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.

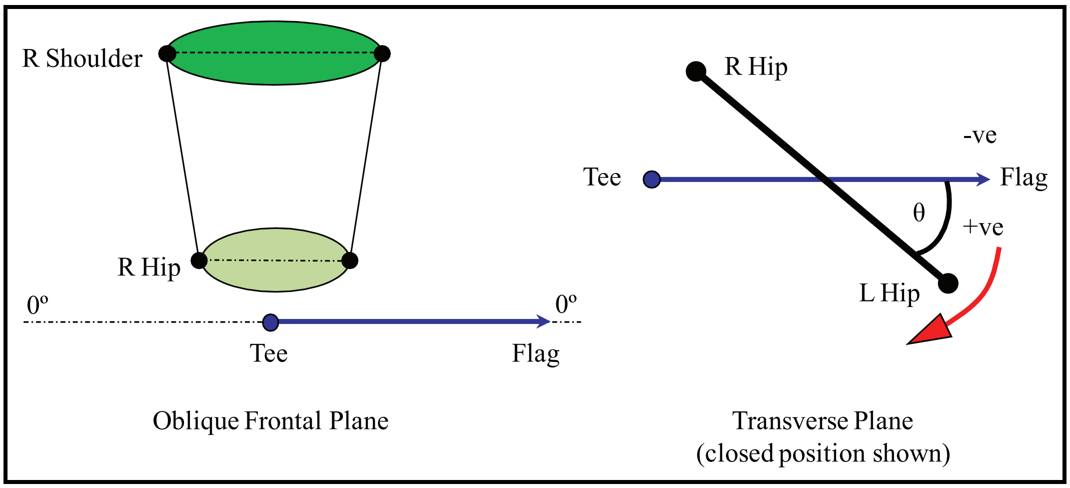

Figure 2: The defined hip and shoulder segments and the method used to calculate the hip and shoulder angles as viewed from the oblique frontal and transverse planes

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).

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RESULTS
HIP ANGLE

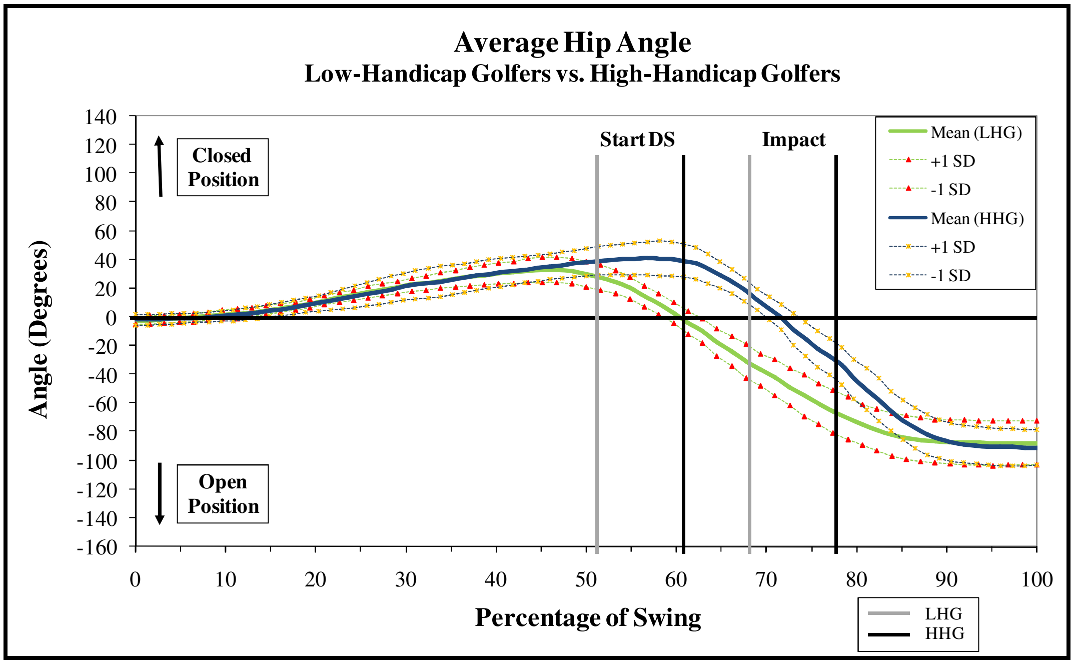

Figure 3: The mean (± 1 SD) hip angle during the backswing, downswing and follow-through for both the low- and high-handicap golfer groups. Event lines show the commencement of the downswing and impact and the two traces conclude at the end of the follow-through.

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

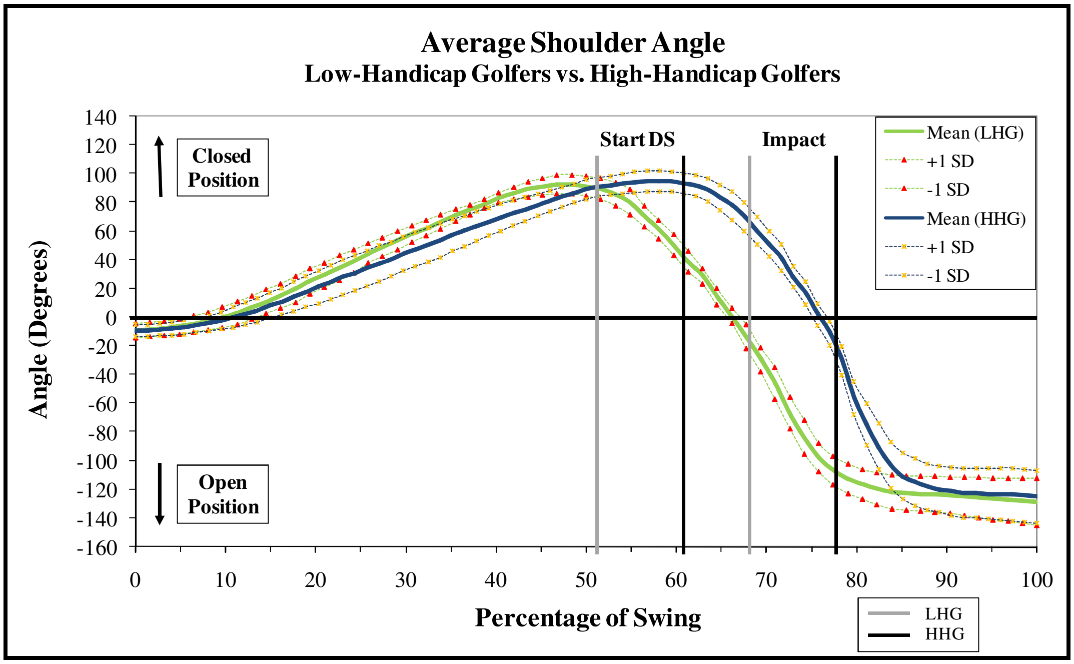

Figure 4: The mean (± 1 SD) shoulder angle demonstrated by both the low- and high-handicap golfers during the backswing, downswing and follow-through phases of the movement. The beginning of the downswing and impact is identified by event lines on the graph, whilst the curves end at the completion of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

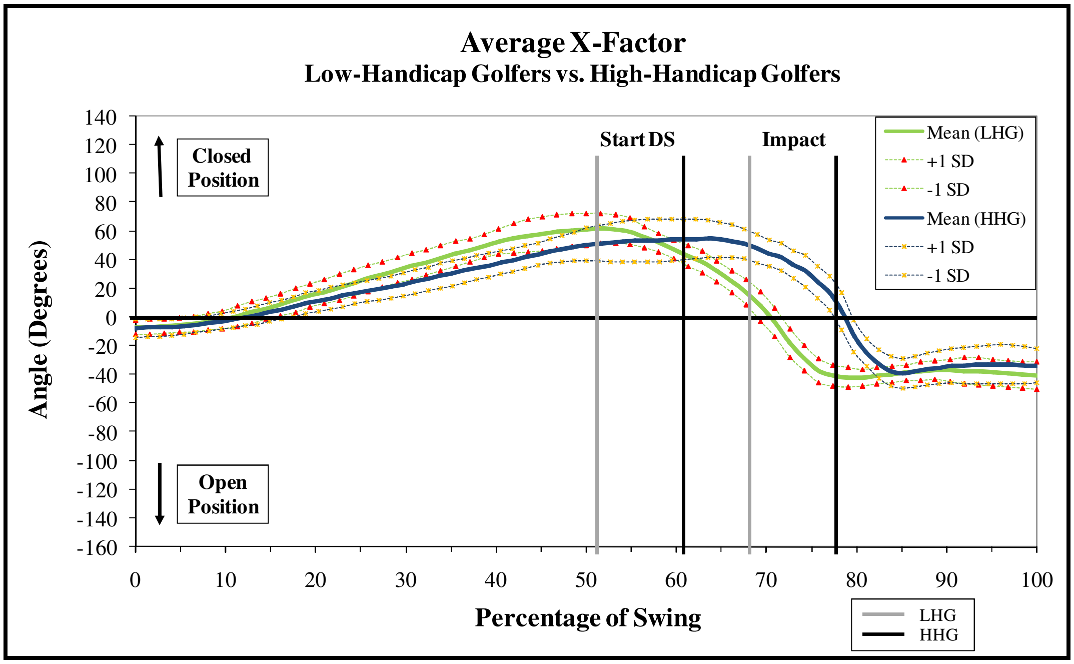

Figure 5: The mean (± 1 SD) hip to shoulder differential (X-Factor) recorded for the low- and high-handicap golfers throughout the golf swing.

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 ± 2.77°) than the HHG group (3.30 ± 4.23°). 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 *d*)					
	Hip Angle		Shoulder Angle		X-Factor	
	Cohen's *d*	Effect Size	Cohen's *d*	Effect Size	Cohen's *d*	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)													
Sub-10 Handicap	**Mean**	**-5**	na	**-20**	**32**	**-7**	na	**-10**	**102**	**2**	na	**10Ŧ**	**70Ŧ**
	SD	*8*		*13*	*8*	*10*		*17*	*16*	*11*		*9*	*20*
Age = 36.7 ± 7.5													
Egret et al. (2004)													
Expert	**Mean**	na	**52.9**	na	na	na	**100.6**	na	na	na	**47.7Ŧ**	na	na
	SD		*9.6*				*9.9*				**		
Experienced	**Mean**	na	**37.9**	na	na	na	**84.1**	na	na	na	**46.2Ŧ**	na	na
	SD		*8.1*				*15.5*				**		
Age range = 17 - 37													
Grimshaw & Burden (2000)													
Pro (pre)	**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*	
Pro (post)	**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)													
PGA	**Mean**	na	**55**	**-32**	na	na	**87**	**-26**	na	**5**	**32Ŧ**	**6Ŧ**	na
	SD		*3*	*3*			*3*	*3*		*1*	**	**	
Senior PGA	**Mean**	na	**49**	**-34**	na	na	**78**	**-28**	na	**5**	**29Ŧ**	**6Ŧ**	na
	SD		*3*	*4*			*4*	*4*		*1*	**	**	
Amateur	**Mean**	na	**53**	**-35**	na	na	**87**	**-27**	na	**5**	**34Ŧ**	**8Ŧ**	na
	SD		*4*	*3*			*4*	*3*		*1*	**	**	
Age = not stated													
Myers et al. (2008)													
Low velocity	**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*
Medium velocity	**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*
High velocity	**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
Ŧ 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

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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.