reduce discomfort during the golf swing by possibly reducing the amount of impingement of the supraspinatus tendon against the acromion. This current study measured trunk lean in all subjects to determine if differences existed in the amount of trunk lean used by each of the groups. The angle measured for the degree of trunk lean is shown in Figure 3-11. The angle of $134^0$ indicated the internal angle between the trunk segment and the thigh segment. Anatomical position was indicated by a $180^0$ measurement, with the internal angle decreasing as the golfer flexed their trunk. This method of determining the degree of trunk lean was employed in this study.

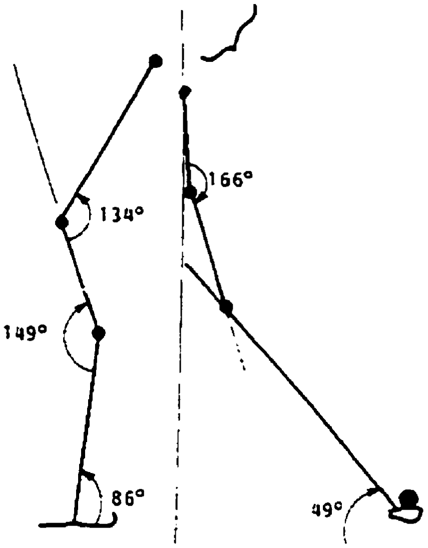


**Figure 3-11.** Sagittal view of a golfer indicating various angles including the measurement of trunk lean (Adrian & Cooper, 1995), p. 380.

### Club velocities

In addition to the range of motion data, two velocities were determined and included in the description of the kinematics of the swing. The magnitude of peak linear velocity of the club head and the instant when it occurred during the backswing and downswing was included in the analysis. The linear velocity of the club head was the resultant of the horizontal and vertical velocities analyzed, and was determined by the Peak program software. Peak linear velocity during the backswing and the point where it occurs is not a typically measured variable, however it was included as a potentially useful variable in describing the pattern of the backswing for comparison between subjects. It was possible that the linear velocity of the club head would have been greater and occur later in the backswing for individuals with the healthy rotator cuff. To help to assess whether this occurred, a ratio was calculated which determined the amount of the backswing completed when the peak linear velocity of the club head was measured in the backswing. This ratio was determined by taking the instant of peak linear velocity in the backswing and dividing it by the total duration of the backswing. The linear velocity profile of the club head was matched with the sequencing of movement of the hip rotation, trunk rotation, lead shoulder linear velocity, lead arm elbow linear velocity, and lead arm wrist linear velocity. These measurements enabled comparison of swing parameters and sequencing of each measured linear velocity value from the golfers graphically.

### Swing duration

The duration of the golf swing was included as another parameter in the kinematic description of the swing. The duration of the swing was measured from the instant of take away to a position when the club head was stationary as the backswing, from the top of the backswing to ball contact as the downswing, and from ball contact to completion of the swing as the follow-through. The time for the downswing to the point of ball contact was determined from reading the horizontal (x) coordinate from graphs generated by the Peak program software. Duration for the backswing and entire swing were determined by dividing the number of frames by sixty, which represented the data capture frequency. It was expected that downswing duration would range from .25 - .35 seconds based on previous studies (Cochran & Stobbs, 1968; Koenig et al., 1993; Milburn, 1982) and pilot data calculations. The backswing was expected to be two to three times the duration of the downswing.

### Summary of variables

The variables that were compared and measured during the swing include the following; lead shoulder flexion, lead shoulder adduction, lead shoulder horizontal adduction, lead arm elbow flexion, lead arm wrist range of motion, hip rotation, and trunk rotation, at the top of the backswing. The peak linear velocity during the backswing and downswing, and when they occur was determined. The final variable calculated was the amount of trunk lean of each golfer at address. Each of the calculated variables were averaged for each group of golfers to provide a mean with two standard error values above and below the mean. These average values were compared against each other to test the null hypothesis that there were no significant differences between non injured, RCR, and RCN golfers.

## Statistical Analysis

SPSS Base 7.5 for Windows was the statistical software used for analysis. One-way analysis of variance (ANOVA) was used to test for significance among all measured variables of the three groups. Any differences found were tested for significance using a Tukey's multiple comparison post-hoc test.

Each of the tested variables were also correlated with one another to determine if any positive or negative relationships were present between variables. A bi-variate correlation matrix was calculated for all variables, from which significant correlation coefficients were determined. Variables were correlated both with respect to individual group and as a total group of golfers. All data was screened by observing scatterplots to determine the linear characteristics of the data before discussing relationship among variables. A statistical significance level of $p < .05$ was used for both the ANOVA and the correlation between variables.

# IV. RESULTS

## Pilot study results

The results of the pilot study suggested that the camera configuration was adequate for data collection; and that the proposed variables could all be accurately determined. The results of the pilot study are reported in Table 4-1.

The mean angle of horizontal adduction measured from the pilot study data using the transparency tracing was $36.5^0$ for the non injured group, $45^0$ for the RCN group, and $50^0$ for the RCR group. These angles determined from transparency tracings compared to the values of $37^0$, $28.6^0$, and $40.9^0$ for the lead shoulder horizontal adduction angles at the top of the backswing measured by the Peak motion analysis system for the three non injured subjects in the pilot data.

Lead shoulder flexion range of motion was nearly identical for two golfers. The third golfer showed a decrease in the range of motion for shoulder flexion of the lead arm marginally greater than five degrees when compared to the other two golfers. The same golfer with the lower range of shoulder flexion also showed the least range of motion in lead shoulder adduction. There was also a difference seen between subjects 1 and 3 that were similar in shoulder flexion. Subject 2 showed the highest range of motion in lead shoulder horizontal adduction at the top of the backswing.

Subject 3 had the highest level of shoulder adduction, but showed the least range of motion in shoulder horizontal adduction. Subject 1 was approximately midway between the two measurements of horizontal adduction seen for the other golfers. Subject 3 also demonstrated the greatest amount of lead arm elbow flexion at the top of the backswing.

Subject 1 had the least amount of elbow flexion of the lead arm. Subject 3 had the least amount of wrist range of motion when measured, despite having the highest degree of elbow flexion.

Trunk and hip rotation was similar in subjects 1 and 2 producing ratios of trunk to hip rotation of 1: 0.54 and 1: 0.56, respectively. Subject 3 had a slightly greater ratio of 1: 0.63, which indicated that there was less difference between the trunk and hip rotation seen for this golfer since a ratio of 1: 1 would indicate the trunk and hip were rotating the exact same amount.

Peak linear velocity of the club head during the backswing was greatest in subject 1, who subsequently had the shortest duration of a backswing as well. Subjects 2 and 3 had comparatively similar duration in the peak linear velocity of the club head during the backswing, however subject 2 took much longer to complete his backswing.

The fastest downswing was also seen from subject 1 who had the highest peak linear velocity recorded in the downswing by a marginal amount. While subject 2 had a similar peak linear velocity as subject 1, the duration of the downswing was much longer. The values for trunk lean for subjects 1 and 2 were very similar, while subject 3 was substantially less.

**Table 4-1.** Calculated variables obtained from pilot data of the golf backswing and downswing for three normal subjects

| CALCULATED VARIABLES | VARIABLE MEASUREMENT | | |
|---|---|---|---|
| | Subject 1 | Subject 2 | Subject 3 |
| *lead shoulder flexion (deg.) | 109.4 | 104.2 | 109.3 |
| *lead shoulder adduction (deg.) | 96.2 | 93.9 | 113.3 |
| *lead shoulder horizontal adduction (deg.) | 37.0 | 28.6 | 40.9 |
| *lead arm elbow flexion (deg.) | 157.3 | 140.3 | 134.6 |
| *lead arm wrist ROM (deg.) | 123.7 | 122.0 | 129.8 |
| maximal hip rotation (deg.) | 39.1 | 37.8 | 58.7 |
| maximal trunk rotation (deg.) | 72.6 | 67.4 | 93.0 |
| peak club head linear velocity during backswing (m/s) | 13.97 | 10.65 | 10.08 |
| peak club head linear velocity during downswing (m/s) | 34.85 | 34.82 | 33.43 |
| duration of backswing (s) | .69 | 1.11 | .79 |
| duration of downswing (s) | .29 | .42 | .36 |
| trunk lean (deg.) | 142.9 | 139.5 | 125.5 |

* indicates calculated variables measured at the top of the backswing.

## Present Study

### Subjects

The RCR group averaged the oldest golfers in the study which was consistent with them also having the greatest average number of years of golf experience. The individual duration since rotator cuff repair for each of the RCR golfers is summarized below in Table 4-2. The remaining information describing all subjects in the study is provided in Table 4-3.

**Table 4-2.** Duration since surgical repair of the rotator cuff.

| RCR Subject # | #1 | #2 | #3 | #4 | #5 | #6 |
|---|---|---|---|---|---|---|
| Duration since repair (number of months) | 21 | 24 | 22 | 22 | 26 | 19 |

Table 4-3. Summary information for subjects involved in the study.

| Group | # of subjects | mean age {range} (yrs.) | Duration since repair (avg. # of months) | handicap (avg.) | Years of golf experience (avg.) |
|---|---|---|---|---|---|
| **Non injured (N)** | 10 | 45.5 {27-70} | N/A | 11.7 | 25 |
| **Rotator cuff injury repaired (RCR)** | 6 | 58 {49-66} | 22.3 | 8.7 | 39 |
| **Rotator cuff injury non-repaired (RCN)** | 4 | 40.8 {26-61} | N/A | 10.5 | 24 |

## Range of Motion Measurements

### Interpretation of graphs

The results reporting the mean and two standard errors above and below the mean are illustrated in the following pages. The standard error limits are shown by the upper and lower end bars on the vertical lines. The mean value is located on the midpoint of each set of error bars as the large point. The vertical axis indicates the variable tested for statistical difference among the three groups and includes the magnitude of the measurement. The horizontal axis indicates the group of golfers and the number of subjects within each group. The individual measurements recorded for each subject are included in Appendix IV.

### Shoulder flexion

The mean amount of lead shoulder flexion at the top of the backswing was highest for the non injured group of golfers. The amount of lead shoulder flexion for the RCR and RCN groups were more similar considering mean values, however the variability seen within the RCR group was more consistent with the variation seen within the non injured group. The variability was large in the RCN group, especially when compared to the variation seen in the non injured and RCR golfers. No significant differences were found between groups for the mean amount of lead shoulder flexion measured. The results for all groups are shown in Figure 4-1.

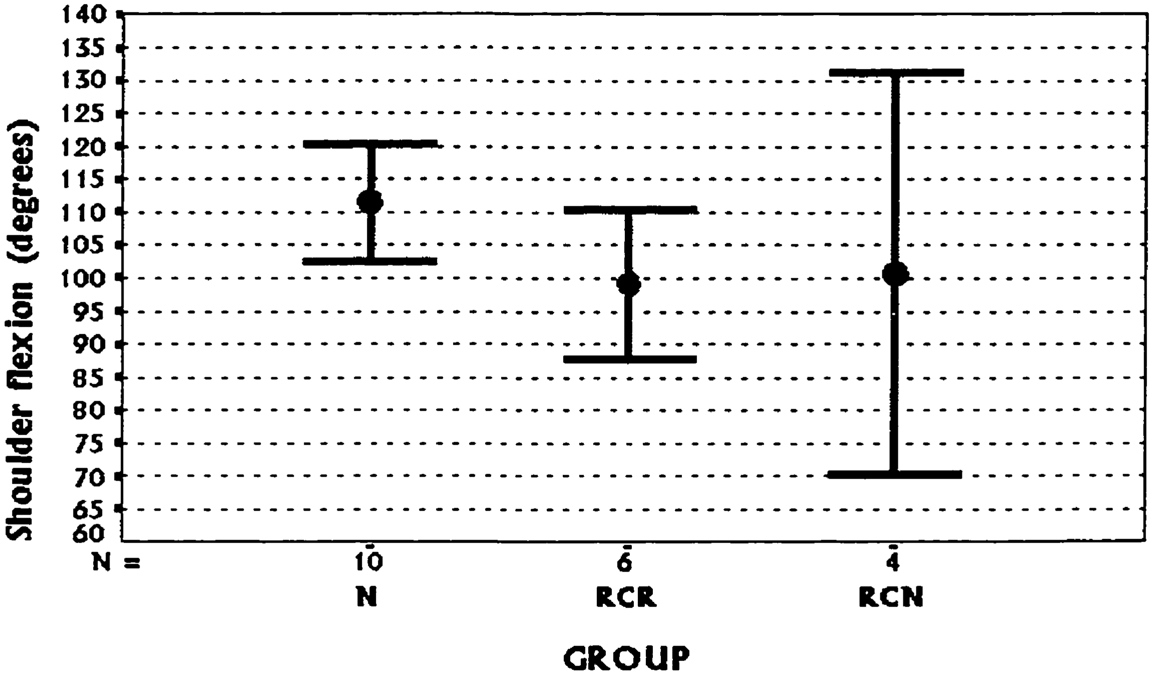


**Figure 4-1.** Lead shoulder flexion at the top of the backswing. Mean values (•) ± 2 standard error values are indicated on the graph.

## Shoulder adduction

The amount of lead shoulder adduction at the top of the backswing was greatest for the group of non injured golfers. As seen with shoulder flexion, the means for the RCR and RCN golfers were similar, with the RCR group showing a slightly greater range of motion. There was less variability seen among all three groups when compared with shoulder flexion, and no statistical differences were seen among the three groups for shoulder adduction either. The RCN golfers continued to show a large amount of variability when compared to the other two groups. The results for all groups are shown in Figure 4-2.

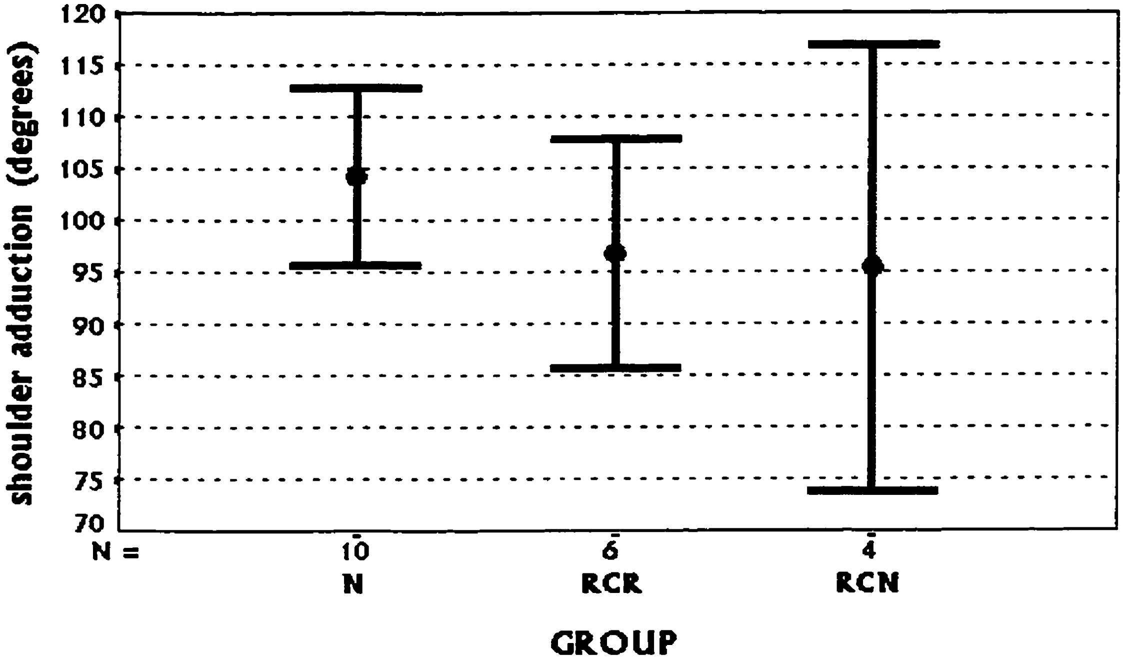


**Figure 4-2.** Lead shoulder adduction at the top of the backswing. Mean values (•) ± 2 standard error values are indicated on the graph.

### Shoulder horizontal adduction

The mean amount of lead shoulder horizontal adduction at the top of the backswing was greatest for the non injured group of golfers. With the measurement indicating the internal angle, the smaller the angle, the greater the range of motion at the top of the backswing. The least range of lead shoulder horizontal adduction was seen in the group of RCR golfers. The variability was greatest within the RCN group, with the lower SE value being below the mean of the non injured group, and the upper SE being above the upper SE value for the RCR golfers. There was a significant difference between the non injured and RCR golfers since no overlap was seen between the upper and lower SE limits of each group. This observation was confirmed with a Tukey's post-hoc test following an ANOVA which confirmed a statistical difference was found between non injured and RCR golfers (p=.03) The results for all groups are shown in Figure 4-3.

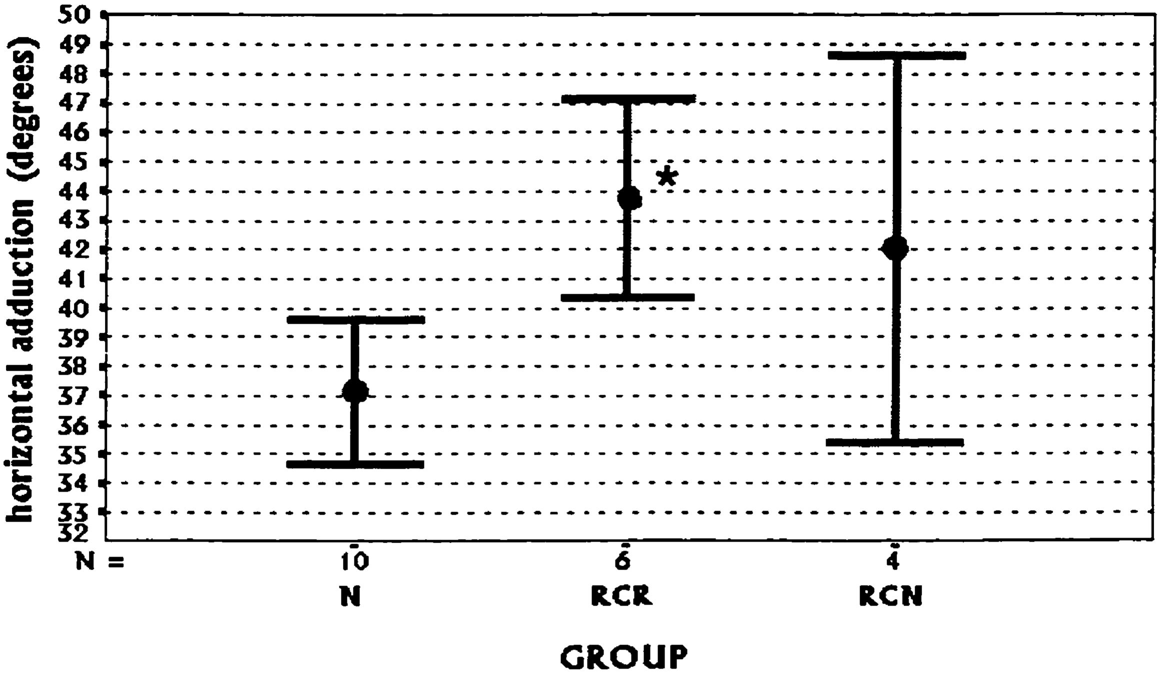


Figure 4-3. Lead shoulder horizontal adduction at the top of the backswing. Mean values (•) ± 2 standard error values are indicated on the graph. Significantly decreased range of motion seen in the RCR group when compared to N group is marked (*).

### Elbow flexion

The RCR group produced the greatest amount of lead elbow flexion at the top of the backswing. The non injured golfers were observed as having the second greatest amount of lead arm elbow, leaving the RCN group as showing the least amount of lead arm elbow flexion at the top of the backswing. Lead arm elbow flexion was the first variable measured that RCN golfers appeared to demonstrate similar amounts of variation as the other two groups, although the non injured group had the smallest level of variation out of all three groups. No significant differences were found among the three groups for lead arm elbow flexion. The results for all groups are shown in Figure 4-4.

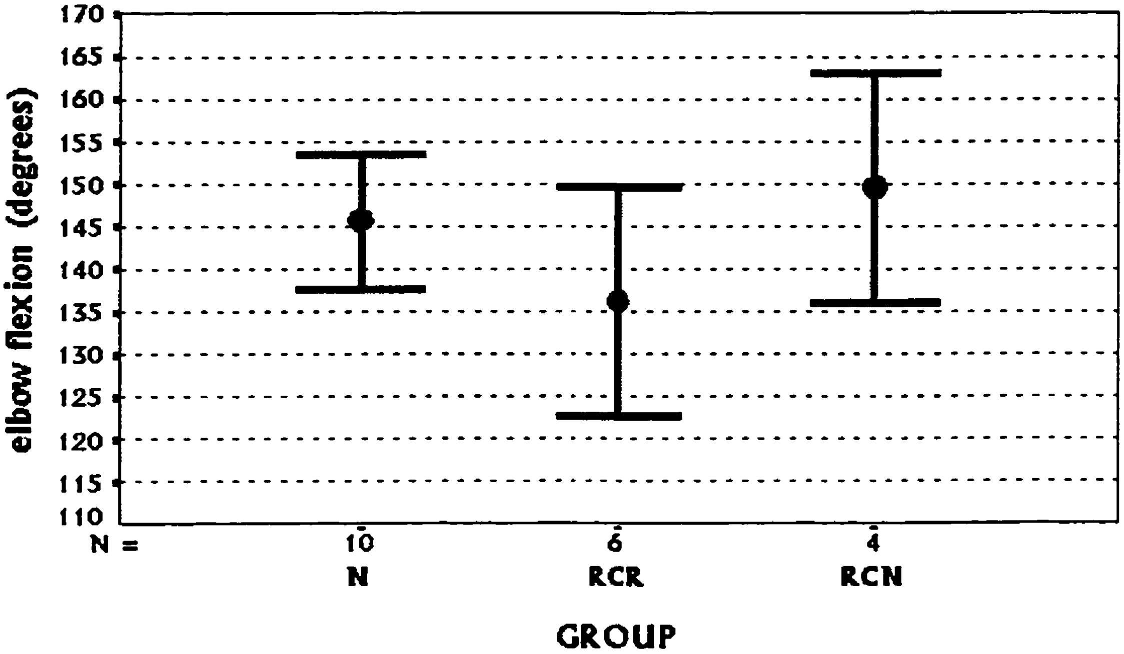


Figure 4-4. Lead arm elbow flexion at the top of the backswing. Mean values (•) ± 2 standard error values are indicated on the graph.

### Wrist range of motion

The amount of lead wrist flexion at the top of the backswing was greatest in the non injured group, followed closely by the golfers in the RCN group. The group of RCR golfers demonstrated the greatest amount of variation, and also the smallest range of motion in lead arm wrist range of motion. The values shown correspond to a combination of all movements that occur at the wrist, however a value of zero would closely approximate the position of the wrist in anatomical position. No statistical difference was found among the three groups studied. The results for all groups are shown in Figure 4-5.

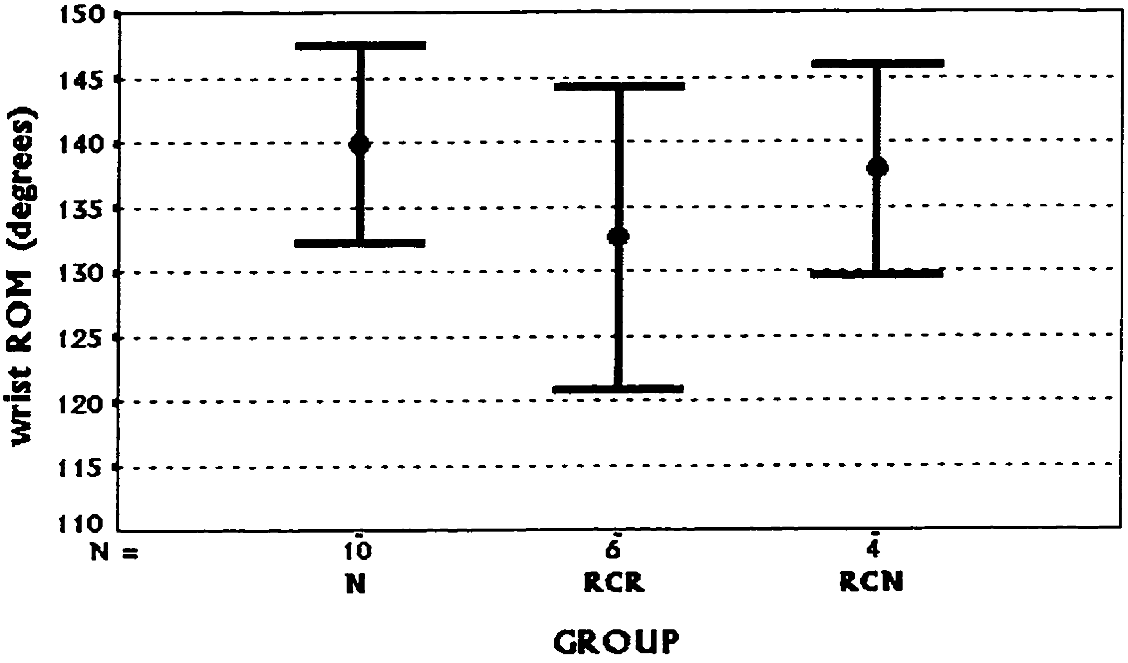


**Figure 4-5.** Lead arm wrist range of motion at the top of the backswing. Mean values (•) ± 2 standard error values are indicated on the graph.

### Hip rotation

The maximal amount of hip rotation occurring during the backswing was very similar for both non injured and RCR golfers, with the non injured golfers showing a slightly greater amount of maximal rotation measured during the backswing. The variability is close to equal for the non injured and RCR golfers as well, with the RCN golfers showing both least amount of hip rotation and the greatest variation. No significant differences were found among either of the three groups of golfers. The results for all groups are shown in Figure 4-6.

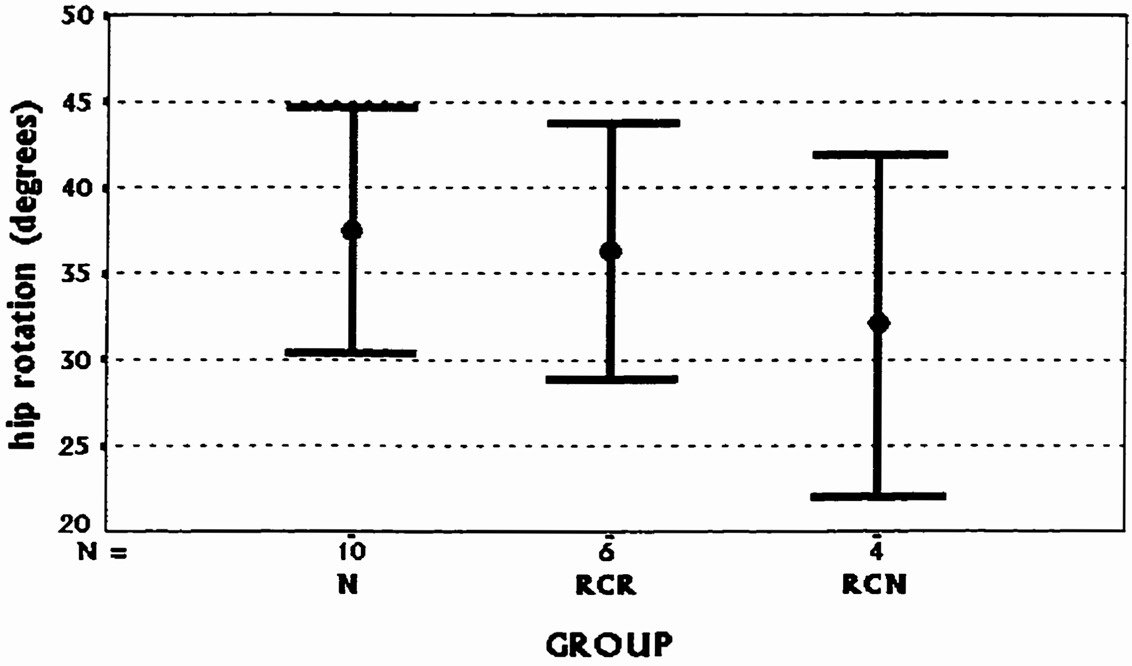


**Figure 4-6.** Maximal hip rotation during the backswing. Mean values (•) ± 2 standard error values are indicated on the graph.

## Trunk rotation

The maximal amount of trunk rotation occurring during the backswing was seen in the non injured group of golfers, however it was only .05$^0$ higher than the amount of trunk rotation seen in the RCR group of golfers. This difference was obviously negligible, especially since variation between these two groups was nearly identical as well. The RCN group measurement of trunk rotation was highly variable. The upper SE limit was very similar to that seen for the non injured and RCR golfers, however the mean and lower SE limit was considerably lower. No statistical differences were found to be significant. The results for all groups are shown in Figure 4-7.

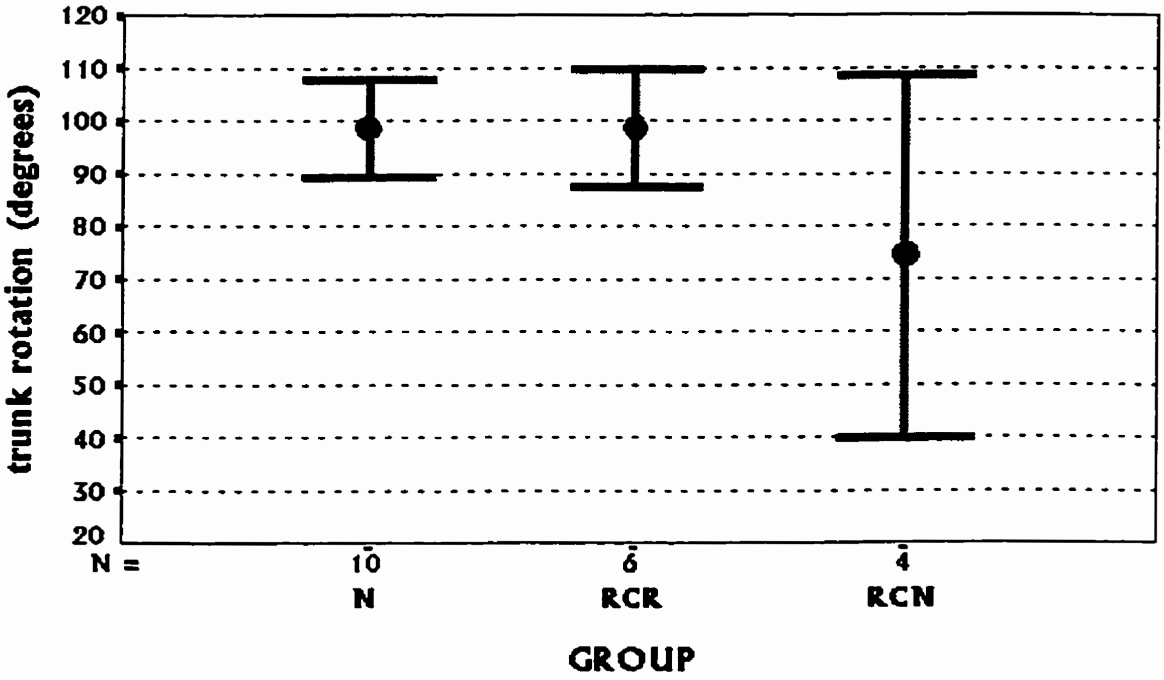


**Figure 4-7.** Maximal trunk rotation during the backswing. Mean values (•) ± 2 standard error values are indicated on the graph.

## Trunk lean

The amount of trunk lean at address to the ball was greatest in the RCN group of golfers. The RCR golfers were shown to have the next highest amount of trunk lean at address, while the non injured golfers had the most upright posture at ball address. Large variation was seen in all three groups, with the RCN golfers recording the highest amount of variation. No significant differences were found among the three groups. The results for all groups are shown in Figure 4-8.

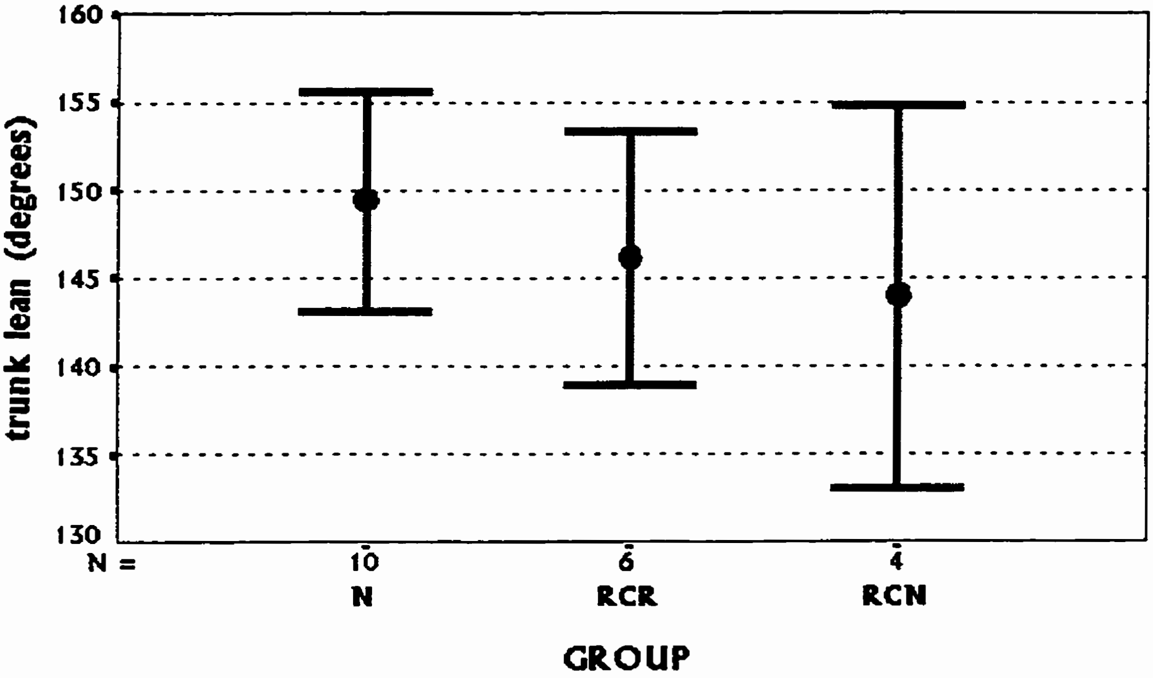


**Figure 4-8.** Trunk lean at ball address. Mean values (•) ± 2 standard error values are indicated on the graph.

## Swing and Club Velocity Measurements

### Backswing peak velocity

The peak velocity of the backswing was similar in all three groups, although the greatest peak linear velocity of the club head during the backswing was seen in the RCN group. The group of non injured golfers showed the next greatest value, while the RCR group showed the slowest velocity recorded. The ratio that described the amount of the backswing completed when peak linear velocity of the club head was reached showed that both the RCN and the RCR golfers reached the peak linear velocity of the club head during the backswing earlier in their swing than the non injured golfers. The differences seen between the three groups were not significant. The results for all the groups are shown in Figures 4-9a and 4-9b.

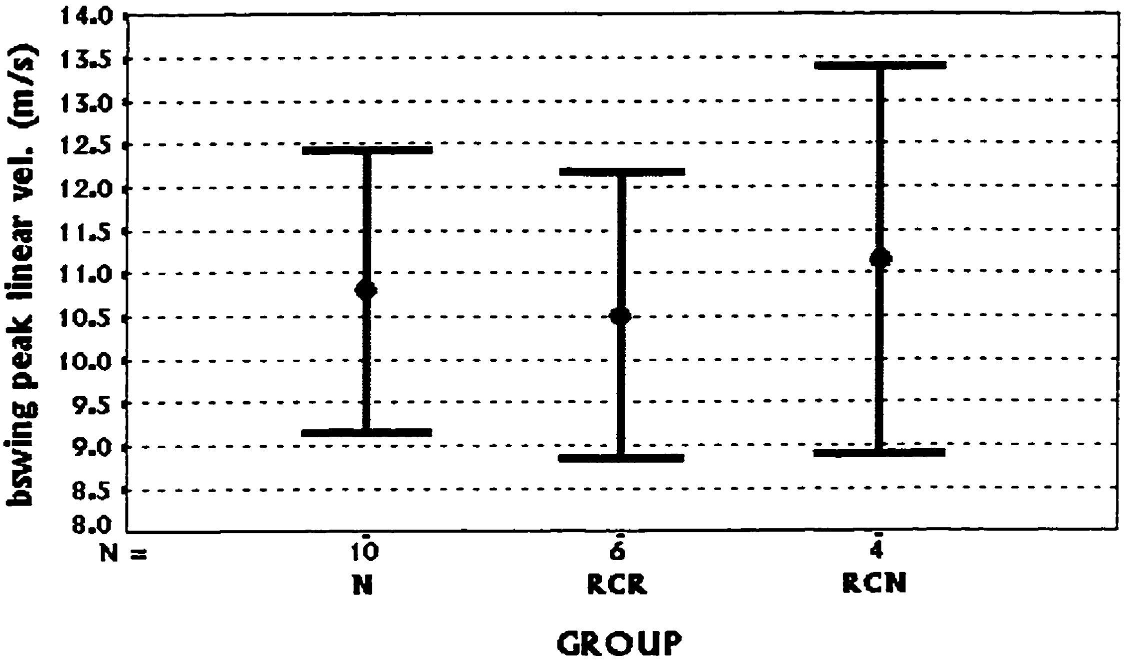


Figure 4-9a. Peak linear velocity during the backswing. Mean values (•) ± 2 standard error values are indicated on the graph.

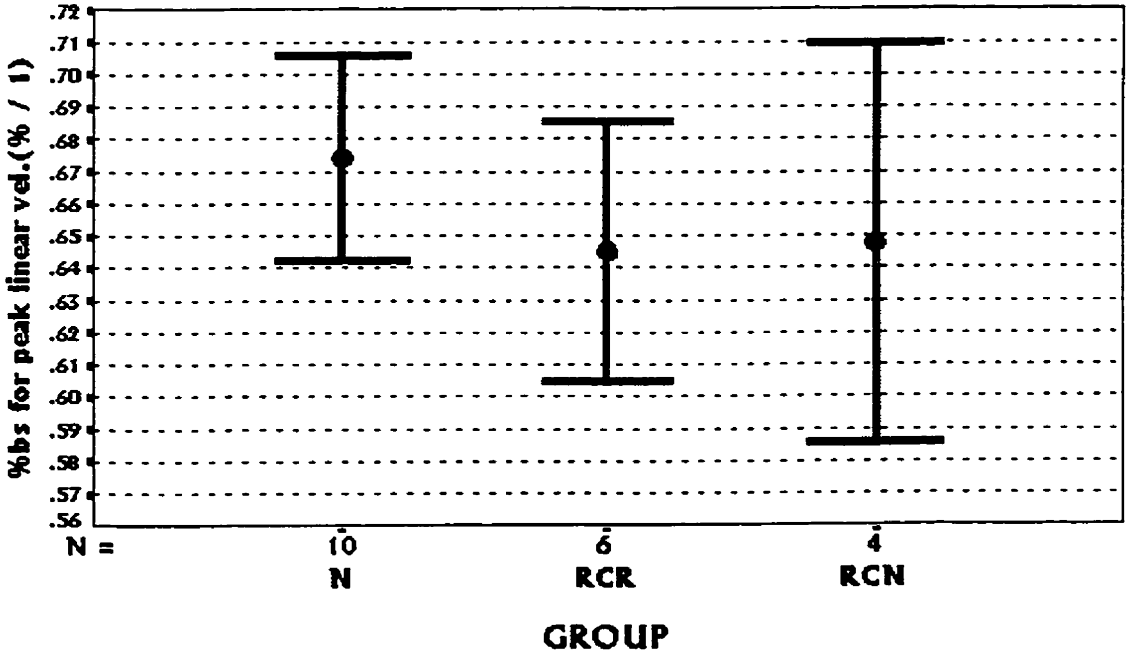


Figure 4-9b. Percentage of backswing completed when peak linear velocity occurs. Mean values (•) ± 2 standard error values are indicated on the graph.

### Downswing peak velocity

The peak linear velocity of the club head during the downswing was seen to be greatest in the RCN group, but only slightly greater than the non injured golfers. This left the RCR golfers as having the slowest peak linear velocity of the club head measured during the downswing. The means for all three groups were very similar. Despite the highest velocity recorded for the RCN golfers, the lower SE limit associated with the RCN golfers was actually well below the lower SE limits for both the non injured and the RCR groups due to substantial variation in the RCN group. The values of the means recorded for peak linear velocity of the club head during the downswing were not significantly different. The results for all groups are shown in Figure 4-10.

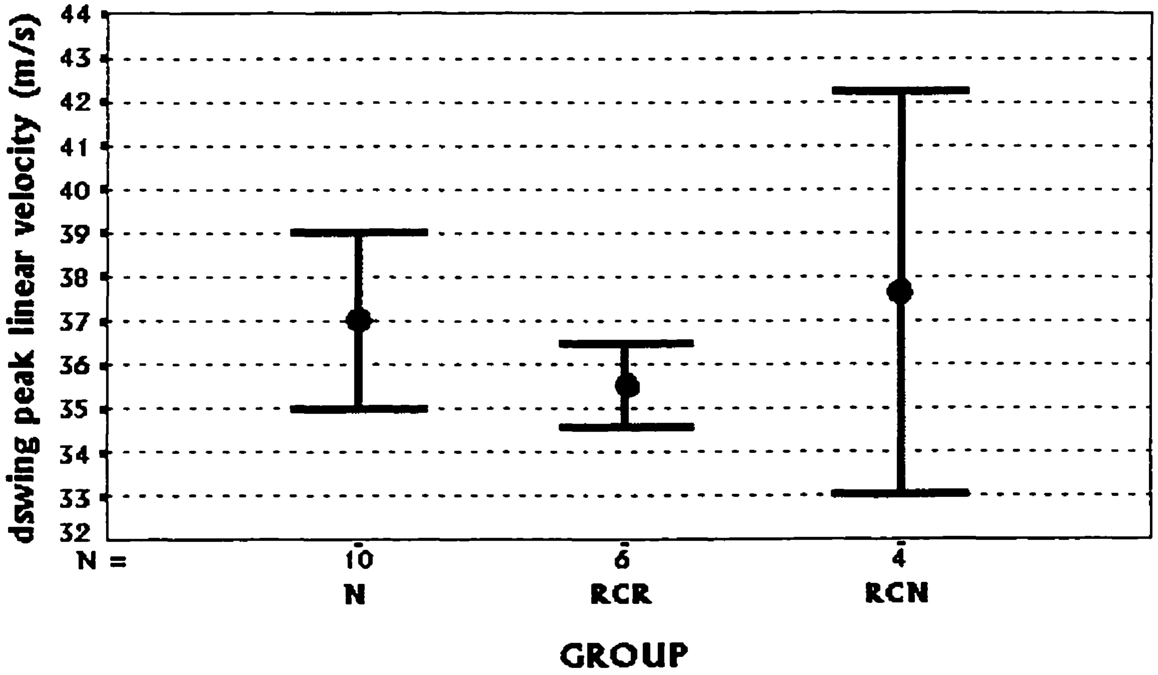


**Figure 4-10.** Peak linear velocity of the downswing. Mean values (•) ± 2 standard error values are indicated on the graph.

### Duration of the backswing

The duration of the backswing was seen to be longest in the RCR golfers, but also the most variable. The non injured golfers showed a slightly shorter duration of backswing with much less variation. The RCN golfers showed the shortest duration of backswing with a similar amount of variation as compared to the non injured golfers. The mean values of the backswing duration were not significantly different among the three groups. The results for all groups are shown in Figure 4-11.

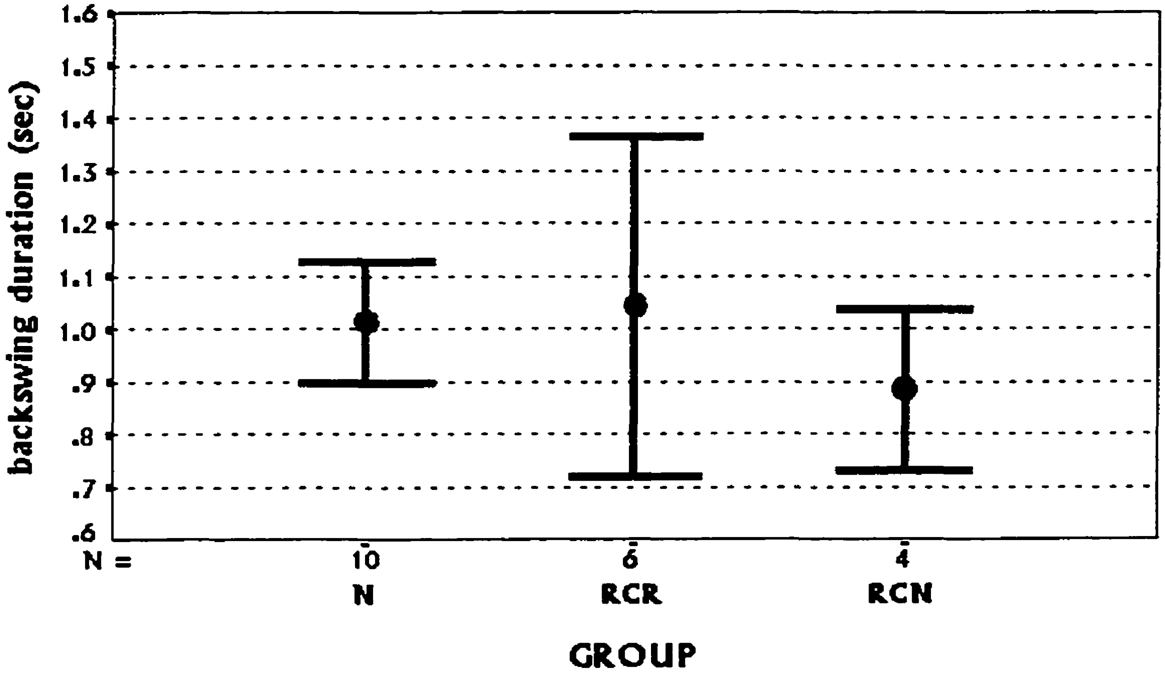


Figure 4-11. Duration of the backswing. Mean values (•) ± 2 standard error values are indicated on the graph.

### Duration of the downswing

The duration of the downswing was quite similar considering means, yet highly variable considering standard error seen for each group of golfers. The RCR golfers recorded the shortest downswing by a marginal amount, with the RCN golfers showing the next shortest, and the non injured golfers showing the longest duration from from the point of the start of the downswing to ball contact. None of the differences found among groups were found to be significant. The results for all groups are shown in Figure 4-12.

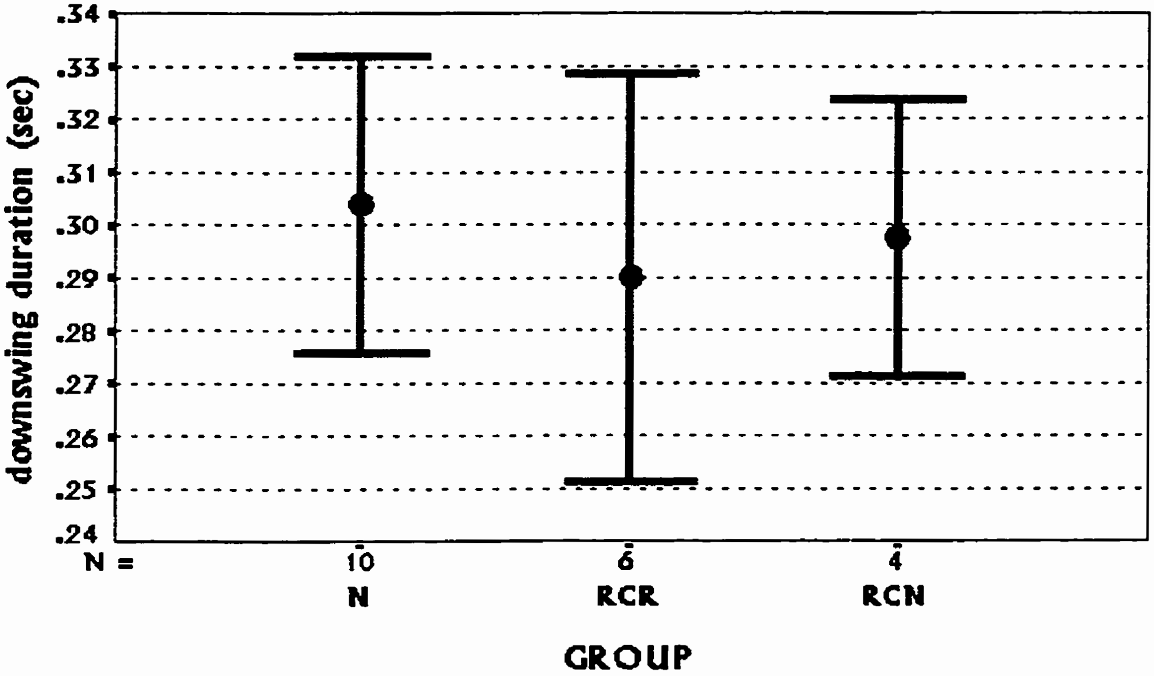


**Figure 4-12.** Duration of the downswing. Mean values (•) ± 2 standard error values are indicated on the graph.

## Duration of the full swing

The duration of the full swing was longest for the RCR group of golfers. Non injured golfers had the next longest duration of swing, but only .02 seconds shorter than the RCR group. The RCN group had a swing that lasted about two tenths of a second less than the other two groups and showed similar variation to that seen in the group of non injured golfers. The variation seen in the RCR golfers was quite large. None of the differences seen among groups was found to be significant. The results for all groups are shown in Figure 4-13.

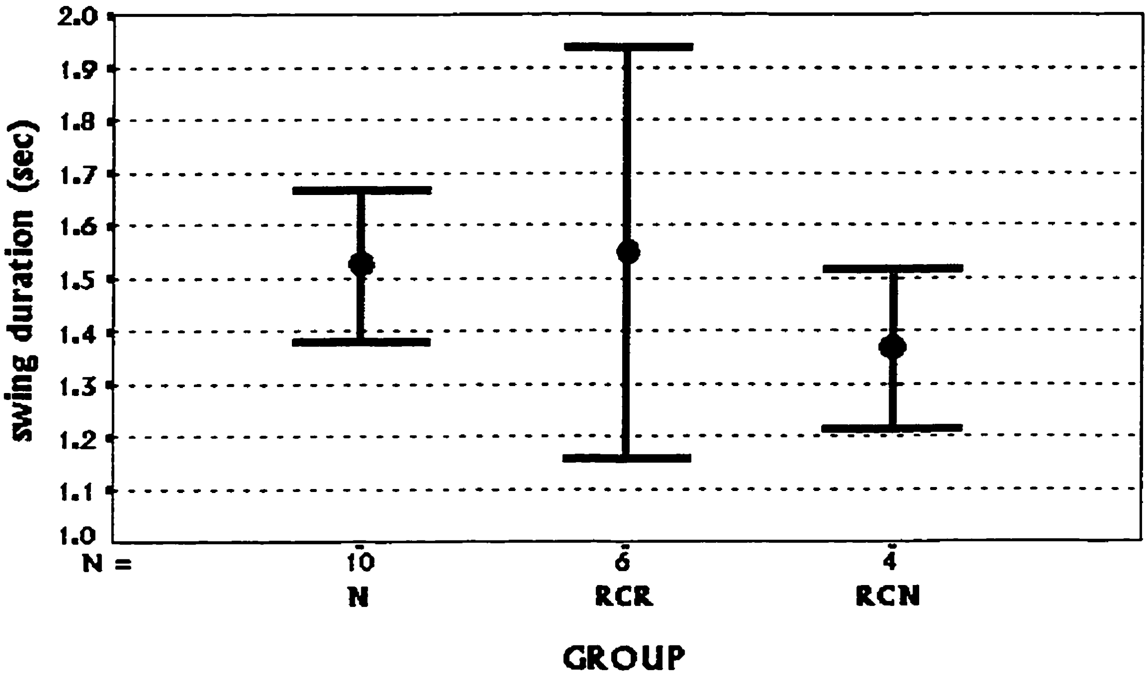


Figure 4-13. Duration of the full swing. Mean values (•) ± 2 standard error values are indicated on the graph.

## Statistical Testing

### Significant group differences

A significant difference was found for shoulder horizontal adduction in the lead shoulder at the top of the backswing. A Tukey's post-hoc test determined that the significant difference was found to be between the rotator cuff repaired and the non injured golfers (p=.03). No other significant results were found. All ANOVA results and summaries of mean and standard deviations for each variable tested among the three groups of golfers are shown in Table 4-4.

**Table 4-4.** ANOVA results for measured variables (mean and SE values included).

| VARIABLE | N (± SE) | RCR (± SE) | RCN (± SE) | F-value | p-value |
|---|---|---|---|---|---|
| handicap | 11.70 (.67) | 8.67 (1.87) | 10.50 (3.57) | .98 | .39 |
| sh flex | 111.45 (3.91) | 99.12 (4.39) | 100.68 (9.61) | 1.92 | .18 |
| sh add | 104.34 (4.26) | 96.76 (5.52) | 95.43 (10.79) | .72 | .50 |
| sh hor. adduction | $37.11^{a}$ (1.23) | $43.74^{b}$ (1.69) | 42.03 (3.32) | 4.41 | .03* |
| elbow flex | 145.59 (3.98) | 136.07 (6.72) | 149.46 (6.71) | 1.32 | .29 |
| wrist rom | 139.89 (3.87) | 132.63 (5.88) | 137.87 (4.09) | .67 | .53 |
| hip rot'n. | 37.53 (3.59) | 36.34 (3.70) | 32.00 (4.96) | .40 | .68 |
| trunk rot'n. | 98.63 (4.66) | 98.58 (5.60) | 74.36 (17.11) | 2.50 | .11 |
| trunk lean | 149.37 (3.12) | 146.10 (3.60) | 143.94 (5.42) | .51 | .61 |
| backswing peak veloc. | 10.79 (.82) | 10.51 (.83) | 11.16 (1.13) | .09 | .92 |
| bswing dur. | 1.01 (.06) | 1.04 (.16) | .89 (.08) | .48 | .62 |
| % of bswing for peak veloc. | .67 (.02) | .65 (.02) | .65 (.03) | .73 | .50 |
| dswing peak veloc. | 37.01 (1.01) | 35.53 (.47) | 37.63 (2.31) | .65 | .54 |
| dswing dur. | .30 (.01) | .29 (.02) | .30 (.02) | .20 | .82 |
| full swing dur. | 1.53 (.07) | 1.55 (.20) | 1.38 (.08) | .46 | .64 |

a,b- means with different letters are significantly different
* ($p \le .05$)

## Relationships among tested variables

Each of the tested variables were correlated with one another to determine if any positive or negative relationships were present between variables. Variables were correlated both between individual groups and between all groups. The significant correlations are shown in Tables 4-5 to 4-8.

Table 4-5. Correlation coefficients and probability values (p) for all subjects.

| | shoulder adduction | trunk rotation | downswing peak linear velocity |
|---|---|---|---|
| trunk lean | - | .46<br>(.04) | - |
| shoulder flexion | .92<br>(.00) | .70<br>(.00) | .57<br>(.01) |
| downswing peak linear velocity | .53<br>(.02) | .49<br>(.03) | 1.00<br>- |
| shoulder adduction | 1.00<br>- | .75<br>(.00) | .53<br>(.02) |

Table 4-6. Correlation coefficients and probability values (p) for N subjects.

| | downswing peak linear velocity | hip rotation | shoulder adduction |
|---|---|---|---|
| trunk rotation | .74<br>(.02) | .63<br>(.05) | - |
| shoulder flexion | - | - | .91<br>(.00) |
| elbow flexion | -.69<br>(.03) | - | - |

Table 4-7. Correlation coefficients and probability values (p) for RCR subjects.

| | shoulder flexion | shoulder adduction |
|---|---|---|
| shoulder adduction | .87<br>(.03) | 1.00<br>- |
| trunk rotation | .90<br>(.02) | .95<br>(.00) |

Table 4-8. Correlation coefficients and probability values (p) for RCN subjects.

| | shoulder adduction | shoulder flexion | downswing duration |
|---|---|---|---|
| trunk lean | 1.00<br>(.00) | .97<br>(.03) | - |
| trunk rotation | .94<br>(.06) | .92<br>(.08) | - |
| downswing peak linear velocity | - | .95<br>(.05) | - |
| shoulder flexion | .97<br>(.03) | - | - |
| shoulder horizontal adduction | - | - | .98<br>(.02) |

## Descriptive Measurements

The relationship between trunk and hip rotation during the golf swing was determined, with an example of the angular displacement of the hip and trunk rotation about a longitudinal axis through the spine shown in Figure 4-14. Maximal values of hip and trunk rotation during the backswing and point of ball contact are indicated on the graph.

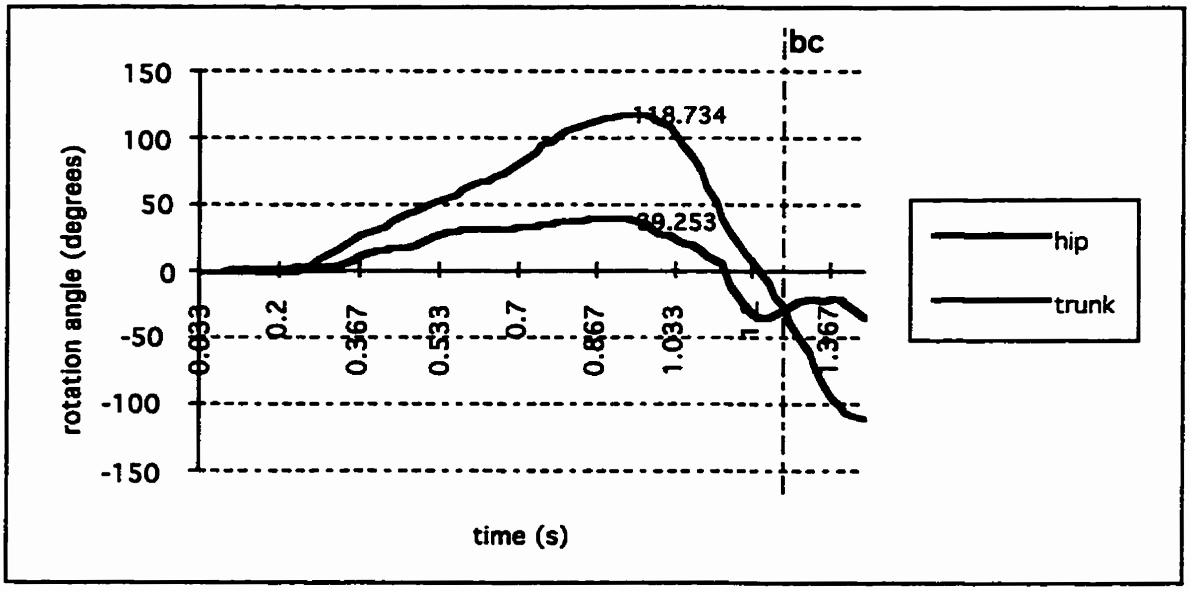


**Figure 4-14.** Hip and trunk rotation during the golf swing for RCN subject #4. The x-axis indicates the zero line of the hips and trunk at ball address. The dashed vertical line indicates ball contact (bc).

Graphs illustrating sequential rotation of body segments and the golf club were produced from the Peak motion analysis system. The series of graphs (Figures 4-15 to 4-17) illustrates the sequential pattern of rotation used to achieve higher club head velocities at ball contact. The point of ball contact was at 1.35 s into the swing with a linear velocity of the club head of 41.08 m/s for the non injured golfer (Subject #9), 1.0 s into the swing with a linear velocity of the club head of 35.35 m/s for the RCR golfer (Subject #3), and 1.08 s into the swing with a linear velocity of the club head of 40.10 m/s for the RCN golfer (Subject #3). The clubhead linear velocity curves are shown for the same three subjects in Figures 4-18 to 4-20. These graphs were not included on the actual sequence graphs due to the scale being significantly greater which would make interpreting the other four curves for hip, shoulder, elbow and wrist linear velocity nearly impossible.

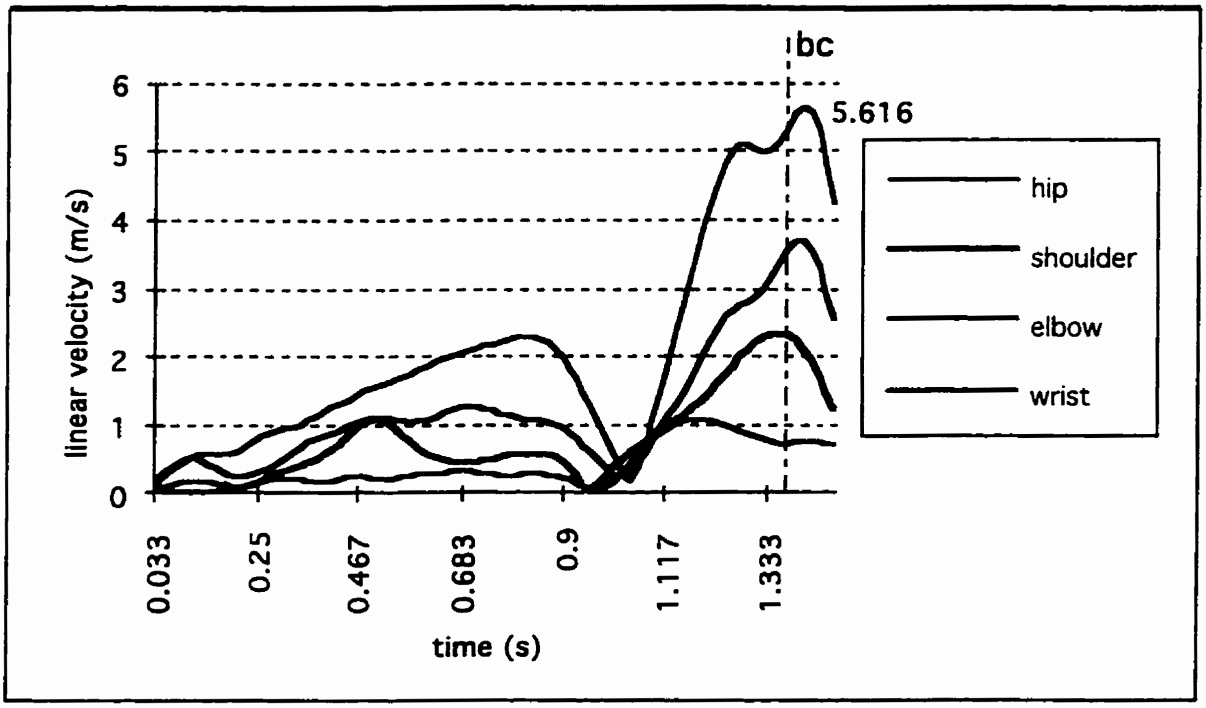


**Figure 4-15.** Linear velocity of active lead arm and hip joints for non injured subject #9. All joints refer to the left side since subject #9 was a right handed golfer. The point of ball contact (bc) is shown with the dashed vertical line.

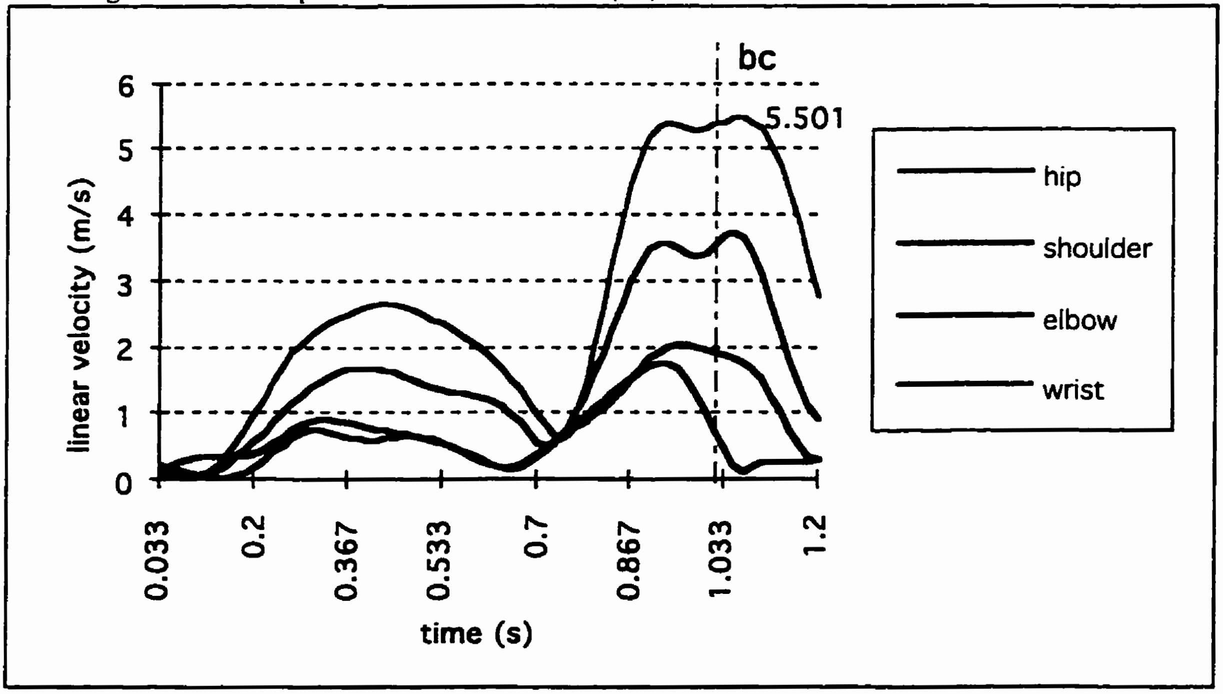


**Figure 4-16.** Linear velocity of active lead arm and hip joints for RCR subject #3. All joints refer to the left side since subject #13 was right handed. The dashed vertical line indicates point of ball contact (bc).

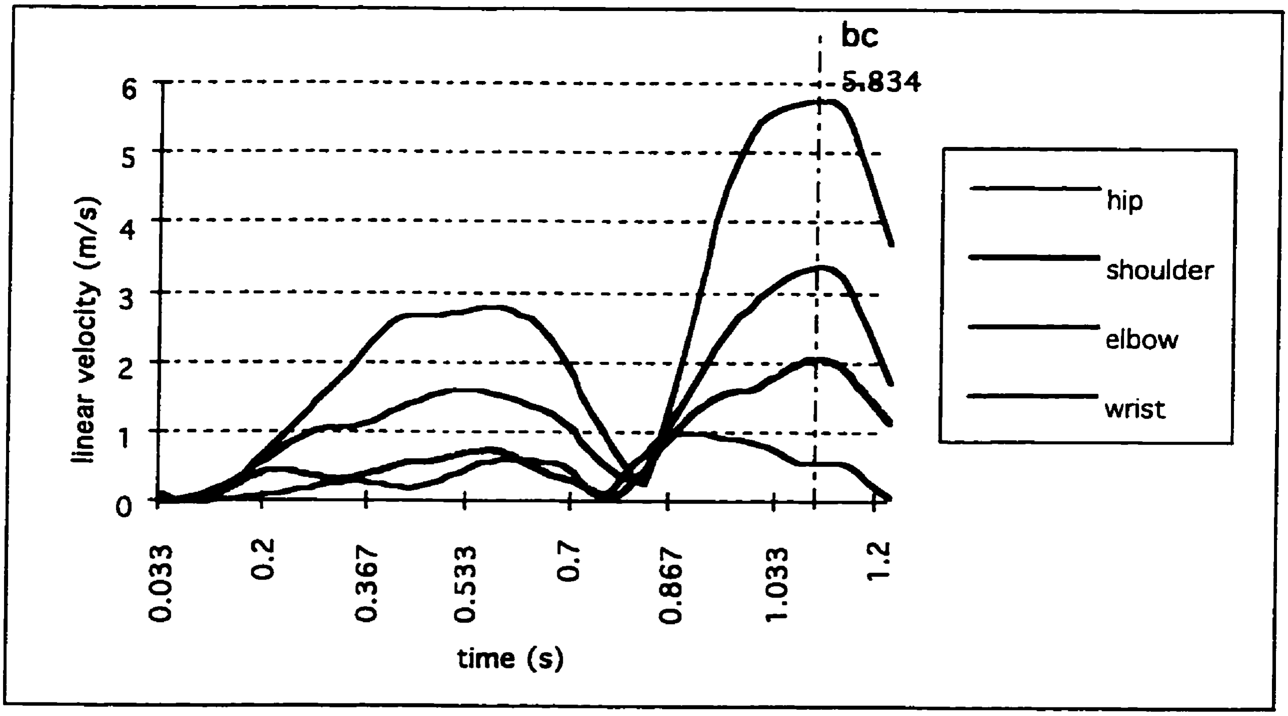


**Figure 4-17.** Linear velocity of active lead arm and hip joints for RCN subject #3. All joints refer to the left side since subject #3 was right handed. The dashed vertical line indicates the point of ball contact (bc).

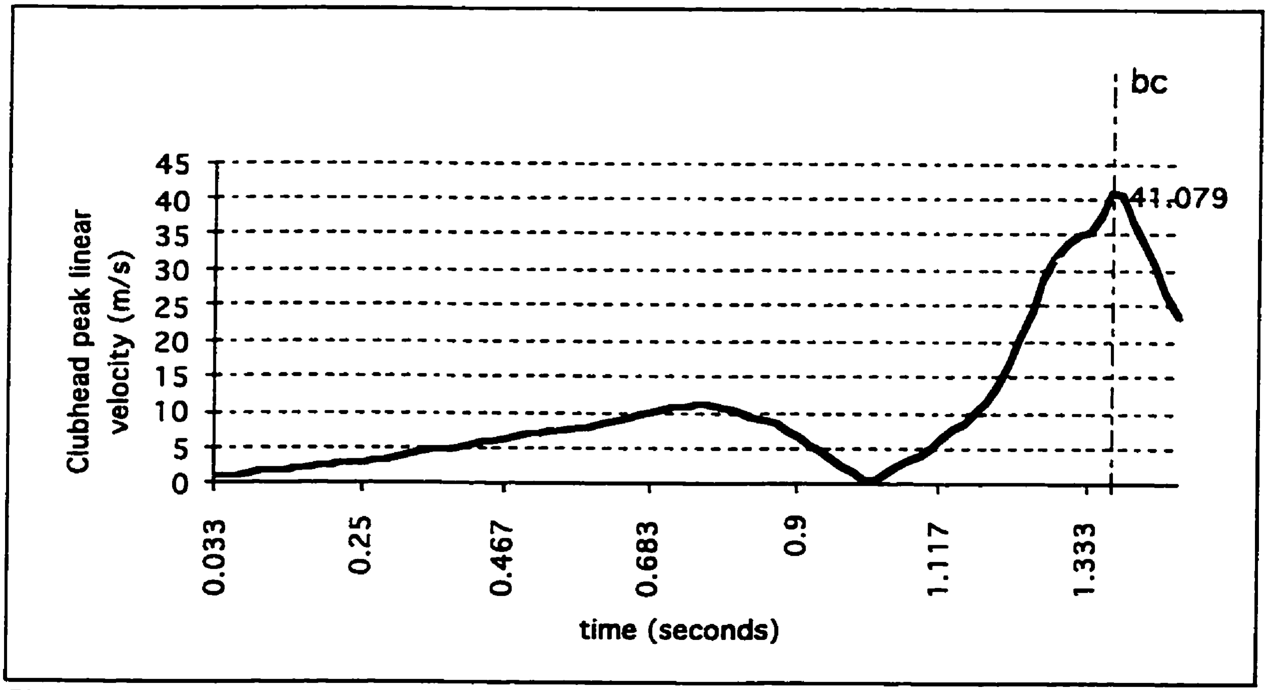


**Figure 4-18.** Linear velocity of the clubhead for non injured subject #9. The dashed vertical line indicates the point of ball contact (bc).

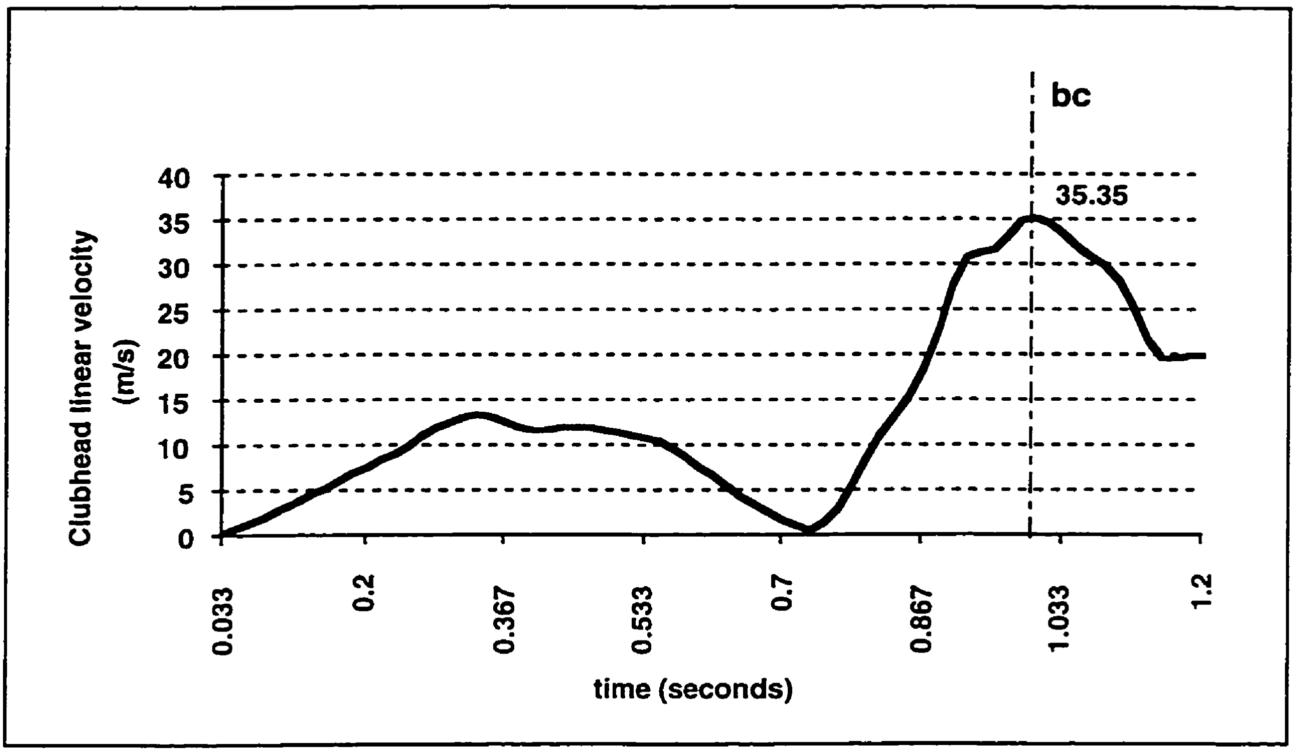


**Figure 4-19.** Linear velocity of the clubhead for RCR subject #3. The dashed vertical line indicates the point of ball contact (bc).

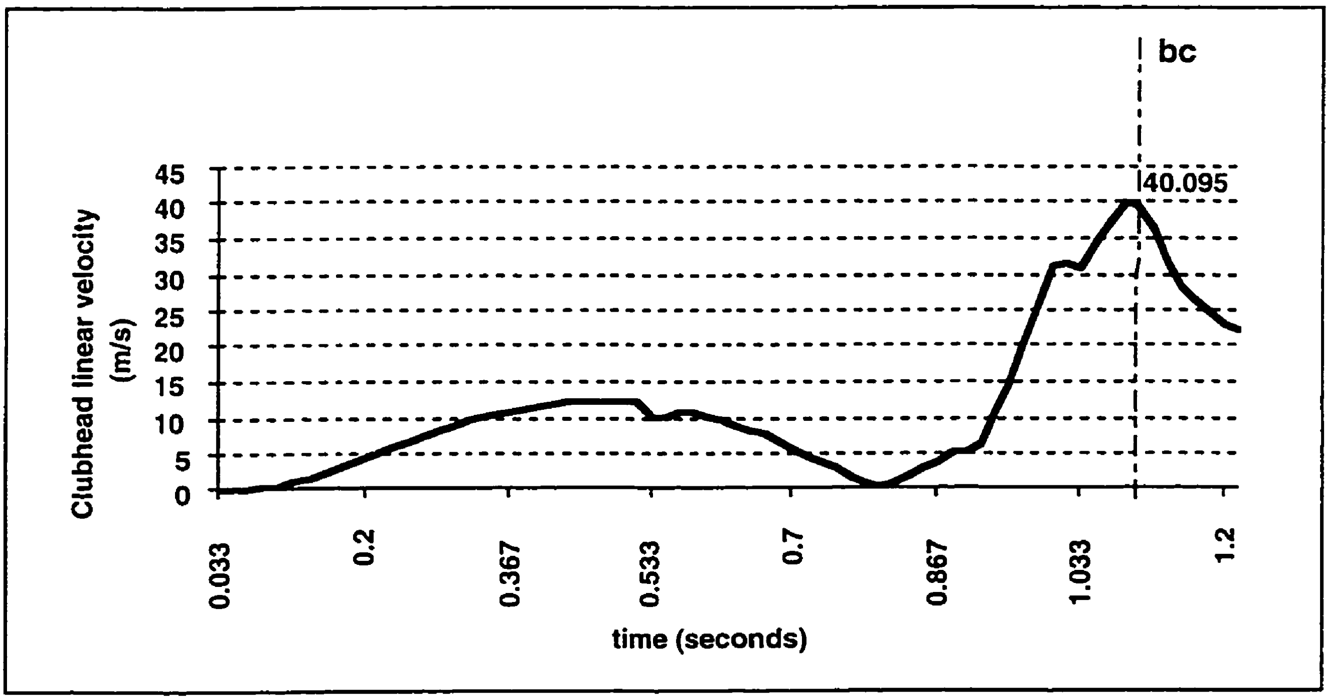


**Figure 4-20.** Linear velocity of the clubhead for RCN subject #3. The dashed vertical line indicates the point of ball contact (bc).

# V. DISCUSSION

## Pilot study

Examination at the data collected from the pilot study indicated values for calculated variables were comparable to those found in the literature. This suggested that the methods chosen to collect data for each of the variables were valid and reliable. The variables presented that were comparable to existing literature were the angles found for horizontal adduction. The values of $37^0$, $28.6^0$ and $40.9^0$ compared favorably with the $38^0$ measurement presented by Mallon (1996). The values found for left elbow flexion were not indicative of "slight elbow flexion" as was typically reported. With $180^0$ indicating a straight arm, these three subjects were demonstrating a range of 22.7 - $45.4^0$ from full extension. It was expected that elbow flexion would show a greater variability with all golfers studied due to variation in technique and differing levels of range of motion in the shoulder, possibly due to a painful or dysfunctional rotator cuff.

The values reported for trunk to hip rotation produce a ratio from 1: 0.5 - 0.63 for all three subjects, which is between estimates given by Hay (1985) of 1: 0.5, and 1: 0.7, given by Adrian & Cooper (1995).

The amount of trunk lean recorded for all three subjects is comparable with values found by Adrian & Cooper (1995). At this point in observing the pilot data, no obvious effect on the golf swing from the varying amount of trunk lean was evident amongst the three subjects. The increased amount of trunk lean seen in subject 3 may have been evident in their golf swing as a flatter swing since the shoulders must be flexed more to maintain a distance from the ball that allows contact of the club head with the ball. While this may have been the case, the amount of shoulder flexion did not confirm this potential relationship when the position at the top of the backswing was observed. A golfer with a large amount of trunk lean would be seen at address as possibly being too far away from the ball. This may be the situation demonstrated by subject 3 in this pilot study, however distance from the ball at address was not measured.

Finally, it would be assumed that while subject 2 had a greater peak linear velocity of the club head during the backswing, subject 3 must have had a greater average linear velocity allowing them to complete the backswing in less time than subject 2, although subject 2 may have completed the backswing with less angular displacement of the club; seen as a shorter backswing. Concerning the difference in downswing duration for the first two subjects, once again, explanation would likely be found in comparison of the average linear velocity for the downswing of both golfers.

### Present study

Since one primary purpose of the study was to develop a filming configuration enabling acquisition of three dimensional coordinates of the glenohumeral joint during the golf swing, shoulder range of motion values will be the focus of the discussion. The results indicated there was success in capturing all 27 spatial model points in at least two of the three camera views for all golfers at all times. The three-dimensional representation of each golfer enabled the output of linear and angular kinematic values which appeared to accurately describe the movements occurring.

### Range of motion differences

The seven range of motion variables measured produced only one significant difference among the three groups studied. Lead shoulder horizontal adduction range of motion (Figure 4-3) was significantly less in rotator cuff injury-repaired golfers compared to non injured golfers. The horizontal adduction angles at the top of the backswing reported for N, RCR, and RCN groups of $37.11^{0}$, $43.74^{0}$, and $42.03^{0}$, respectively compare favorably with the value of $38^{0}$ reported by Mallon (1996). The values reported represent an increasing range of motion as the angle decreases.

Examination of the individual golfers that comprised the RCR group indicated that three of the six golfers had horizontal adduction values above the mean for the group. One of these three golfers also had the least time transpired since their surgical repair (<18 months). Another golfer had one of the longest durations since repair (24 months), however he was scheduled to receive additional surgery to treat recurring pain in his lead shoulder. The third subject, who recorded the least range of motion, had had a previous repair to the same rotator cuff twelve years prior. This previous surgical repair used a far more invasive technique. This subject had likely adapted his swing over years of golfing with a tight rotator cuff leading to decreased range of motion in the lead shoulder. The significant p-value of .03 would suggest that despite low numbers of subjects, the possibility of a type I error is low.

This measurement of horizontal adduction/abduction may have described angles inaccurately since one shoulder can move independently of the other with scapular movement. However, scapular motion was not included in the analysis due to the difficulties associated with detecting the subcutaneous movement of the scapula. The exclusion of scapular movement did not affect the inter-subject comparison of angles since the method of analysis remained constant for all subjects. In addition, the values reported compared favorably with available literature.

Figure 5-1 illustrates the reduction in lead shoulder horizontal adduction at the top of the backswing in RCR subject #5. When compared to RCN and non injured golfers at the same position at the top of the backswing, the decreased range of motion of the RCR subject is evident. The particular subject shown below was a left handed golfer demonstrating a reduced range of motion in the right shoulder since it was his lead shoulder. This RCR subject was substantially older than the other two subjects in Figures 5-2 and 5-3 however, and there is evidence that flexibilty decreases with age (Jobe & Pink, 1996; Morehouse, 1990). Further contributing to the decrease in range of motion is the evidence that suggests a decrease in shoulder mobility associated with prolonged injury to the rotator cuff (Rathbun & MacNab, 1970).

**Figure 5-1.** RCR subject #5 at the top of the backswing

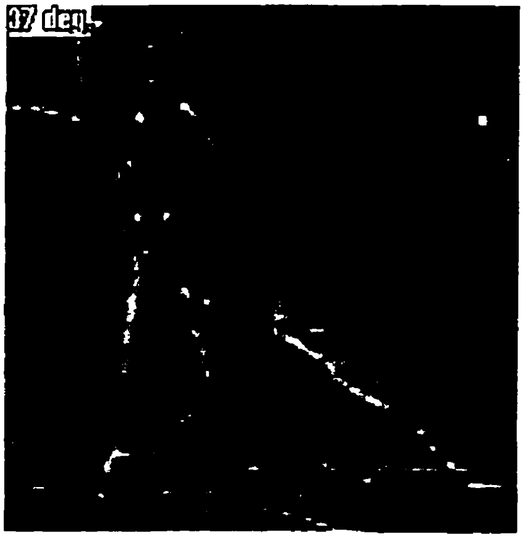


**Figure 5-2.** Non injured subject #9 at the top of the backswing

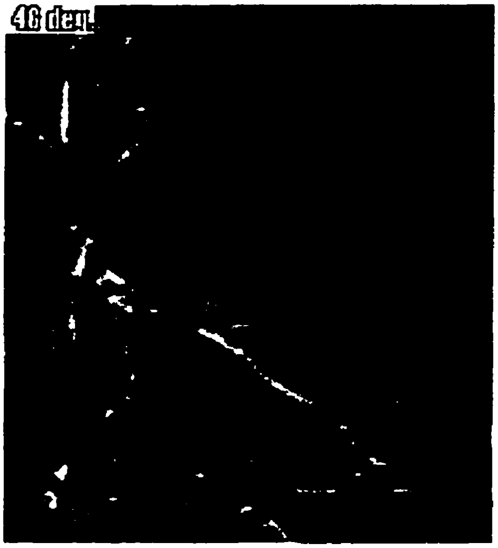


**Figure 5-3.** RCN subject #4 at the top of the backswing

Other range of motion values not found to be significantly different, but of interest were shoulder flexion and trunk rotation. Shoulder flexion values were lower than the 30° value reported by Mallon (1996). The 30° angle was measuring shoulder flexion that occurred above the horizontal plane of the shoulders, therefore 30° would be equal to 120° of shoulder flexion when measured the same as in the current study. The shoulder flexion values determined from this study of 111.45°, 99.12°, and 100.68°, for N, RCR, and RCN golfers equate to 21.45° for N golfers, 9.12° for RCR golfers, and 10.68° for RCN golfers. Mallon (1996) used professional golfers in determining the angle of 30° which does fall within the greater range of motion seen among non injured golfers. Once again, the RCR group of golfers attained the least range of motion in shoulder mobility when shoulder flexion was studied. The difference was not significant however.

Trunk rotation (Figure 4-7) was much lower in the RCN golfers than compared to both the other two groups and with existing values in the literature. The value found of 74.36° was much less than the 98.63° and the $98.58^0$ found for both N and RCR golfers, respectively. The N and RCR values compare favorably with values reported of $87^0$ (McTeigue et al., 1994) and $90^0$ (Hay, 1985). The lower RCN value may not actually be related to less trunk rotation however, due to a large variance among a small number of subjects within the RCN group. The reduced range of trunk rotation seen in the RCN golfers was not representative of the entire group, but rather of two subjects in the RCN group that demonstrated poor technique in the amount of trunk rotation that they utilized in their swing.

Lead shoulder adduction (Figure 4-2) did not produce any significant differences, which was notable considering the high correlation between shoulder adduction and shoulder flexion for all three groups studied. The non injured golfers did have a greater difference in range of motion values of shoulder adduction as compared to shoulder flexion when compared with the RCR and RCN golfers. This greater difference reduced the variation between the non injured golfers and the other two groups thereby reducing the likelihood of significant differences occurring.

Elbow flexion of the lead arm (Figure 4-4) and the range of motion measured at the wrist joint of the lead arm (Figure 4-5) produced no values that approached significance. The contribution these measurements made was to describe some quantitative values for the elbow and wrist during the swing. Also, linear displacement data for the lead elbow and wrist provided kinematic values to describe segmental movement patterns during the downswing.

Trunk lean measurements (Figure 4-8) averaged slightly greater than the values reported by Adrian et al. (1995) of $134^0$, although the lower range of measurements seen in all three groups would be much closer. The values reported by Adrian et al. (1995) did not indicate whether the values were derived based on an average of several golfers, or from which level of golfer they were calculated. Trunk lean at address indicated no significant differences between groups, however the trend that the values reported would support previous claims by Mallon (1996) that suggested increasing the trunk lean may increase the steepness of the plane that the humerus travels in to alleviate shoulder discomfort in some individuals. Non injured golfers showed the least amount of trunk lean at address, while RCR and RCN golfers each showed a higher degree of trunk lean, with the RCN golfers exhibiting the greatest. This would potentially support the notion that the RCN golfers experience the most acute pain associated with the injured rotator cuff and may alter the way they address the ball to attempt to reduce the pain associated with the position at the top of the backswing.

If altering the angle of the trunk lean causes a changing in the position of the humerus throughout the swing, then differences in trunk lean would alter the angle of pull of the rotator cuff muscles during the golf swing. Increasing the amount of shoulder flexion may promote more assistance from larger muscles, such as the clavicular head of pectoralis major, to help adduct and horizontally adduct the humurus during the backswing (Basmajian, 1985; Tortora, 1995). Any modification of the angle of pull of the rotator cuff muscles would be likely to provide mimimal relief since the end position will still impinge the affected supraspinatus tendon if the golfer completes a full backswing to the end range of motion. The most effective way to alleviate the pain associated with an injured rotator cuff at the top of the backswing is to limit the range of motion in the backswing. The reduction in the range of motion of the backswing is less likely to cause painful impingement of the aflicted supraspinatus tendon against the inferior surface of the coracoacromial arch.

Internal and external rotation of the humerus during the golf swing would have been valuable in comparison between groups. The limitations of the increased field of view on gathering range of motion measurements for humeral internal and external rotation was likely to cause an incomplete description of glenohumeral movement during the golf swing. Future research examining rotator cuff function in the golf swing should utilize a filming configuration and spatial model that allows collection of accurate coordinate data that can be used to describe internal and external rotation of the humerus. The impingement that causes pain at the top of the backswing is most likely exacerbated by the pressure of the greater tuberosity of the humeral head as it internally rotates in the lead shoulder at the top of the backswing.

### Relationships among range of motion values

The Tables of correlation coefficients (Tables 4-5 to 4-9) suggest interesting associations among the variables studied. The most consistent and strongest relationship appears to be between shoulder flexion and shoulder adduction during the backswing, which was highly correlated in all three groups and among all the golfers grouped together. This relationship is not surprising since the golf swing approximates a swing plane that is at an angle requiring near equal adduction for the same degree of flexion of the lead shoulder. Since the movement of the left arm during the backswing occurs in a plane that is approximately $45^0$, then equal shoulder flexion angular displacement should occur for similar amounts of shoulder adduction angular displacement. While the end position of the humerus could reach the top of the backswing travelling in a path that was different from the $45^0$ angle described, it is not evident during observation of the golf swing. If a plane was not relatively symmetrical for both shoulder flexion and shoulder adduction of the lead shoulder, the result would be an uncoordinated and jerky movement which would not be characteristic of a skilled golf swing.

Trunk rotation was highly correlated with both shoulder adduction (r=.75, p=.00), and shoulder flexion (r=.70, p=.00) when all subjects were grouped together. The non injured golfers did not demonstrate either of these relationships, although the RCR golfers supported both relationships. Possible reasoning why RCR golfers demonstrate this relationship between trunk rotation and shoulder flexion and adduction is discussed below. With the RCR golfers, the trunk rotation and shoulder adduction showed a very high correlation (r=.95, p=.00) while trunk rotation and shoulder flexion showed a lower correlation (r=.90, p=.02). RCN golfers showed a trend in supporting the relationship between both shoulder flexion and shoulder adduction with trunk rotation, however the small number of subjects required very high correlation coefficients to produce significance.

The relationship between trunk rotation and shoulder adduction and shoulder flexion suggests that a greater range of motion is seen for shoulder flexion and adduction as the range of trunk rotation is increased. The relationship is likely related to timing of the swing. Golfers that have tentative movement, possibly related to a dysfunctional lead shoulder, may limit their trunk rotation to avoid producing an excessive amount of shoulder range of motion in all three planes.

Since the trunk has considerable mass, a golfer rotating their trunk through a large range of motion would tend to cause a large range of motion in the shoulder or require significant eccentric muscular effort to limit the range of motion of the humerus caused from the angular momentum of the trunk. Angular momentum is the product of the segment's moment of inertia about its axis of rotation and the angular velocity of the segment measured at the center of mass of the segment ($H=I\omega$). The large moment of inertia of the trunk caused from the distribution of upper body mass multiplied by the angular velocity of the trunk produces a large amount of angular momentum. The extremities experience a significant increase in acceleration due to the angular momentum being transferred from what was generated by the action of the trunk, to the much lighter segments of the extremities and golf club. The transfer of angular momentum acting on the extremely light club head causes a considerable increase in the angular velocity seen as a greater club head velocity at impact. However the benefits of the transfer of angular momentum during the downswing could lead to undesirable positions at the top of the backswing if the golfer does not control the movement with an easy backswing motion.

Trunk rotation was also correlated with trunk lean ($r=.46$, $p=.04$), but only when all golfers were grouped together. There is likely a limit to the amount of trunk lean that is effective in allowing considerable rotation of the trunk, but maintaining a position that provides optimal execution of the golf swing. While increasing trunk lean would likely increase the amount of trunk rotation possible, the forward flexion of the trunk may shift the center of mass of the golfer anteriorly. If the golfer compensates by flexing more at the hips and knees to maintain the position of the center of mass, hip rotation will likely be reduced. A center of mass that is shifted anteriorly any significant amount would cause a problem in balance when the golfer shifts laterally over the rear leg at the top of the backswing. Even with sufficient balance to have a large trunk lean, beyond an undetermined range, the radius of rotation about the axis of the spine greatly decreases which may cause a decrease in the linear velocity of the club head that is needed through impact.

Since the linear velocity was a product of the radius of rotation and the angular velocity ($v=r\omega$), decreasing the radius would cause a decrease in the linear velocity unless the angular velocity increased as the radius decreased. While this is possible with a decrease in the radius also causing a decrease in the moment of inertia about the axis of the spine, the mass of the club is light, therefore the moment of inertia is not great enough to cause a large reduction in the angular velocity when the radius is increased. However, reducing the radius does seem to drastically reduce the amount of club head linear velocity at ball contact. Therefore, greatly reducing the radius of the club about the spine should be accepted as causing a reduction in the potential linear velocity of the club head at contact. Golfers with a painful rotator cuff may accept the decrease in linear velocity at ball contact to avoid causing excessive discomfort during their swing. It is likely that modifications among golfers experiencing pain during their swing are individually adjusted making detection of a common adjustment difficult. With respect to the current study, limitations imposed by the fact that modifications may be individualised, would require many more subjects in the RCN group to assist in definatively noting differences present.

Trunk lean was also correlated with shoulder adduction ($r=.9974$, $p=.00$) and shoulder flexion ($r=.97$, $p=.03$) in the group of RCN golfers. The relationship between trunk lean and shoulder flexion and adduction was presented briefly in the review of literature and suggested that an increase in trunk lean may be used to increase the amount of shoulder flexion earlier in the swing to promote a swing with less shoulder stress and a lessened chance of impingement at the top of the backswing. This study would suggest that trunk lean, shoulder flexion, and shoulder adduction were not increased in the RCN golfers, but rather by decreasing the amount of trunk lean, the RCN golfers exhibited a more linear relationship with shoulder flexion and adduction. The relationship between shoulder flexion and shoulder adduction with trunk lean assumes more linearity when one scatterplot of trunk lean with shoulder flexion and another with trunk lean and shoulder adduction both demonstrate a linear trend in the data. Figure 5-4 provides an example of a linear relationship among these two variables.

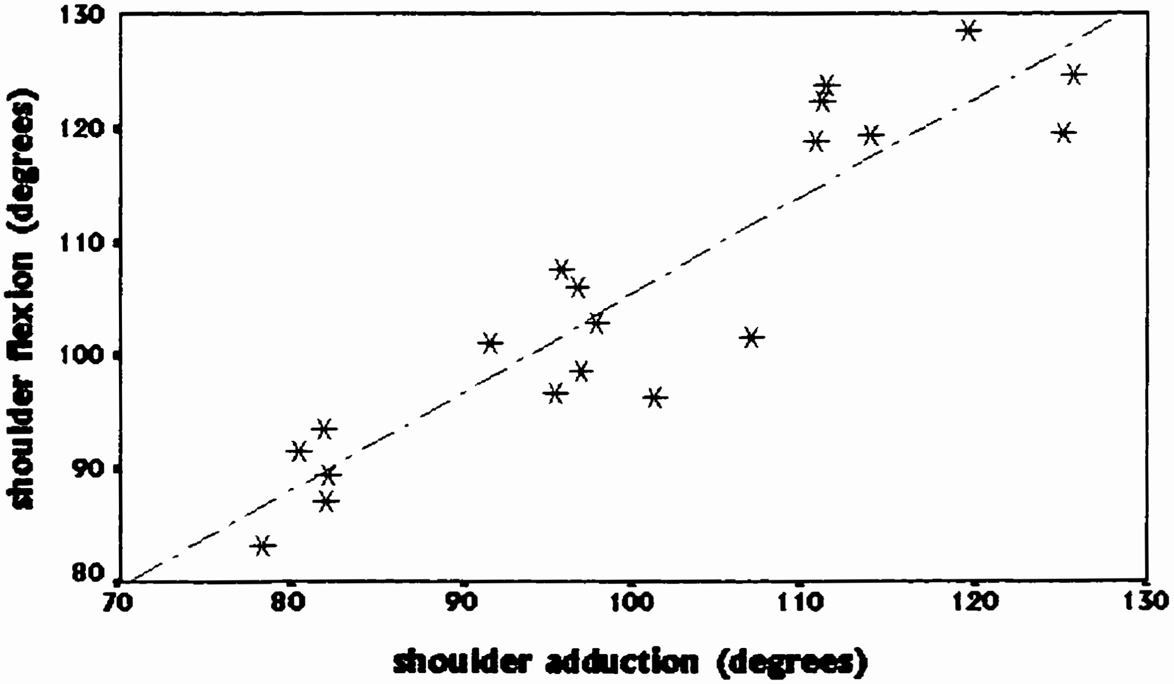


**Figure 5-4.** Sample scatterplot produced from all 20 subjects for shoulder adduction and shoulder flexion to illustrate linearity (r=.92, p=.00).

Finally, trunk and hip rotation at the top of the backswing showed a correlation in the non injured golfers (r=.62, p=.05). Trunk and hip rotation are often discussed simultaneously and it is surprising that they do not appear correlated within the other groups, or as a stronger correlation in the non injured golfers. Trunk rotation, seen as the shoulder turn, is the end product of intervertebral rotation that occurs at each level of the vertebrae, starting at the lumbar spine. Hip rotation included lumbar spine as well as hip joint rotation. The amount of intervertebral rotation about a longitudinal axis increases as the movement progresses superiorly (Lindh, 1989). However, trunk and hip rotation would understandably be related since rotation about the longitudinal axis in the golf swing would begin at the hip and progress superiorly, if the movement follows a pattern of segmental rotation.

The length of the backswing appears to be variable in maintaining a consistent and a relatively high velocity club head through ball impact (Jorgenson, 1970). While a long backswing, in which the club shaft reaches a horizontal position parallel to the ground, is desirable for optimal results, a backswing that utilizes a smaller range of motion allows similar club head velocities to be produced. A reduced backswing length has been suggested as one method to assist in alleviating shoulder discomfort during the golf swing (Mallon, 1997). The maintenance of sufficient club head velocity through ball impact is possible provided correct weight shift patterns and good posture is present through the remainder of the swing. This fact is supported by the current study which demonstrated similar peak linear velocity measurements for all golfers despite varying lengths and durations of backswings.

## Swing and club parameters

The six variables examined among the three groups of golfers that examined various parameters of the swing produced no significant differences between any of the groups. The fact that no significant differences were evident would suggest that despite the large variety of methods used to execute the golf swing, the end result is fairly typical, at least when the swing of more highly skilled golfers is examined. Larger numbers of subjects in each of the groups, especially the RCN group may have produced more variation between groups leading towards more differences present.

While high velocity of the club during the backswing is not desirable, looking at the velocity profile of the peak linear velocity and when it occurs provided a basis of swing evaluation amongst the golfers in this study. The peak linear velocity of the backswing appeared very similar in all groups, as was the duration of the backswing, with the exception of the RCN golfers that showed a shorter time for completion of the backswing, although, this difference was not significant. One variable that was included as possibly indicating some differences among the groups was the backswing ratio which indicated at what point during the backswing the golfer reached the peak linear velocity of the club head. The ratio was included to determine if either group of golfers were reaching the peak linear velocity of their backswing earlier or later in the backswing than another group. The rationale for this variable was the suspicion that golfers with a dysfunctional shoulder may reach both lower velocities during the backswing, but also may reach the peak earlier. The golfer may be apprehensive about reaching their shoulder end range of motion, due to the increased discomfort felt at the top of the backswing that is characteristic of rotator cuff injury of the lead shoulder. The results showed a small trend that the injured golfers in the RCR or RCN groups may have compensated for their shoulder dysfunction by altering the velocity of the backswing. This observation was not supported by a statistical difference that was significant, however data collection on this ratio using a greater number of subjects could examine further evidence of differences.

The downswing peak linear velocity was not significantly different among any of the three groups, and all the results compared favorably with existing literature suggesting a mean of about 36.4 m/s when averaged from amatuer golfers studied (Barrentine, et al., 1994). The velocities measured during the downswing were less than the majority of reported values that indicate linear velocities of the club head at impact to be from 43 - 55 m/s (Cochran & Stobbs, 1968; Mallon, 1996; Milburn, 1982). The greater velocities noted in these later studies were for professional and collegiate level golfers.

The duration of the downswing was nearly identical in all golfers. The average value of .30s was about 7/100ths slower than values reported for professional golfers (Budney, 1979; Cochran & Stobbs, 1968), but did appear to agree with values reported in a recent study which averaged downswing durations at around .30s for fourteen golfers of varying abilities (Koenig, 1993). This .30s value also comprised a much smaller proportion of the backswing than was previously reported when divided by the duration of the backswing (Cochran & Stobbs, 1968). These differences would suggest either a slower backswing in the current study, or perhaps a faster downswing. Since the possibility of a faster downswing was already negated, a slower backswing must be present. Increasing the filming speed of cameras in this current study would have produced a higher sampling rate of data points. The potential benefit resulting from a higher sampling frequency of data points would be to have more accurate measurement of swing and club parameters closer to the point of actual ball contact.

Finally, full swing duration did not produce any significant differences within any of the groups. There was a large variation in each of the three groups, especially within the RCR group. The variation in this particular group was skewed predominately by one subject that had a swing over a full second longer than any other group subject. While this particular subject's downswing was similar in duration to other subjects, his backswing was considerably longer in duration. A long history of rotator cuff dysfunction was cited by the individual as the reason for developing the excessively cautious backswing.

### Swing and club parameter relationships

Peak linear velocity of the downswing was correlated with several range of motion variables in all subjects grouped togehter, in non injured subjects, and in the RCN golfers. Peak linear velocity of the downswing was not shown to demonstrate a strong relationship with any range of motion variables in the RCR golfers. The explanation of why RCR golfers failed to demonstrate any significant relationship between peak linear velocity of the downswing and the range of motion variables studied was not clear. The velocity recorded for the RCR golfers of the club head was the slowest. When combined with other range of motion variables that did not either increase or decrease, the downswing peak linear velocity would not have produced the linear relationship needed to show significant correlation among variables. The downswing velocity showed much less variability than the backswing velocity in all subjects. Since high variability is unlikely to produce a linear relationship such as the one shown in Figure 5-4, correlations with the peak linear velocity of the backswing were not likely.

With all golfers grouped together, peak linear velocity of the downswing showed a relationship with shoulder adduction ($r=.53$, $p=.02$), shoulder flexion ($r=.57$, $p=.01$), and with trunk rotation at the top of the backswing ($r=.49$, $p=.03$). Each of these relationships are addressed below once all associations with peak linear velocity of the downswing are reported.

The non injured golfers also showed a relationship between peak velocity of the downswing and trunk rotation ($r=.74$, $p=.02$). In addition, the non injured golfers showed an interesting negative correlation between peak linear velocity of the downswing and elbow flexion at the top of the backswing ($r=-.69$, $p=.03$). Elbow flexion of the lead arm is often discouraged among golf instructors and golf professionals. However, the relationship found here suggests that in an effort to focus on having the lead arm straight for ball contact -which is indisputably important- the golfer may impede the ability to generate a high linear velocity of the clubhead for ball impact. A straight lead arm maximizes the radius about which the club rotates. Recalling the equation $\mathbf{v=r\omega}$ indicates the importance of the radius (r) in maximizing the linear velocity (v). The reason for the reduced velocity may possibly be due to muscle tightness during the backswing. The link between muscle tightness and potentially hindering the swing mechanics has been reported previously concerning the lead elbow (Adlington, 1996), and for the wrist concerning reducing range of motion (Cochran & Stobbs, 1968). Both of these previous studies suggest that the tightening of muscles required to maintain a position thought to be necessary may actually impede full range of motion since the movement is no longer relaxed. Tightening of the elbow extensors to limit elbow flexion at the top of the backswing may also limit the amount of humeral movement of horizontal adduction or adduction across the body since the primary elbow extensors also cross the glenohumeral joint. While this was not demonstrated in the groups studied, it is possible that a further decrease in lead shoulder horizontal adduction range of motion could be seen if RCN golfers focused on a rigid left arm as well.

Peak linear velocity of the downswing continued to show an association in the RCN golfers with shoulder flexion (r=.95, p=.051), although the relationship between shoulder flexion and peak linear velocity of the downswing was not significant.

The duration of the downswing in the RCN golfer group was significantly correlated with shoulder horizontal adduction (r=.98, p=.02). The apparent connection between these two variables is that as the range of motion of horizontal adduction increases, the duration of the downswing decreases. While this would appear contradictory, it is likely that the greater range of motion of horizontal adduction caused an increase in the stretch of the horizontal abductors and other muscle groups responsible for generating torque during the downswing. This may have resulted in a greater amount of force application from the muscles that were stretched resulting in a greater average velocity of the club head. The greater average velocity of the club head during the downswing could explain the shorter duration of the downswing.

The relationship seen in several groups between shoulder flexion, shoulder adduction, and trunk rotation with peak linear velocity of the club head during the downswing seems to be logical. The relationship between shoulder flexion and shoulder adduction has already been discussed, so it is not surprising that if one variable was related to the downswing velocity, then the other was as well. Trunk rotation was also shown to be related to both shoulder flexion and shoulder adduction in some groups, which indicates the inter-related behavior of all three variables. Increasing the range of motion of shoulder flexion, adduction, and trunk rotation during the swing may promote a greater amount of linear velocity of the club head through ball contact according to the correlations reported. However, determining cause and effect of one measurement on another requires more sophisticated statistical testing such as a regression analysis, which was not included in the current study. The questionable ability of a regression analysis to provide accurate prediction information with the small numbers of subjects in each group and in the number of total subjects was the reason for not conducting this type of analysis in the present study.

### Trunk and hip rotation

Current literature has reported varying ratios of trunk rotation to hip rotation, although hip rotation is often reported to be half the range of trunk rotation. The $90^0$ value of trunk rotation is often presented as approximately average (Adrian & Cooper, 1995; Dante & Elliot, 1962; Hay, 1985; McTeigue, et al., 1994), which would equate to $45^0$ of hip rotation, if a 1: 0.5 ratio is used (Adrian & Cooper, 1995; Dante & Elliot, 1962). The golfers in this study all seemed to demonstrate greater ranges of trunk rotation, with the exception of the RCN golfers, and a lower range of motion in hip rotation. The end result is a ratio of trunk rotation to hip rotation that deviates from values reported in existing literature. The values of hip rotation of $37.53^0$ for non injured, $36.34^0$ for RCR, and $32^0$ for RCN golfers are well below the $45^0$ value noted above, and the $53^0$ reported by McTeigue et al. (1994). The resulting trunk to hip rotation ratios for the current study were 1: 0.38 for the non injured golfers, 1: 0.37 for the RCR golfers, and 1: 0.43 for the RCN golfers. The higher number of subjects in the non injured groups makes the two groups appear to be more equal in their variation than would likely be demonstrated with a fewer number of non injured or a greater number of RCR golfers. Varying results due to altered sample size are only speculative, however.

The trunk and hip rotation relationship illustrated in Figure 4-14 for RCN subject #4 shows hip rotation reaching close to full range of motion for the subject about .5 seconds into the swing and increasing at a slower rate until the point of maximal hip rotation of $39.25^0$. The trunk rotation increases at a greater rate than the hip rotation at all stages of the swing and reaches a peak of $118.73^0$ within 2 frames or .03 seconds following hip rotation. The subject depicted in Figure 4-14 demonstrated a high degree of trunk rotation, but a comparatively low range of hip rotation. The subject chosen had the greatest velocity of the club head at ball contact of all subjects in the study. The ability to generate the high linear velocity of the club head at ball contact is likely related to the high degree of trunk rotation. This was confirmed by the correlation of trunk rotation and peak linear velocity of the club head shown for the group of non injured golfers ($r=.74$, $p=.02$).

The potential implications for golfers in the injured groups may be to reduce their trunk rotation and increase the amount of hip rotation to maintain club head velocity for ball contact. Reduction in the amount of trunk rotation may have a negative effect on the swing in producing club head velocity, however the ability to swing a golf club with less discomfort may be a desirable outcome.

### Sequential rotation of body segments and the club

Given the desirable goal of any throwing or striking skill to achieve maximal linear velocity of the distal segment prior to contact or release (Kreighbaum & Barthels, 1996), the series of graphs (Figures 4-15 to 4-20) in the previous chapter were included to provide evidence of this occurring in the current study. Observing the distal end point linear velocities of segments is not the best method for describing sequential rotation of segments. Angular velocities of each segment is the preferred method of describing sequential rotation of segments. However, the linear velocity is indicative of the magnitude of the angular velocity since they are related to each other by the formula $\mathbf{v=r\omega}$, where v is linear velocity, r is the radius from the axis of rotation of the segment, and $\omega$ is the angular velocity. With minimal flexion of the elbows, the length of the radius -which includes the club and arms- would not change significantly, causing a peak linear velocity that would correspond to a peak angular velocity. The corresponding instances of peak angular velocity of the club and peak linear velocity of the club head are likely to vary, especially among lesser skilled golfers.

Also, the main justification for using angular kinematics to describe sequential rotation of segments is to determine how the segment obtained a particular torque about a given joint (Putnam, 1993). Linear kinematic description gives no explanation of how the end point of a segment reached the peak velocity when it did. For the current study, the objective was to examine the end velocity of each segment and how it interacted with the adjoining segment regarding the sequence of the golf swing. Therefore, examining the more complex description of segmental movement using angular kinematics to describe joint and segment rotation interaction was beyond the scope of the current study.

Graphs 4-15 and 4-18 of the non injured golfer clearly shows the evidence that each distal segment reaches a peak linear velocity later in the swing than the preceding segment's distal end point. The club head for the non injured golfer actually reaches peak linear velocity .05 seconds prior to the left wrist reaching peak linear velocity. It is likely that having the peak linear velocity of the wrist occur prior to the peak velocity of the club head would result in a greater linear velocity of the clubhead that could result in greater driving distance for the golfer studied. Other variables such as angle of the club face and angle of the trajectory of the ball at impact would also need to be considered. However, with these confounding factors remaining constant, increasing the linear velocity of the clubhead at ball impact would result in a further length of ball drive, assuming constant clubhead and ball characteristics.

The RCR golfer also demonstrated a greater peak linear velocity of each segment progressing distally from the hip, shoulder, elbow, wrist, and club head of the lead side during the swing (Figures 4-16 and 4-19). While the peak linear velocities all progressed distally for the segment end points on the body, the peak linear velocity of the club head preceded the wrist by .07 seconds. This discrepancy between peak linear velocity measurements seems excessive, and while it may be accurate and indicative of poor skill of the golfer, it is more likely that the temporal limitations of the data capture of 60 Hz. may have failed in obtaining higher linear velocities closer to ball contact. The .07 second lapse between peak linear velocity of the club head and the peak linear velocity of the wrist was greatest in the RCR golfer shown (Subject #3). The other RCR golfers showed values more comparable to the .02 - .05 second values seen with the RCN and non injured golfers.

Finally, the RCN golfer demonstrated the smoothest of all three group sample profiles of peak linear distal end point velocities. Peak linear velocity of the club head occurred only .02 seconds prior to the peak linear velocity of the distal lead wrist. While it would be desirable to have the wrist precede the club head in peak linear velocity, the RCN subject represented by the graph in Figure 4-17 and 4-20 is closest to achieving this goal. This particular subject also recorded one of the top five highest peak linear velocities of the club head at ball contact. While the smoothness of the sequential graphs may provide significant explanation for this, the non injured golfer selected for the sequential linear velocity analysis shown in Figure 4-15 and 4-18 actually recorded the second highest club head velocity value. Both subjects were of similar age at 30 and 28 years old, respectively.

Therefore, conclusions as to more correct sequencing may be misleading, although it was suggested above that the non injured golfer may have had an even greater club head velocity if the peak linear velocity followed that of the wrist. The situation of the club head peak linear velocity occurring closer to an optimal sequence was shown by the RCN subject.

## Study review

This study was successful in developing a filming configuration that enabled three dimensional coordinate data to be produced from three two dimensional camera views. The use of this configuration for filming three groups of golfers, two of which had history of rotator cuff dysfunction, made it possible to provide kinematic data for comparison among the three groups.

The variables measured to compare the three groups indicated significant difference between the non injured and rotator cuff injury repaired groups for the range of motion seen in lead shoulder horizontal adduction at the top of the backswing ($p=.03$). No other significant differences were found, however, lead shoulder flexion range of motion at the top of the backswing in the rotator cuff repaired group showed a trend of decreased range of motion compared to the non injured group. The maximum amount of trunk rotation during the backswing showed evidence of being less in the non repaired rotator cuff group compared to both the rotator cuff repaired and non injured groups of golfers. High variation in the results, and the low number of subjects in some groups may explain for the lack of significant differences at the $\alpha$ level of .05.

Several relationships were seen between tested variables and reported using a correlation coefficient. The strongest relationships were shown between shoulder flexion and shoulder adduction of the lead shoulder, and between trunk rotation and shoulder adduction in most of the groups and with all the golfers grouped together. Other relationships of lesser significance were also found involving the variables studied, including the peak linear velocity of the club head during the downswing with shoulder adduction, shoulder flexion, and trunk rotation.

Trunk and hip rotation measurements during the swing and shown how they correspond to one another. The trunk and hip data demonstrated both trunk and hip angular displacement rotating beyond the angle they each were at address at the instant of ball contact (Figure 4-14).

Finally, segment distal end points were measured for peak linear velocity and depicted graphically to show sequencing of the swing. All three examples demonstrated swings which had peak velocity of the distal wrist of the lead arm occur following peak linear velocity of the club head. Ball contact did occur, in most cases, approximately equal to the point of peak linear velocity of the club head during the downswing.

# VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

## Summary

One of the most common injuries to older golfers is a rotator cuff tear which is thought to affect the overall mechanics of the golf swing. Observing golfers with a history of rotator cuff dysfunction may begin to isolate differences occurring in the swing mechanics when compared to non injured golfers. Before comparison between groups of golfers is made, a camera configuration that provides accurate collection of glenohumeral joint action is necessary.

Considering the rationale above, there were three purposes to this study. The first was to develop a filming configuration that would enable acquisition of video film data to determine three dimensional coordinates of the glenohumeral joint during a golf swing. The second was to use the filming technique to acquire kinematic data for low-handicap golfers that had either a recent surgical repair of the lead shoulder rotator cuff, or a current injury to the lead shoulder. Finally, the third purpose was to determine if differences in selected golf swing mechanics existed between non injured golfers, golfers with current injury to the rotator cuff, and golfers that had surgical repair of the rotator cuff.

Golfers were recruited from local golf clubs as non injured subjects, while rotator cuff injury repaired and non-repaired golfers were referred to the investigator from local orthopaedic surgeons and physiotherapists. The total number of golfers involved was twenty. All subjects each hit six golf balls with their driver after a general warm-up. One swing was selected out of the six for analysis based on which trial captured a frame closest to ball contact. While completing the trials, the golfers were filmed from three camera views which were genlocked together. The three views were a frontal view, an overhead view, approximately perpendicular to the swing plane of the golfer, and a rear sagittal view. The three views were then combined using the Peak Performance Motion Analysis System to compute the direct linear transformation of the data to provide 3D kinematic data. The kinematic data was then used to produce quantitative measurements on 14 selected variables describing the golf swing with an emphasis on lead arm glenohumeral position at the top of the backswing. The handicap values of all golfers were included as a fifteenth variable to assist in description of the golfers.

Horizontal adduction of the lead shoulder in the rotator cuff repair (RCR) group of golfers was found to be statistically different from the non injured group of golfers. The RCR golfers demonstrated a decrease in the range of motion at the top of the backswing when compared to non injured golfers. The RCR golfers were not statistically different from the golfers that had the currently injured rotator cuff (RCN). There were no other statistical differences found between any of the other variables tested.

Relationships among all variables were tested for the combined group of all twenty golfers by calculating correlation coefficients. The same correlations were then tested with each of the individual groups. Results of the testing of correlations amongst all variables indicated that the range of motion of shoulder adduction and shoulder flexion was highly correlated in every subdivision of the groups, and for all golfers combined. The most common variable that was observed as being related to several variables was shoulder adduction. Shoulder adduction was related to peak linear velocity of the downswing, trunk rotation, and trunk lean in varying groups, as well as with shoulder flexion. Other correlations existed, but with lesser significance than those reported above.

The interaction of segments and the result of the summation of velocities at each segment's distal end point were presented graphically. These series of graphs illustrated the increasing linear velocity of each segment moving distally. The club head linear velocity reached a considerably greater linear velocity in all cases since it is the most distal point in the system. The instant that this peak linear velocity occurred varied amongst the golfers studied, but did occur within .03 seconds of ball contact in nearly all cases. In some instances, the peak linear velocity of the lead arm wrist reached a peak after that of the club head which was discussed as not being optimal. The pattern of joint linear velocities was consistent with that of skilled golfers for all three groups tested, suggesting that the rotator cuff dysfunction did not significantly alter the swing mechanics seen in either group.

## Conclusions

Based on the results of this study, the following conclusions appear justified:

1. Use of a camera configuration as utilized in this present study has shown to be adequate in acquiring video data for the golf swing obstructed views.
2. The range of horizontal adduction in the lead shoulder is decreased in the golfers that had surgical repair of their rotator cuff.
3. There is a significant relationship between shoulder flexion and shoulder adduction in the golf swing.
4. Sequencing of segmental rotations is demonstrated effectively by examining segment end point linear velocities.

5. Differences in technique, ranges of motion, and duration of the various phases of a golf swing can all be individually optimized to attain a relatively high linear velocity of the clubhead at ball contact.

## Recommendations

Future studies on the golf swing to determine kinematic differences or similarities should consider the following recommendations that would likely improve the quality of the study.

1. A golf study collecting kinematic data for a large number of golfers (>50) for every joint to provide the basis for determining a normal range of movement would be a useful resource.
2. A study addressing the previous recommendation that also divided subjects into category based on distance of drive, path of drive, and handicap would assist in providing rationale for choosing particular criteria for golfers to be included in studies.
3. A detailed spatial model with a field of view which included only the arms would be optimal for getting more accurate kinematic data on the shoulder during the golf swing. A spatial model that enabled precise collection of internal and external rotation of the humerus, as well as pronation and supination of the forearms, would provide a detailed framework for comparison among injured rotator cuff golfers.
4. Using the same filming configuration with high speed video cameras of 200Hz or greater would greatly enhance the amount of data produced during portions of the golf swing with greater velocity of movement.

5. Future studies comparing range of motion measurements should make every effort to recruit subjects of similar age and background since age is known to decrease range of motion.
6. Studies involving injured subjects, or subjects that have received surgical repair should minimize differences in duration of injury or time since repair was completed.
7. The most ideal contribution in this particular area of research would be to have several golfers without injury on record and keep contact with the golfers in the possibility of one of the golfers incurring an injury to their rotator cuff. Having the same person for comparison before injury, during injury, and ideally post-surgery would be a long-term study of questionable ethics. The greater the number of golfers filmed would increase the potential for a subject to incur an injury within the duration of the study.
8. Examining normative tables of flexibility for male subjects in different age ranges could determine if the RCR and RCN groups were within normal limits for shoulder flexibility.

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# APPENDICES

## Appendix I

## Pain Questionnaire for RCN subjects

**1. Have you had your shoulder diagnosed as a rotator cuff strain or tear by a medical professional?**

YES_______NO_________

**2. How often has your shoulder pain made completing a golf swing impossible?**

Never_____ Seldom____ Occasionally_____Frequently______Always____
(2 or less) (2-5 times) (5 or more)

**3. Please indicate at which portion of your swing that you would feel the greatest discomfort.**

start of the take away __ early backswing (bs)__ mid-bs __ top of the bs __

start of the downswing (ds)__ mid-ds __ ball contact __

early follow through (ft)__ mid-ft __ late ft __

**4. If you have received therapy for the current shoulder injury, please indicate how many treatments.**

2 or less __ 3-5 __ 6-10 __ have not received therapy __

**5. What type of treatment/program have you received for your shoulder?**

Flexibility_______Strengthening________Ultrasound______Heat/Ice________
Massage________Interferential_________TENS______Medication______

**6. On a scale of 1 -10 with 1 being very little pain that doesn't last, and 10 being extreme pain that makes it impossible to complete a full swing, please indicate your current level of pain as you swing today.**

1 2 3 4 5 6 7 8 9 10

# Appendix II

## Personal Consent Form for Non injured Subjects

# Personal Consent Form

You have been selected to participate in a study entitled "A comparison of golf swing kinematics among non injured, rotator cuff injury-repaired and rotator cuff injury nonrepaired golfers". This study is the topic of a master's thesis being completed by the Investigator, Bill Gillespie, a graduate student in the Faculty of Physical Education and Recreation Studies at the University of Manitoba.

Selection for your part in the study was made on a volunteer basis with the only requirements being that you are a low handicap, male golfer with no previous history of rotator cuff injury or surgery who was born prior to 1967.

The purpose of this study is to determine if a kinematic difference exists, involving the golf swing, between subjects who have had a rotator cuff surgically repaired, or currently have pain in their rotator cuff, as compared to subjects who have a healthy rotator cuff. This study will determine if a difference exists by looking at range of motion and velocity values throughout the golf swing in order to determine if a pattern, or a change in pattern exists between the groups of subjects.

In the present study you, being classified as a healthy, low handicap, male golfer with no previous history of rotator cuff injury or repair, will be asked to take four swings with your driver while being filmed.

Three cameras will be used to record your swings, and the video tapes will only be used for kinematic descriptions, and calculations. Your name, age, and handicap will be recorded by the Investigator, Bill Gillespie, and all information and video tapes will remain confidential. The recorded films will not be redistributed or used for any purpose other than this research study.

If for any reason you feel it necessary to talk to the Investigator, Bill Gillespie, you can do so by calling 474-6875 or 475-7562, or the M. Sc Coordinator, Dr. Jennifer Mactavish at 474-8627.

Since you are an experienced golfer it is assumed that you are capable of perfoming a golf swing and that the risk of injury is low.

I, ______________________________, have read the above information and understand the testing procedure, the risks involved, and I agree to participate at my own risk. I acknowledge that the golf swing is within my capability and I can successfully perform this skill on a regular basis. I also understand that I have the right to withdraw from the study at any time. In case of injury, I relieve the University of Manitoba and the Investigator of any liability that may result from my participation in this study.

| | |
|---|---|
| ______________________________ | ____________________ |
| **Signature of Investigator** | **Date** |
| ______________________________ | ____________________ |
| **Signature of Subject** | **Date** |
| ______________________________ | ____________________ |
| **Signature of Witness** | **Date** |

# Appendix III

## Personal Consent Form for RCR and RCN Subjects

# Personal Consent Form

You have been selected to participate in a study entitled "A comparison of golf swing kinematics among non injured, rotator cuff injury-repaired, and rotator cuff injury nonrepaired golfers". This study is the topic of a master's thesis being completed by the Investigator, Bill Gillespie, a graduate student in the Faculty of Physical Education and Recreation Studies at the University of Manitoba.

Initial contact with you was made previously by the Investigator, Bill Gillespie, and your referral to him was made either directly or indirectly through Dr. Peter MacDonald.

The purpose of this study is to determine if kinematic differences exist in the golf swing among subjects who have had a rotator cuff surgically repaired, or currently have pain in their rotator cuff, as compared to subjects who have a healthy rotator cuff. This study will determine if a difference exists by examining range of motion and velocity values throughout the golf swing in order to determine if a pattern, or a change in pattern exists between the groups of subjects.

In the present study you, being classified as a low handicap, male golfer with previous history of rotator cuff injury and/or repair in the left shoulder, born prior to 1967, will be asked to take four swings with your driver while being filmed.

Three cameras will be used to record your swings, and the video tapes will only be used for kinematic descriptions, and calculations. Your name, age, handicap, and date of rotator cuff repair will be recorded by the Investigator, Bill Gillespie, and all information and video tapes will remain confidential. The recorded films will not be redistributed or used for any purpose other than this research study.

If for any reason you feel it necessary to talk to the Investigator, Bill Gillespie, you can do so by calling 474-6875 or 475-7562, or the M. Sc Coordinator, Dr. Jennifer Mactavish, at 474-8627.

Since you are an experienced golfer it is assumed that you are capable of perfoming a golf swing and that the risk of injury is low.

I, ______________________________, have read the above information and understand the testing procedure, the risks involved, and I agree to participate at my own risk. I acknowledge that the golf swing is within my capability and I can successfully perform this skill on a regular basis. I also understand that I have the right to withdraw from the study at any time. In case of injury, I relieve the University of Manitoba and the Investigator of any liability that may result from my participation in this study.

| | |
|---|---|
| ______________________________<br>**Signature of Investigator** | ____________________<br>**Date** |
| ______________________________<br>**Signature of Subject** | ____________________<br>**Date** |
| ______________________________<br>**Signature of Witness** | ____________________<br>**Date** |

# Appendix IV

## Individual Results for Golfers by Group

| VARIABLE | VARIABLE MEASUREMENT FOR N GOLFERS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| *left shoulder flexion (deg.) | 93.42 | 102.81 | 118.75 | 119.46 | 128.43 | 105.98 | 123.77 | 98.55 | 101.09 | 122.26 |
| *left shoulder adduction (deg.) | 81.91 | 97.95 | 110.92 | 125.14 | 119.58 | 96.68 | 111.47 | 96.97 | 91.46 | 111.28 |
| *left shoulder horizontal adduction (deg.) | 36.31 | 32.24 | 37.53 | 38.48 | 38.31 | 33.23 | 35.05 | 46.57 | 36.79 | 36.56 |
| *left elbow flexion (deg.) | 152.93 | 148.96 | 134.07 | 120.04 | 160.84 | 142.5 | 141.26 | 163.21 | 144.23 | 147.88 |
| *left wrist ROM (deg.) | 126.31 | 125.37 | 145.49 | 160.39 | 139.69 | 145.77 | 155.64 | 136.60 | 135.83 | 127.77 |
| max. hip rotation (deg.) | 17.26 | 48.00 | 28.82 | 27.64 | 40.70 | 47.18 | 30.64 | 38.34 | 42.10 | 54.65 |
| max. trunk rotation (deg.) | 62.22 | 93.45 | 101.52 | 107.34 | 98.11 | 107.82 | 101.83 | 90.67 | 108.71 | 114.59 |
| trunk lean (deg.) | 143.65 | 150.87 | 150.62 | 145.86 | 155.75 | 138.45 | 132.31 | 150.07 | 164.52 | 161.56 |
| club head peak linear velocity during backswing (m/s) | 9.93 | 10.07 | 7.65 | 10.81 | 10.83 | 8.65 | 11.41 | 10.02 | 11.12 | 17.44 |
| club head peak linear velocity during downswing (m/s) | 33.67 | 34.66 | 37.94 | 40.92 | 35.73 | 37.76 | 35.96 | 31.85 | 41.08 | 40.51 |
| duration of backswing (sec) | .92 | 1.17 | 1.37 | .87 | 1.10 | 1.08 | 1.02 | .87 | 1.02 | .72 |
| duration of downswing (sec) | .22 | .33 | .33 | .28 | .33 | .25 | .37 | .30 | .33 | .30 |
| ratio of peak backswing linear velocity/ duration of backswing | .65 | .67 | .72 | .67 | .68 | .72 | .67 | .66 | .74 | .56 |
| duration of swing (sec) | 1.45 | 1.82 | 1.95 | 1.40 | 1.55 | 1.48 | 1.57 | 1.43 | 1.47 | 1.13 |

* indicates variables measured at the top of the backswing

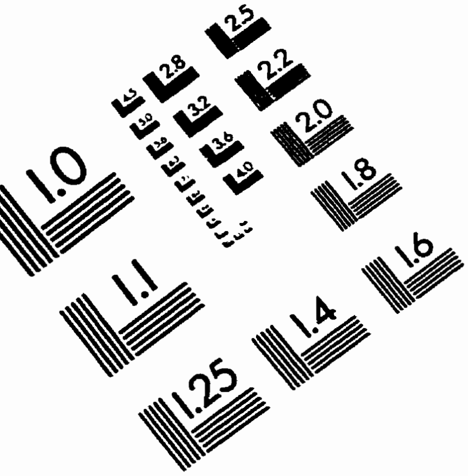
| VARIABLE | VARIABLE MEASUREMENT FOR RCR GOLFERS | | | | | |
|---|---|---|---|---|---|---|
| [redacted] | 1 | 2 | 3 | 4 | 5 | 6 |
| *left shoulder flexion (deg.) | 89.41 | 119.27 | 101.51 | 91.50 | 96.35 | 69.65 |
| *left shoulder adduction (deg.) | 82.15 | 114.08 | 107.15 | 80.38 | 101.41 | 95.41 |
| *left shoulder horizontal adduction (deg.) | 39.77 | 45.60 | 42.57 | 38.98 | 50.02 | 45.49 |
| *left elbow flexion (deg.) | 154.86 | 117.29 | 134.67 | 134.14 | 119.87 | 155.60 |
| *left wrist ROM (deg.) | 131.21 | 141.32 | 156.30 | 127.70 | 115.41 | 123.83 |
| max. hip rotation (deg.) | 47.13 | 28.23 | 45.73 | 29.44 | 27.46 | 40.02 |
| max. trunk rotation (deg.) | 85.73 | 117.62 | 108.34 | 81.33 | 96.04 | 102.42 |
| trunk lean (deg.) | 148.36 | 152.38 | 130.33 | 142.37 | 148.32 | 154.84 |
| club head peak linear velocity during backswing (m/s) | 11.67 | 6.68 | 11.88 | 11.84 | 9.78 | 11.21 |
| club head peak linear velocity during downswing (m/s) | 35.81 | 36.91 | 35.35 | 35.98 | 35.72 | 33.42 |
| duration of backswing (sec) | .92 | 1.83 | .75 | .83 | 1.03 | .90 |
| duration of downswing (sec) | .30 | .38 | .25 | .27 | .28 | .26 |
| ratio of peak backswing linear velocity/ duration of backswing | .67 | .63 | .60 | .70 | .58 | .69 |
| duration of swing (sec) | 1.47 | 2.50 | 1.20 | 1.27 | 1.45 | 1.40 |

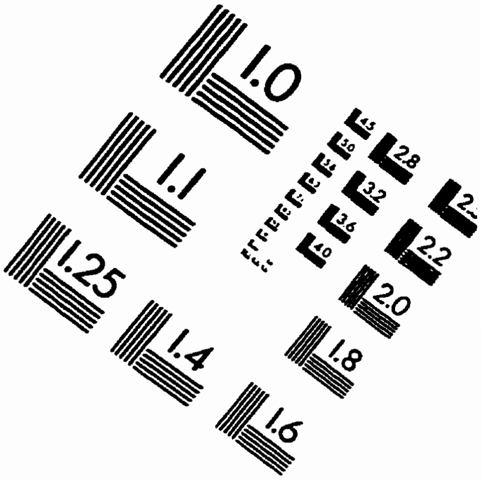
*indicates variables measured at the top of the backswing

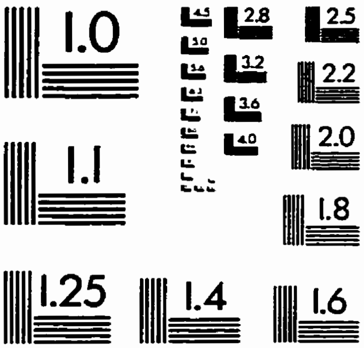
| VARIABLE | VARIABLE MEASUREMENT FOR RCN GOLFERS | | | |
|---|---|---|---|---|
| [redacted] | 1 | 2 | 3 | 4 |
| *left shoulder flexion (deg.) | 87.21 | 83.29 | 107.52 | 124.68 |
| *left shoulder adduction (deg.) | 81.93 | 78.33 | 95.68 | 125.78 |
| *left shoulder horizontal adduction (deg.) | 35.49 | 49.11 | 37.35 | 46.17 |
| *left elbow flexion (deg.) | 155.81 | 130.88 | 161.88 | 149.28 |
| *left wrist ROM (deg.) | 146.25 | 132.10 | 143.38 | 129.73 |
| max. hip rotation (deg.) | 17.77 | 32.71 | 38.21 | 39.25 |
| max. trunk rotation (deg.) | 68.73 | 35.02 | 75.35 | 118.73 |
| trunk lean (deg.) | 136.23 | 136.32 | 143.93 | 159.26 |
| club head peak linear velocity during backswing (m/s) | 11.69 | 7.84 | 12.40 | 12.69 |
| club head peak linear velocity during downswing (m/s) | 32.66 | 35.02 | 40.10 | 42.75 |
| duration of backswing (ms) | .73 | 1.08 | .80 | .93 |
| duration of downswing (ms) | .27 | .32 | .28 | .32 |
| ratio of peak backswing linear velocity/ duration of backswing | .68 | .65 | .56 | .70 |
| duration of swing (ms) | 1.27 | 1.55 | 1.22 | 1.43 |

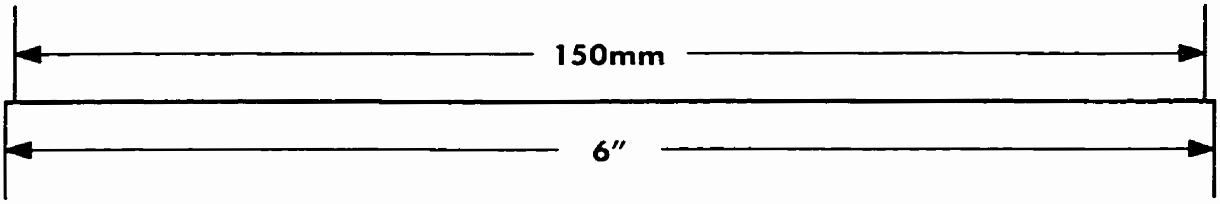
* indicates variables measured at the top of the backswing

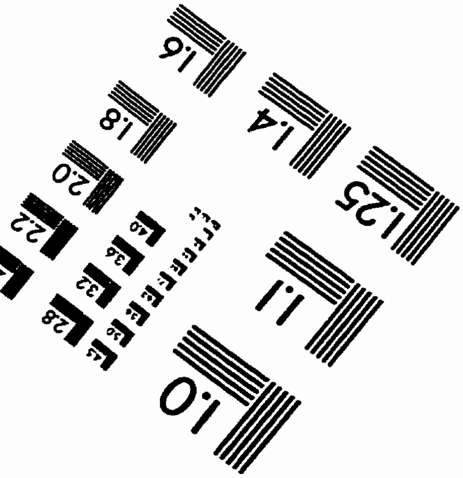
# IMAGE EVALUATION TEST TARGET (QA-3)











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