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The X-Factor and Its Relationship to Golfing Performance

Michael H. Cole and Paul N. Grimshaw

Abstract

It is often postulated that an increased hip to shoulder differential angle ('X-Factor') during the early downswing better utilises the stretch-shorten cycle and improves golf performance. The current study aims to examine the potential relationship between the X-Factor and performance during the tee-shot. Seven golfers with handicaps between 0 and 10 strokes comprised the low-handicap group, whilst the high-handicap group consisted of eight golfers with handicaps between 11 and 20 strokes. The golfers performed 20 drives and three-dimensional kinematic data were used to quantify hip and shoulder rotation and the subsequent X-Factor. Compared with the low-handicap group, the high-handicap golfers tended to demonstrate greater hip rotation at the top of the backswing and recorded reduced maximum X-Factor values. The inconsistencies evident in the literature may suggest that a universal method of measuring rotational angles during the golf swing would be beneficial for future studies, particularly when considering potential injury.

KEYWORDS: kinematic analysis, golf, X-Factor, hip to shoulder differential

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INTRODUCTION

During the early 1990s, researchers estimated that the game of golf was enjoyed on a regular basis by at least 35 million people worldwide (Sherman & Finch, 2000). However, over the past decade or more, the global popularity of golf has increased significantly (Thériault & Lachance, 1998), with some research indicating that participation rates have increased by more than 33 percent in the United States alone (Mitchell, Banks, Morgan, & Sugaya, 2003). Similar trends have been reported for European countries, such as Germany, where participation in golf was observed to increase by an average of 10 percent every year between 1990 and 2000 (Gosheger, Liem, Ludwig, Greshake, & Winkelmann, 2003). The increased popularity of the game has effectively established golf as one of the most popular sporting activities in both Australia and the United States, attracting as many as 875,000 (Australian Bureau of Statistics, 2007) and 27 million (Seaman & Bulbulian, 2000; Thériault & Lachance, 1998) participants, respectively. Over 20 percent of the adult population in many countries play golf either as a competitive sport or as a leisure activity (Thériault & Lachance, 1998). One of the fundamental skills of golf is the swing, which is typically used to progress the ball from the tee to the green and this may be performed more than fifty times during a normal round of golf (Thériault & Lachance, 1998). The golf swing is a precise movement, comprised of a complex sequence of events that are ideally brought together at the point of impact to meet the main requirements of an effective golf swing; distance and direction (Hume, Keogh, & Reid, 2005; Kim, Millett, & Warner, 2004; Richards, Farrell, Kent, & Kraft, 1985).

Due to the positive association that exists between the displacement of the golf ball and the velocity of the club head, it is desirable for a golfer to attain maximum club head velocity at the point of impact to maximise the distance traveled by the ball (Burden, Grimshaw, & Wallace, 1998; Hume et al., 2005). In order to achieve high club head velocities, many golf coaches and professionals advocate the restriction of hip rotation, whilst allowing larger amounts of shoulder rotation during the backswing (Hosea & Gatt, 1996). This movement sequence results in those muscles surrounding the hips, trunk and upper extremities being lengthened before they undergo a concentric contraction at the initiation of the downswing phase (stretch-shorten cycle). According to Enoka (1994), the utilization of the stretch-shorten cycle (SSC) produces a more effective and efficient muscle contraction, as actively stretching a muscle (eccentric) prior to shortening it (concentric) allows it to perform more positive work than is possible during a concentric contraction alone. This notion may be supported by a study conducted by Burden et al. (1998) who reported that a skilled group of sub-10 handicap golfers attained a peak hip-to-shoulder separation angle of a 70° during the performance of the golf swing. Further evidence for this point was provided

by McLean (1992), who suggested that a larger angle of separation between the hips and shoulders (referred to as the 'X-Factor') resulted in an increased driving distance in professional golfers. Despite these findings, McTeigue, Lamb, Mottram and Pirozzolo (1994) identified no statistically-significant differences in the peak amounts of hip and shoulder rotation shown by amateur (Hips = 53°; Shoulders = 87°) and professional golfers (Hips = 55°; Shoulders = 87°). Based on their findings, McTeigue et al. (1994) concluded that there was no evidence to suggest that the magnitude of the X-Factor at the top of the backswing was a key discriminator between the skill levels of amateur and professional golfers. Similarly, Egret, Dujardin, Weber and Chollet (2004), demonstrated that expert (47.7°) and experienced (46.2°) golfers achieved similar X-Factor values at the top of the backswing. However, in a recent study it was shown that whilst the magnitude of hip and shoulder rotation did not differ between golfers who produced low (n = 21), medium (n = 65) and high ball velocities (n = 14), the X-Factor at the top of the backswing and at maximum value was greater in those golfers who produced greater ball velocities (Myers et al., 2008). Despite the diversity of these findings, it is important to consider that this 'torqued' spinal posture may be a contributory factor in the development of low back injuries. Some evidence for this concept may be provided by an earlier study conducted by Grimshaw and Burden (2000), who reported that the reduction of the X-Factor in a golfer suffering with chronic low back pain was associated with the alleviation of the painful symptoms in this player.

Although several investigations have aimed to quantify the magnitude of the X-Factor at the top of the backswing (e.g. Burden et al., 1998; Grimshaw & Burden, 2000; McTeigue et al., 1994; Myers et al., 2008), few investigations have looked at how the X-Factor changes in different golfing populations early in the downswing phase of the movement (Cheetham, Martin, Mottram, & St. Laurent, 2001). Cheetham et al. (2001) showed that although the X-Factor was comparable between amateur and professional golfers at the top of the backswing, the change in X-Factor between the top of the backswing and the peak value achieved during the downswing ('X-Factor Stretch') was greater in professionals. It is likely that the X-Factor Stretch reported by Cheetham et al. (2001) could be explained by the golfers initiating the downswing with the rotation of their hips back toward the flag, whilst their shoulders are still completing their rotation away from the flag. This movement sequence commonly referred to as 'leading with the hips', was observed in three-quarters of a group of sub-10 handicap golfers (Burden et al., 1998) and is suggested to further accentuate the stretch of those muscles involved in the SSC throughout the swing.

Based on the findings presented by Cheetham and colleagues (2001), it is plausible to suggest that the role of the X-Factor in driving performance is more complex than perhaps originally thought. It appears that the timing and

magnitude of the X-Factor Stretch during the early stages of the downswing may play a more important role than the magnitude of the X-Factor at the top of the backswing in determining the efficacy of a golf stroke. Therefore, it was the aim of this research to quantify the hip and shoulder rotation demonstrated by both low- and high-handicapped golfers and further investigate the role of the X-Factor in the successful execution of a tee-shot. Specific attention was given to the magnitude and timing of peak values, as a better understanding of this component would be important for both golfing professionals and clinicians who are seeking to provide both effective and safe methods of performance enhancement and/or rehabilitation.

METHODS

SUBJECTS

For the purpose of this research, 15 male golfers with a player handicap of 20 strokes or less were recruited and assessed using three-dimensional videography (demographic information included in Table 1). To limit the influence of playing standard, the golfers were divided into two separate handicap-specific groups; the low-handicapped group (LHG), who had a handicap of 10 strokes or less ($n = 7$); and the high-handicapped group (HHG), who had a handicap between 12 and 20 strokes ($n = 8$). All subjects gave written informed consent to participate in this research and the experimental protocol of this investigation was approved by the Human Research Ethics Committee at the University of South Australia.

	Low-Handicapped Golfers					High-Handicapped Golfers				
	Age (yrs)	Height (m)	Mass (kg)	BMI (kg/m ²)	Handicap (Strokes)	Age (yrs)	Height (m)	Mass (kg)	BMI (kg/m ²)	Handicap (Strokes)
Mean	33.57	1.76	80.71	26.29	6.71*	44.88	1.78	84.50	26.65	13.63*
SD	14.06	0.06	5.19	2.75	2.75	12.29	0.05	6.00	2.43	1.51

Table 1: The mean age, height, mass and handicap of the golfers comprising both the low- and high-handicapped groups. * indicates a significant difference between the groups ($p < 0.01$).

TASK

For the purposes of this research, all data collection took place on a designated grassed area at a local practice driving range, so as to allow the golfers to perform the task in an uninhibited manner. Before data collection commenced, the subjects were allowed as much time as they felt necessary to perform their normal warm-up routine and to familiarise themselves with the surrounding experimental conditions. Following this, the golfers were asked to use their own driver to perform a total of twenty (20) tee-shots using their “natural” technique in the

direction of a flag, which was positioned 320 metres away from the tee. The subjects were free to position themselves and the ball anywhere within a two-metre square area (tee-off box), which was clearly defined on the grass with custom-made markers.

DATA COLLECTION

All subjects were required to wear short-length trousers and a sleeveless top, to assist in the accurate identification of specific anatomical landmarks, which were determined via means of palpation. Two markers made from reflective adhesive tape were placed on the lateral aspect of the subjects' shoes, overlying the fifth metatarsophalangeal joint. In addition to this, reflective joint markers were positioned bilaterally over the lateral malleolus of the fibula; the lateral epicondyle of the femur; the greater trochanter; the temporomandibular joint; the lateral border of the acromion; the lateral epicondyle of the humerus; and the ulnar styloid. Finally, a further two markers were placed on the golf club; one just below the club grip and the second at the base of the shaft, close to the club head. Prior to commencing data collection, a 2.2 m × 1.9 m × 1.6 m calibration frame (Peak Performance Technologies Inc., USA), which comprised 24 points of known three dimensional spatial coordinates (x, y and z) was placed in the tee-off box and filmed to later facilitate the reconstruction of the three-dimensional digitised coordinates.

Whilst performing the golf drives, the subjects were videoed by three genlocked Panasonic SVHS video cameras (Matsushita Electric Industrial Co Ltd., JP), which all had an effective sampling frequency of 50 Hz and a shutter speed of 1/2000th of a second. Although it may be suggested that 50 Hz sampling rate is insufficient to study high-speed movements such as the golf swing, it should be acknowledged that this research aims to assess the general patterns of motion throughout the swing. As previous researchers (Burden et al., 1998; Egret, Nicolle, Dujardin, Weber, & Chollet, 2006; Grimshaw & Burden, 2000) have used similar methods to assess patterns of motion in golf, the use of such equipment was considered adequate to meet the needs of the proposed research. Each camera was positioned at a horizontal distance of 5.625 m from the centre of the tee-off box and at a vertical height of 1.25 m, as measured from the centre of the camera lens. The specific positioning of the videography equipment is illustrated in Figure 1 and is comparable to previous three-dimensional videographic designs used to assess the golf swing (e.g. Burden et al., 1998). In addition, a similar video camera configuration and digitisation process was utilised by Salo, Twigg, Grimshaw and Viitasalo (2006) and Salo, Grimshaw and Viitasalo (2004) in their assessment of kinematic reliability and variability during different camera orientations and set-ups.

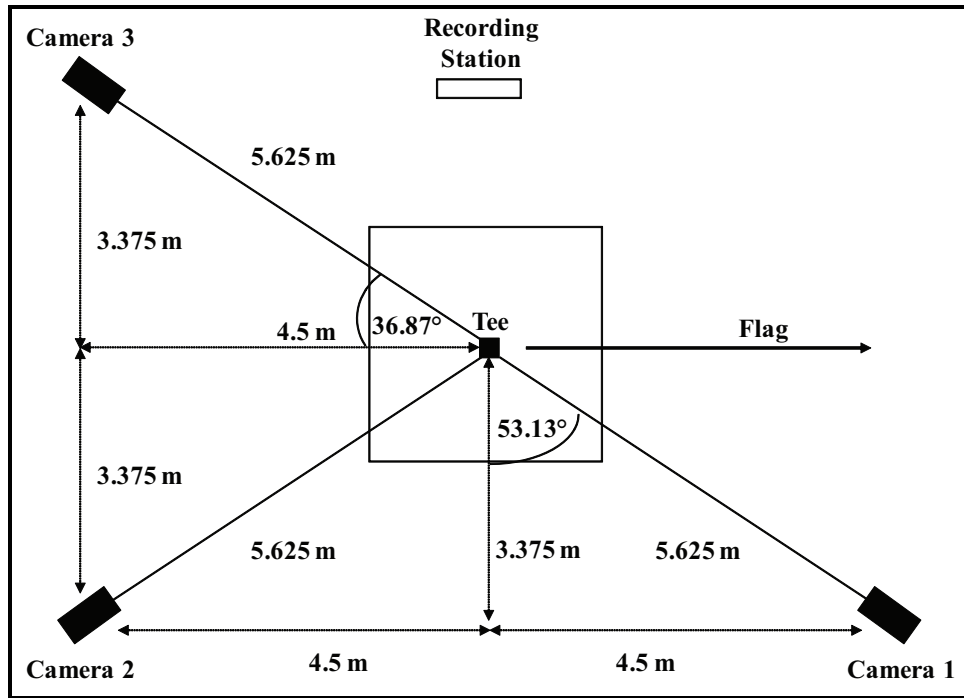


Figure 1: The experimental setup of the videography equipment.

DATA ANALYSIS

For the purposes of calculating the three-dimensional kinematic data, the video footage for the best three swings for each golfer was digitised using Peak Motus 2000 (Peak Performance Technologies Inc., USA) and reconstructed using the direct linear transformation (DLT) algorithm (Abdel-Aziz & Karara, 1971). The selection of these trials was reliant on a qualitative assessment made by the principal researcher on the shot's accuracy (i.e. directed toward the target) and flight path (i.e. no slice/hook and limited draw/fade) following ball contact. In this context, it is important to add that the principal researcher was an experienced golfer who, at the beginning of the experiment, was instructed by a professional golf coach in the correct identification of what characteristics constitute a 'good' golf drive. Following the digitisation procedure and three-dimensional reconstruction, a quintic spline function (Woltring, 1985) was applied to the raw coordinates in order to smooth the data and calculate kinematic quantities. Digitisation of the video data within the Peak Motus 2000 software enabled a three-dimensional full body linked-segment model to be created, which was used to calculate two primary angles; the hip angle; and the shoulder angle. The hip angle was defined as the angle formed between the line joining the hip joint centres and a theoretical line parallel to the y-axis between the tee and the target, as viewed in the transverse plane (Figure 2). Similarly, the shoulder angle was

the angle that was formed between this theoretical line and the line between the shoulder joint centres (estimated using the shoulder markers). For both the hip and shoulder angles, a positive value was indicative of rotation from the neutral position away from the target (closed position), whilst rotation from the neutral position towards the target (open position) was represented by a negative value.

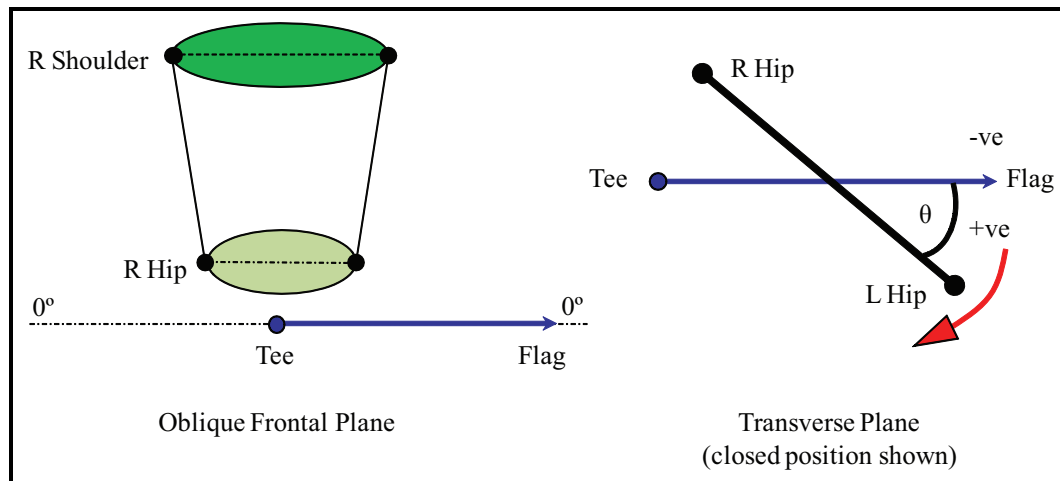


Figure 2: The defined hip and shoulder segments and the method used to calculate the hip and shoulder angles as viewed from the oblique frontal and transverse planes

STATISTICAL ANALYSIS

For the purposes of assessing any differences between the hip and shoulder angles (including the resulting X-Factor) demonstrated by the groups, a non-parametric statistical analysis (Mann-Whitney U), was conducted using SPSS 12.0, with the level of significance set at $p < 0.05$. Unlike parametric statistics, the Mann-Whitney U test does not require the data to be normally distributed (Portney & Watkins, 2000), but it is assumed that the measures within each group are independent and taken from a random sample of the population (Vincent, 1999).

To provide insight into the degree to which the independent and dependent variables were related, effect sizes were calculated using the Cohen's d method (Cohen, 1992). For the purposes of this research, an effect size of less than 0.2 was identified as a negligible effect, whilst an effect size of between 0.2 and 0.5 was classified as small. Similarly, effect sizes of between 0.5 and 0.8 were deemed to be indicative of a medium effect, whilst a value greater than 0.8 was representative of a large effect size (Cohen, 1992). Effect size is a measure of the degree of association that exists between the independent (IV) and dependent variables (DV) and assesses what proportion of the total variance in the DVs (e.g. hip angle, shoulder angle) can be predicted by knowledge of the levels of the IVs (Tabachnick & Fidell, 2007).

RESULTS

HIP ANGLE

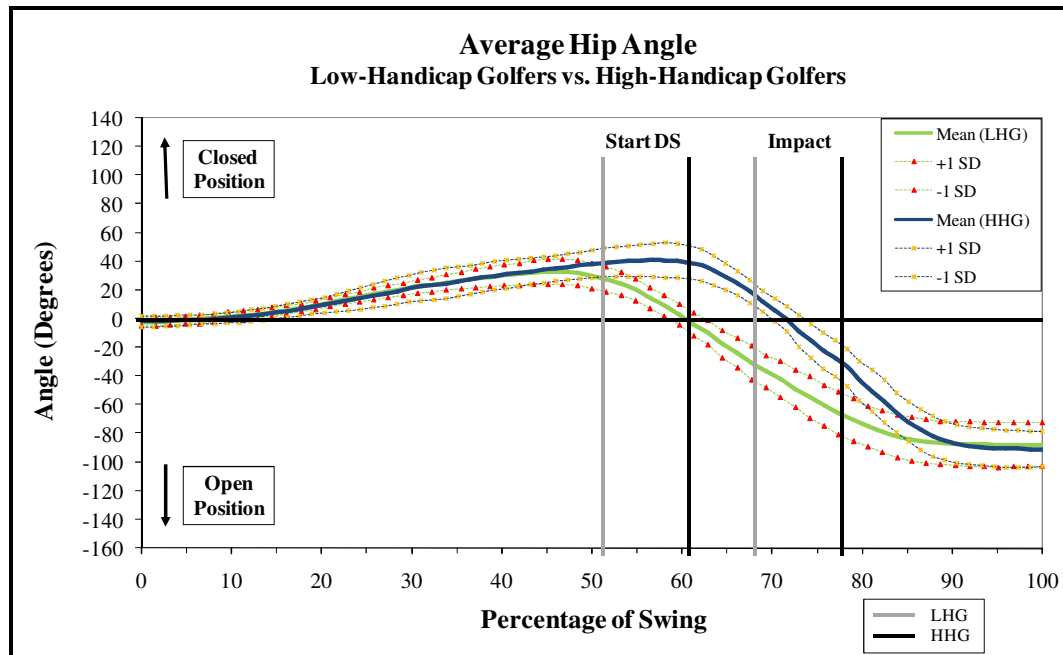


Figure 3: The mean (± 1 SD) hip angle during the backswing, downswing and follow-through for both the low- and high-handicap golfer groups. Event lines show the commencement of the downswing and impact and the two traces conclude at the end of the follow-through.

The data presented in Figure 3 demonstrates that, on average, the golfers comprising the two groups assessed in this research tended to address the ball with their hips in a slightly open position. As the golfers began the backswing, the hip angle increased in both groups, as the hips moved from an open position to a closed position. For both groups of golfers, peak closed hip angle was attained prior to the top of the backswing (TBS), with the LHG demonstrating reduced hip rotation compared with the HHG ($p = 0.132$; $d = 0.82$). From TBS, both groups initiated the downswing with a counter-clockwise rotation of the hips from a closed position to achieve an open position at impact. For the purposes of this research, the top of the backswing/start of the downswing was defined as the first instance that the club head began rotating back towards the flag (i.e. change in swing direction). The results of the statistical analysis confirmed that there was no significant difference between the two groups with respect to their hip angle whilst addressing the ball ($p = 0.728$; $d = 0.09$), at TBS ($p = 0.064$; $d = 0.99$) or at impact ($p = 0.643$; $d = 0.24$).

SHOULDER ANGLE

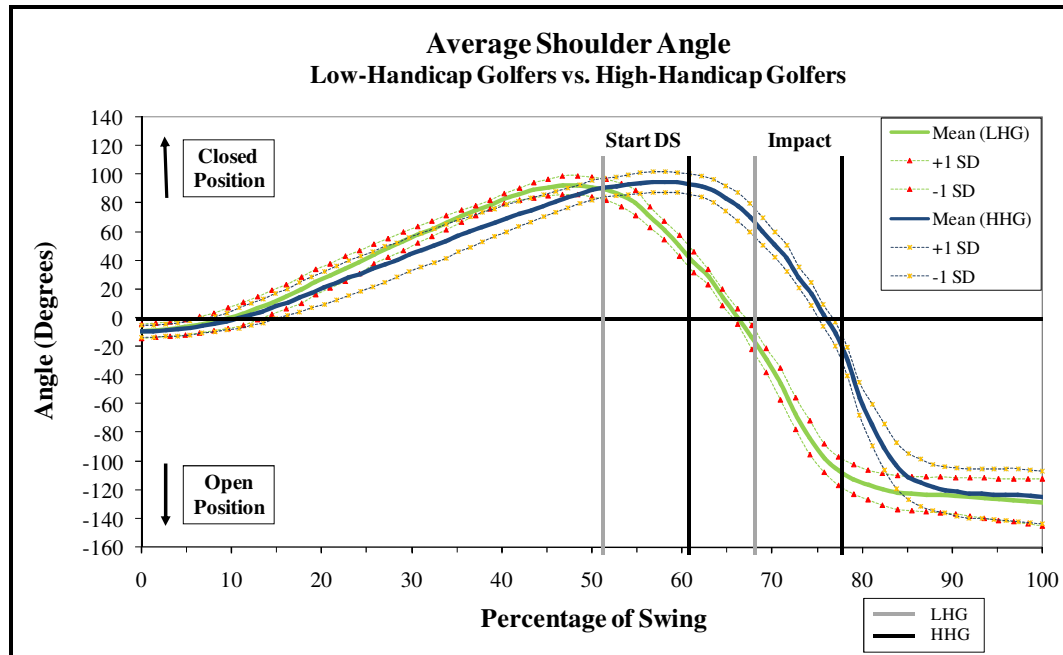


Figure 4: The mean (± 1 SD) shoulder angle demonstrated by both the low- and high-handicap golfers during the backswing, downswing and follow-through phases of the movement. The beginning of the downswing and impact is identified by event lines on the graph, whilst the curves end at the completion of the follow-through.

Following the initiation of the backswing, the shoulder angle rapidly increased, as the shoulders moved into a closed position, reaching peak values at the start of the downswing for both groups of golfers (Figure 4). Throughout the downswing, the shoulder angle decreased as the shoulders rotated back toward the target and finished at the point of impact in an open position for both groups of golfers. Statistical analysis of these results indicated that there were no significant differences between the two groups with respect to the shoulder angles at the address ($p = 0.908$; $d = 0.04$), at the maximum value ($p = 0.298$; $d = 0.41$) or at impact of the club head and the ball ($p = 0.563$; $d = 0.28$).

THE X-FACTOR

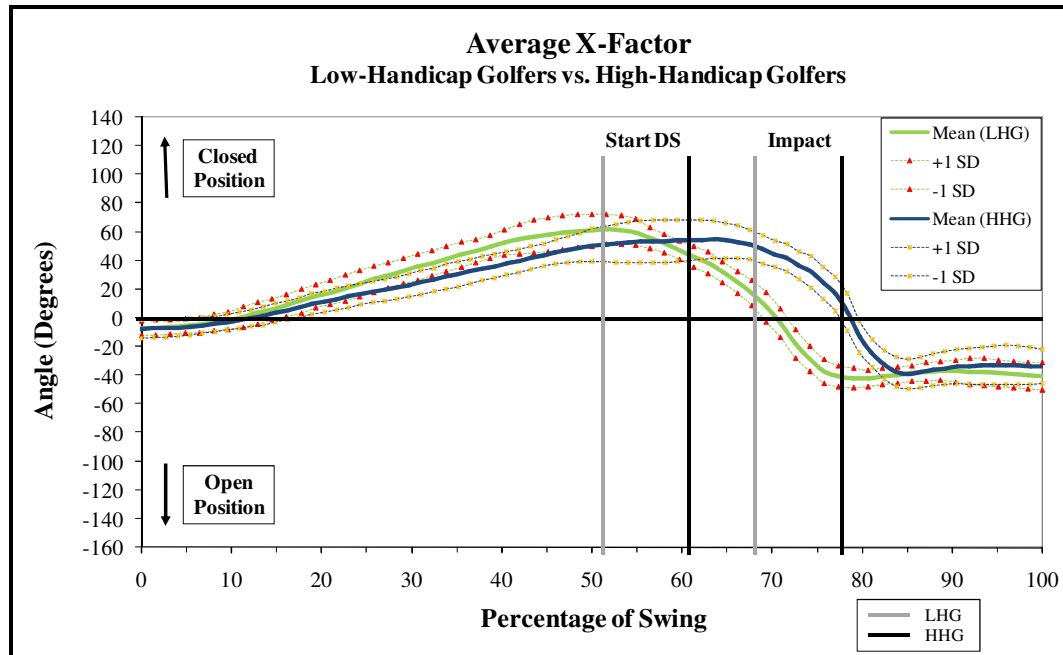


Figure 5: The mean (± 1 SD) hip to shoulder differential (X-Factor) recorded for the low- and high-handicap golfers throughout the golf swing.

Figure 5 shows the calculated X-Factor for the LHG and HHG groups at the address, at TBS, at the point of impact, and the maximum value recorded for each group. These data show that at TBS, the LHG group demonstrated a slightly larger X-Factor compared with the HHG group. However, in the LHG group the maximum X-Factor was recorded 20 milliseconds after the initiation of the downswing, whilst a slight increase was also observed during the early stages of the downswing for the HHG group, who achieved their maximum 40 milliseconds into the downswing. Despite the LHG group demonstrating slightly greater X-Factor values throughout the backswing and initial stages of the downswing, both groups demonstrated comparable hip to shoulder differentials at the point of ball impact. Statistical analysis of these findings indicated that there were no significant differences between the two groups with respect to the hip to shoulder differential reported at TBS ($p = 0.487$; $d = 0.56$) and impact ($p = 0.908$; $d = 0.07$).

With respect to the difference between maximum X-Factor and the X-Factor at the top of the backswing (X-Factor Stretch), the LHG golfer demonstrated a smaller change ($1.47 \pm 2.77^\circ$) than the HHG group ($3.30 \pm 4.23^\circ$). However, the results of the Mann-Whitney U test indicated that there was no significant difference between the groups ($p = 0.298$; $d = 0.51$). The effect sizes

for the assessed variables are given in Table 2. Similarly, the findings presented for the hip and shoulder angle are summarised in Table 3, along with the corresponding X-Factor.

	Effect Size Estimates (Cohen's <i>d</i>)					
	Hip Angle		Shoulder Angle		X-Factor	
	Cohen's <i>d</i>	Effect Size	Cohen's <i>d</i>	Effect Size	Cohen's <i>d</i>	Effect Size
Address	0.09	Negligible	0.04	Negligible	0.08	Negligible
TBS	0.99	Large	0.41	Small	0.56	Medium
Impact	0.24	Small	0.28	Small	0.07	Negligible
Maximum	0.82	Large	0.41	Small	0.46	Small

Table 2: The effect size estimates (Cohen's *d*) for the differences observed between the two groups with respect to the hip and shoulder angles and the X-Factor at the address, the top of the backswing (TBS), at their maximum values and at impact of the club head and the ball.

	Low-Handicapped Golfers						High-Handicapped Golfers					
	Hip Angle		Shoulder Angle		X-Factor		Hip Angle		Shoulder Angle		X-Factor	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Address	-2.2°	2.6°	-9.2°	5.0°	-7.1°	5.0°	-1.9°	3.4°	-9.4°	4.0°	-7.5°	6.0°
TBS	29.9°	8.4°	93.0°	6.8°	61.4°	10.8°	40.3°	12.2°	95.8°	6.9°	54.1°	15.0°
Impact	-30.7°	11.9°	-13.3°	7.8°	17.4°	7.9°	-27.7°	13.4°	-11.0°	8.2°	16.6°	11.8°
Maximum	33.3°	8.6°	93.0°	6.8°	63.5°	9.6°	41.7°	11.8°	95.8°	6.9°	58.3°	13.0°

Table 3: The mean (and SD) values for the hip and shoulder angles and the X-Factor at address, the top of the backswing (TBS) and at impact for both the low and high-handicapped golfers. The average maximum values are also given for the two groups.

DISCUSSION

HIP ANGLE

The results of this study indicated that there were several common characteristics between the LHG and HHG groups with respect to hip rotation throughout the swing. The findings indicated that both groups assumed a slightly open hip position whilst addressing the ball, which was comparable to the group of eight sub-10 handicap golfers (Table 4) assessed by Burden and colleagues (1998). Similarly, in a case study conducted by Grimshaw and Burden (2000), it was reported that the professional golfer also addressed the ball with an open hip angle both prior to and following a structured intervention program. For both the LHG and HHG groups, the maximum hip angle was achieved prior to the completion of shoulder rotation, suggesting that both groups tended to initiate the downswing with a counter-clockwise rotation of the hips (referred to as 'leading with the hips'). 'Leading with the hips' is a common characteristic in the modern golf swing and has been reportedly observed in a high percentage of the golfers involved in several previous research investigations (e.g. Burden et al., 1998; McTeigue et al., 1994). The reduced hip angle demonstrated by the LHG group

(compared with the HHG group) at TBS may be attributable to differences in the playing and practicing history of the two groups. As previously indicated, many coaches and golf professionals promote the restriction of hip rotation during the backswing to accentuate the stretch of the trunk and shoulder muscles and ultimately increase the velocity of the clubhead at impact (Hosea & Gatt, 1996). As the technique of an experienced golfer is typically more refined than that of a less experienced individual (Fradkin, Cameron, & Gabbe, 2005), it is probable that the LHG group would have received more professional coaching aimed at refining their techniques to conform more closely with the ideals of the modern golf swing. Despite this discrepancy, the angles shown for the LHG group at TBS compared well with those angles previously reported at TBS for similar golfing populations (e.g. Burden et al., 1998; Egret et al., 2004). In the study conducted by Egret et al. (2004), fourteen golfers were divided into two handicap-specific groups; 1) expert golfers (mean handicap = 0.4 ± 1.1); and 2) experienced golfers (6.6 ± 1.7). The experienced golfers, who more closely approximated the LHG group of the current study, were shown to rotate their hips to a similar degree during the backswing when compared with the LHG group (Table 4). However, the hip angles recorded in the current investigation at TBS were considerably lower than those presented by Egret and co-workers (2004) for their expert group. Furthermore, McTeigue and colleagues (1994) and Myers et al. (2008) also reported greater hip angles at TBS in their separate investigations involving PGA and Senior PGA golfers and amateur golfers. Whilst it could be argued that differences in methods of data collection (i.e. Swing Motion Trainer vs. 3D videography) could account for the discrepancy observed between the current data and that presented by McTeigue and colleagues (1994), the fact that Egret et al. (2004) and Myers and co-workers (2008) also used 3D videography makes this argument less definitive. With this in mind, it is interesting to note that these highly-skilled golfers rotated their hips extensively, despite the modern golf swing advocating reduced hip rotation to maximise the benefits of the SSC during the latter stages of the backswing and the early stages of the downswing (Burden et al., 1998).

The hip angles reported for the current study at the time of impact were somewhat greater than those presented in the previous research conducted by Burden and colleagues (1998) and Grimshaw and Burden (2000). Conversely, the data published by McTeigue and colleagues (1994) demonstrated that their PGA, Senior PGA and elite amateur golfers assumed a comparable hip position at the point of impact.

		Hip Angle (°)				Shoulder Angle (°)				X-Factor (°)			
Study		Address	TBS	Impact	Max	Address	TBS	Impact	Max	Address	TBS	Impact	Max
Burden et al. (1998)													
<i>Sub-10 Handicap</i>	Mean	-5	na	-20	32	-7	na	-10	102	2	na	10 ^T	70 ^T
	SD	8		13	8	10		17	16	11		9	20
Age = 36.7 ± 7.5													
Egret et al. (2004)													
<i>Expert</i>	Mean	na	52.9	na	na	na	100.6	na	na	na	47.7 ^T	na	na
	SD		9.6				9.9				**		
<i>Experienced</i>	Mean	na	37.9	na	na	na	84.1	na	na	na	46.2 ^T	na	na
	SD		8.1				15.5				**		
Age range = 17 - 37													
Grimshaw & Burden (2000)													
<i>Pro (pre)</i>	Mean	-1.2	9.1	-22.9	na	-4.3	99.9	-4.9	na	2.7	90.2	19.9	na
	SD	4.3	5.1	7.2		1.1	**	**		4.7	4.2	11.7	
<i>Pro (post)</i>	Mean	1.7	31.9	-12.9	na	4.9	101.6	21.9	na	2.5	68.6	35.3	na
	SD	3.6	10.0	6.2		2.6	**	**		2.7	10.0	8.2	
Age = 22													
McTeigue et al. (1994)													
<i>PGA</i>	Mean	na	55	-32	na	na	87	-26	na	5	32 ^T	6 ^T	na
	SD		3	3			3	3		1	**	**	
<i>Senior PGA</i>	Mean	na	49	-34	na	na	78	-28	na	5	29 ^T	6 ^T	na
	SD		3	4			4	4		1	**	**	
<i>Amateur</i>	Mean	na	53	-35	na	na	87	-27	na	5	34 ^T	8 ^T	na
	SD		4	3			4	3		1	**	**	
Age = not stated													
Myers et al. (2008)													
<i>Low velocity</i>	Mean	na	49.8	29.4	53.2	na	94.0	20.3	95.4	na	44.2	na	45.6
	SD		11.4	8.6	10.6		13.5	10.2	13.2		7.7		8.0
<i>Medium velocity</i>	Mean	na	47.5	35.3	51.3	na	97.0	22.8	98.3	na	49.5	na	51.7
	SD		17.4	17.0	16.5		20.2	16.1	19.9		9.6		10.3
<i>High velocity</i>	Mean	na	44.9	38.3	50.4	na	104.0	25.2	106.1	na	59.1	na	61.8
	SD		10.3	7.2	10.1		10.3	8.9	10.6		8.2		7.8
Age = 45.1 ± 15.9													

na Variable was not assessed in this study

** Standard deviation was not presented and could not be calculated from the available data

^T Values calculated post-hoc based on the data presented by the authors

Table 4: Summarises the findings (mean values and SDs) of previous research concerned with assessing hip and shoulder rotation and/or the X-Factor during the golf swing.

SHOULDER ANGLE

The data presented in Figure 4 and Table 3 demonstrate that there were no significant differences between the LHG group and the HHG group with respect to the shoulder angle at any of the major events throughout the swing. The open shoulder angle reported for the LHG and HHG groups at ball address was comparable to the shoulder position assumed by the eight right-handed sub-10 handicap golfers assessed by Burden et al. (1998). Alternatively, the shoulder position at address reported for the LHG and HHG groups tended to be somewhat greater than those published for a professional golfer both prior to and following three months of muscle conditioning and coaching (Grimshaw & Burden, 2000).

Maximum shoulder rotation angles were recorded at the completion of the backswing (i.e. the start of the downswing) for both the LHG and HHG groups. These data compare well with the findings of McTeigue and colleagues (1994), which demonstrated that a group of PGA and elite amateur golfers achieved maximum shoulder angles of close to 90° at the top of the backswing (Table 4). Despite being comparable to those data published by McTeigue et al. (1994), the shoulder angles recorded at the top of the backswing tended to be slightly lower than those presented in the majority of the literature (e.g. Burden et al., 1998; Egret et al., 2004; Grimshaw & Burden, 2000; Mitchell et al., 2003; Myers et al., 2008). In their study, Mitchell and colleagues (2003) presented data for three age-specific groups of golfers, including college (18-24 yrs); middle (25-49 yrs); and senior (≥ 50 yrs). In general, the findings of these studies (Table 4) tended to suggest that maximum closed shoulder angles of around 100° could be expected for professional and skilled amateur golfers (Burden et al., 1998; Grimshaw & Burden, 2000; Mitchell et al., 2003). In addition to this, the expert golfers tested by Egret and colleagues (2004) also demonstrated shoulder angles in excess of 100 degrees at TBS, whilst the angle reported for the group of experienced golfers at this point was considerably less. Interestingly, Myers et al. (2008) reported mean shoulder angles of 94°, 97°, and 104° for golfers who produced low, medium and high ball velocities, which suggested that better golfers were more likely to demonstrate increased shoulder rotation at TBS. The findings of the current study did not support this notion.

Both the LHG and HHG groups rotated their shoulders through a large range of motion following the initiation of the downswing (LHG = 106.3°; HHG = 106.7°), finishing with their shoulders in an open position at ball impact. These results were comparable to those presented by Burden and colleagues (1998), but were considerably lower than those presented by McTeigue et al. (1994) and Myers and co-workers (2008). Alternatively, the shoulder angles presented in the current investigation were markedly higher than those angles published by Grimshaw and Burden (2000) for their professional golfer both prior to and following the three-month period of intervention.

Although a considerable amount of consistency was observed between the LHG and HHG groups with respect to the patterns of shoulder rotation throughout the golf swing, it is interesting to note the disparity that exists between the values presented in this study and between other research studies of a similar nature. A possible explanation for these inter-study differences could be inconsistencies in the definition used to describe the start of the downswing in the respective studies. For example, in the current study and the work conducted previously by Burden et al. (1998) and Grimshaw & Burden (2000), the start of the downswing was identified as the point at which the club head changed direction in the frontal plane. Alternatively, separate research may have used the alternate method,

which defines the start of the downswing as the point at which the hips cease rotating in a clockwise direction (away from the target) and begin rotating back towards the flag (counter-clockwise rotation). In situations where the latter definition was used, it would be expected that hip angles at the top of the backswing would be greater, as these values would tend to correspond to the maximum hip rotation angle. Alternatively, if the former definition was used, the hips are likely to have already begun rotating back towards the target before the start of the downswing, which would result in a smaller angular measurement at this point. An alternate explanation for the variation in these data could be differences in the methods used to calculate these variables. For example, recent research (Wheat, Vernon, & Milner, 2007) has suggested that markers placed on moveable joint positions (such as the acromion process on the scapula) may be subject to large variation, which suggests that a universal method of measurement is needed for future research.

THE X-FACTOR

The results of this study failed to show any significant differences between the LHG and HHG groups with respect to the X-Factor at address or at impact of the club head and the ball. While not significant, it is important to point out that the LHG group did tend to achieve increased X-Factor values at TBS when compared with the less-skilled golfers. However, it is important to consider that the golfers comprising the HHG group tended to be older than the LHG group ($p = 0.105$; $d = 0.92$). As it is well established that the range of hip, vertebral and shoulder joint motion is reduced with increased age (e.g. Morgan, Sugaya, Banks, Moriya, & Cook, 1999; Thériault & Lachance, 1998), it could be equally feasible to suggest that the reduced maximum values recorded by the less skilled golfers was influenced by this difference in age distribution, rather than the golfers' handicap. With respect to the change in X-Factor during the early downswing, it is interesting to note that the HHG group demonstrated a slightly greater increase when compared with the skilled golfers. These findings are in contrast to those presented by Cheetham and co-workers (2001), who reported that the X-Factor Stretch was observed in both professional and less-skilled golfers, but it was significantly greater in the professional players.

In general, the X-Factor values recorded during the address phase were somewhat higher than those previously reported in similar research (e.g. Burden et al., 1998; Grimshaw & Burden, 2000; McTeigue et al., 1994). Similarly, the hip to shoulder differentials at TBS for the LHG and HHG groups were comparable to the values reported by Myers and colleagues (2008) for the medium and high ball velocity groups. Conversely, the hip to shoulder differential for both the LHG and HHG groups at TBS tended to be less than that

reported in previous research (e.g. Burden et al., 1998; Grimshaw & Burden, 2000). In their investigation, Grimshaw and Burden (2000) suggested that prior to the three-month period of muscle conditioning and coaching, their professional golfer demonstrated an exceptionally large X-Factor at TBS, which was suggested to result in larger torsional loads on the lumbar spine. However, following the period of intervention the authors reported that the X-Factor had been reduced considerably, which was important in reducing the torque acting on the lower back and alleviating their subject's low back pain.

DRIVE CONSISTENCY

Although there were no statistically significant differences between the LHG and HHG groups with respect to the patterns of hip and shoulder rotation or the resulting X-Factor (and X-Factor Stretch), it is important to consider that only the best three swings for each of the golfers were considered for this study. As a player's handicap is based on their consistency around the 18 holes and over a number of rounds, it can be inferred that the difference between these groups (with respect to playing ability) is not related to the mechanics of their golf swing, but to their consistency in performing this complex movement repeatedly during a game. The findings of this investigation demonstrated that the LHG group tended to produce more acceptable drives (as determined by the principal researcher's assessment) from the total of their twenty attempts (13.7 ± 2.0) than the HHG group of golfers (9.9 ± 3.1); a finding that was found to be significantly different ($p = 0.021$, between groups).

The lack of statistically significant differences between the two groups provides a clear indication that these golfers demonstrated very similar patterns of hip and shoulder rotation whilst performing a series of tee-shots. This finding was consistent with the previous work comparing different levels of golfers presented by McTeigue and colleagues (1994) and Egret and co-workers (2004). However, it is also important to identify that it is perhaps in contrast to the work of Cheetham et al. (2001) who suggested that the better golfers have a greater X-Factor Stretch at the start of the downswing (i.e. by turning their lower body faster than their upper body). Similarly, research by Burden et al. (1998) also presented this conclusion in a study on a group of eight low handicap golfers. However, if such data is to be used to attempt to quantify the torque on the lumbar spine (as in the case of low back pain research) then some clarification of the reliability of the hip and shoulder angle measurement is required. Future research should be directed towards establishing how well these measures represent the "real" hip and shoulder angles, which are created by the complex anatomical joints.

LIMITATIONS

Due to the nature of this research, there were several limitations that should be considered when evaluating the results and the inferences made throughout the manuscript. Firstly, it is important to acknowledge that the size of the sample populations was small (from a statistical standpoint). However, effect sizes were calculated for the variables assessed to support the statistical analysis and it is recommended that readers consider these when reviewing the findings. Secondly, despite the fact that the methods used in this research have been employed previously (e.g. Burden et al., 1998; Grimshaw & Burden, 2000; Mitchell et al., 2003; Myers et al., 2008), it is important to point out the potential shortcomings of these methods. For example, the most lateral point on the acromion (the acromion process, which was used for digitisation in this study) is not the true anatomical joint centre location of the shoulder and yet, it is the point that is often used to determine the axis that represents the shoulder angle. The acromion process will move throughout the swing due to factors that are not specifically shoulder joint related and, due to scapular retraction and protraction may lead to increased shoulder joint rotation angles being recorded at the top of the backswing (Wheat et al., 2007). Therefore, it may be important for future research to develop and implement a standardised method for measuring these kinematic characteristics in golf, particularly if such angles are to be used to identify elements that are related to performance and injury. Finally, it is important to consider that the lack of significant findings may have been due to an insufficient discrimination between the groups with respect to their driving capabilities. Although the groups differed significantly ($p = 0.001$, see Table 1) with respect to handicap, it is well understood that driving performance does not necessarily correlate with lower handicaps, as some players demonstrate reduced strokes in their short game (e.g. pitching or putting).

CONCLUSIONS

The results of this study demonstrated that the patterns of shoulder rotation demonstrated by the low-handicapped and high-handicapped golfers were similar during the performance of a tee-shot. However, a large effect size indicated that the high-handicap golfers tended to achieve a greater hip angle at the top of the backswing when compared with the low-handicap group. The increased maximum X-Factor values recorded for the low-handicap golfers provided support for a possible relationship between golfing performance and X-Factor Stretch; however, the significance of this finding is questionable given the age difference that exists between the two groups. In addition to these findings, this research emphasised the general lack of consensus between this and previous

research concerned with describing the kinematic patterns of the hips and shoulders during the golf swing. A possible reason for the divergence that exists between the studies could be related to the methods used to define and calculate joint angles. With this in mind, it may be reasonable to suggest that a universal standard of measurement is required to help improve the level of agreement between different data sources and enhance the overall quality of future research in this area. For example, the absolute X-Factor value does not appear to provide insight into the potential benefits of an increased hip-to-shoulder differential angle at the top of the backswing. However, it may be feasible to suggest that a normalised X-Factor value (e.g. normalised to the maximum voluntary range of trunk rotation) could better highlight any differences that might exist between skilled and less skilled players. This approach has been used previously by Lindsay and Horton (2002) to assess trunk kinematics in golfers with low back pain. Their findings suggested that the normalised trunk rotation values demonstrated that injured golfers consistently rotated their trunk through an excessive range (>100%) during the swing, which could have had implications for structural overload and damage (Lindsay & Horton, 2002). The introduction of a standard may not only be important in establishing the significance (or lack thereof) of the X-Factor to golfing performance, but may also be particularly pertinent in providing scientists with a better understanding of the mechanical relationship between the X-Factor and low back injuries.

REFERENCES

- Abdel-Aziz, Y. I., & Karara, H. M. (1971). *Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry*. Paper presented at the Symposium on Close-Range Photogrammetry, Urbana, Illinois.
- Australian Bureau of Statistics. (2007). *Participation in sport and physical recreation* (No. 4177.0). Canberra: Australian Bureau of Statistics.
- Burden, A. M., Grimshaw, P. N., & Wallace, E. S. (1998). Hip and shoulder rotations during the golf swing of sub-10 handicap players. *Journal of Sports Sciences*, 16(2), 165-176.
- Cheetham, P. J., Martin, P. E., Mottram, R. E., & St. Laurent, B. F. (2001). The importance of stretching the "X-Factor" in the downswing of golf: The "X-Factor Stretch". In P. R. Thomas (Ed.), *Optimising Performance In Golf* (pp. 192-199). Brisbane: Australian Academic Press.
- Cohen, J. (1992). A power primer. *Psychological Bulletin*, 112, 155-159.
- Egret, C. I., Dujardin, F. H., Weber, J., & Chollet, D. (2004). 3-D kinematic analysis of the golf swing of expert and experienced golfers. *Journal of Human Movement Studies*, 47, 193-204.

- Egret, C. I., Nicolle, B., Dujardin, F. H., Weber, J., & Chollet, D. (2006). Kinematic analysis of the golf swing in men and women experienced golfers. *International Journal of Sports Medicine*, 27, 463-467.
- Enoka, R. M. (1994). *Neuromechanical Basis of Kinesiology* (2nd ed.). Champaign, IL: Human Kinetics.
- Fradkin, A. J., Cameron, P. A., & Gabbe, B. J. (2005). Golf injuries: Common and potentially avoidable. *Journal of Science and Medicine in Sport*, 8(2), 163-170.
- Gosheger, G., Liem, D., Ludwig, K., Greshake, O., & Winkelmann, W. (2003). Injuries and overuse syndromes in golf. *American Journal of Sports Medicine*, 31(3), 438-443.
- Grimshaw, P. N., & Burden, A. M. (2000). Case report: Reduction of low back pain in a professional golfer. *Medicine and Science in Sports and Exercise*, 32(10), 1667-1673.
- Hosea, T. M., & Gatt, C. J. (1996). Back pain in golf. *Clinics in Sports Medicine*, 15(1), 37-53.
- Hume, P. A., Keogh, J., & Reid, D. (2005). The role of biomechanics in maximising distance and accuracy of golf shots. *Sports Medicine*, 35(5), 429-449.
- Kim, D. H., Millett, P. J., & Warner, J. J. P. (2004). Shoulder injuries in golf. *American Journal of Sports Medicine*, 32(5), 1324-1330.
- Lindsay, D. M., & Horton, J. F. (2002). Comparison of spine motion in elite golfers with and without low back pain. *Journal of Sports Sciences*, 20(8), 599-605.
- McLean, J. (1992). Widen the gap. *Golf Magazine*, 34(12), 49-53.
- McTeigue, M., Lamb, S. R., Mottram, R., & Pirozzolo, F. (1994). Spine and hip motion analysis during the golf swing. In A. J. Cochran & M. R. Farrally (Eds.), *Science and Golf II: Proceedings of the World Scientific Congress of Golf* (pp. 50-58). London: E & FN Spon.
- Mitchell, K., Banks, S., Morgan, D., & Sugaya, H. (2003). Shoulder motions during the golf swing in male amateur golfers. *Journal of Orthopaedic and Sports Physical Therapy*, 33(4), 196-203.
- Morgan, D., Sugaya, H., Banks, S., Moriya, H., & Cook, F. (1999). The influence of age on lumbar mechanics during the golf swing. In M. R. Farrally & A. J. Cochran (Eds.), *Science and Golf III: Proceedings of the World Scientific Congress of Golf* (pp. 120-126). Champaign, IL: Human Kinetics.
- Myers, J., Lephart, S., Tsai, Y. S., Sell, T., Smoliga, J., & Jolly, J. (2008). The role of upper torso and pelvis rotation in driving performance during the golf swing. *Journal of Sports Sciences*, 26(2), 181-188.

- Portney, L. G., & Watkins, M. P. (2000). *Foundations of clinical research: Applications to practice* (2nd ed.). Upper Saddle River, NJ: Prentice Hall.
- Richards, J., Farrell, M., Kent, J., & Kraft, R. (1985). Weight transfer patterns during the golf swing. *Research Quarterly for Exercise and Sport*, 56(4), 361-365.
- Salo, A. I. T., Grimshaw, P. N., & Viitasalo, J. T. (2004). Influence of camera orientations on three-dimensional motion analysis. *Journal of Human Movement Studies*, 47, 253-267.
- Salo, A. I. T., Twigg, D., Grimshaw, P. N., & Viitasalo, J. T. (2006). Extrapolation errors in controlled three-dimensional video camera set-ups. *Journal of Human Movement Studies*, 50, 1-18.
- Seaman, D. R., & Bulbulian, R. (2000). A review of back pain in golfers: Etiology and prevention. *Sports Medicine, Training and Rehabilitation*, 9(3), 169-187.
- Sherman, C. A., & Finch, C. F. (2000). Preventing injuries to competitive and recreational adult golfers: What is the evidence? *Journal of Science and Medicine in Sport*, 3(1), 65-78.
- Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.). Boston, MA: Pearson Education, Inc.
- Thériault, G., & Lachance, P. (1998). Golf injuries: An overview. *Sports Medicine*, 26(1), 43-57.
- Vincent, W. J. (1999). *Statistics in kinesiology* (2nd ed.). Champaign, IL: Human Kinetics.
- Wheat, J. S., Vernon, T., & Milner, C. E. (2007). The measurement of upper body alignment during the golf drive. *Journal of Sports Sciences*, 25(7), 749-755.
- Woltring, H. J. (1985). On optimal smoothing and derivative estimation from noisy displacement data in biomechanics. *Human Movement Science*, 4(3), 229-245.