The relationship between hip torque and club head angular velocity in the driver swing of sub 5 handicap golfers

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Abstract

Despite interest in the literature concerning the angular kinematics of the upper limbs and torso, little has been written about rotation in the lower limbs, or the forces, or moments, within the hip joints during the drive, despite the fact that "loading the hips", and providing resistance to trunk turn by keeping the hips and pelvis stable, are common coaching themes. The purpose of this study was therefore to investigate the relationship between the magnitude of the moments (measured about the vertical axis) within the right and left hips, and maximum the club head angular velocity, at three different golf drive intensities; easy, medium and full strength.

Participants (N=8) performed 18 golf drives; six at each intensity. The drives were performed while standing with their feet on two Kistler force plates, sampling at 1kHz, with an "Airflow" ball on a tee mounted within a golf practise mat. Kinematic data were sampled at 200Hz using a Vicon motion capture system. Data were analysed using Nexus Version 1.4 software. Moments about the hip were calculated using inverse dynamics and a purpose developed kinematic model.

Significant correlations were found between club head angular velocity at the moment of impact with the ball for both left maximum hip moment (r = .999, P= .017) and right maximum hip moment (r = -0.996, P= .028).

The findings suggest that anecdotal evidence concerning the importance of the moments in the hips in achieving driving distance is supported.

Keywords: hip torque, hip moments, hip rotation, golf club head speed, golf club head angular velocity

Introduction

Farrally et al. (2003) estimate that biomechanical studies of the golf swing account for 21% of golf related published papers. Of these, several studies have examined the ground reaction forces (GRF), where the main focus has been on understanding, and quantifying, weight shift throughout the golf swing (Barrentine et al. 1994; Koenig et al. 1994; Gatt et al. 1998, and Dillman & Lange. 1994). Hume et al. (2005) summarises the GRF findings, reporting that body weight is shifted onto the trail foot during the backswing, and then transferred to the front foot during the downswing in an attempt to achieve a greater club head angular velocity.

Despite the interest in the ground reaction forces during the golf drive, few studies have examined the moments at the foot-ground interface, and still fewer have examined the internal joint moments of the lower limbs. Barrentine et al. (1994) attempted to quantify GRF and moments of professional and amateur golfers, and found that mean internal rotation moments of the lead and trail foot were, 23.45 ± 7.13 Nm and 21.98 ± 9.73 Nm respectively. It was also noted that PGA professionals exhibited significantly more internal rotation torque about the lead foot than high handicappers (16+). Worsfold et al. (2008) also found that lower handicap golfers experienced higher torque values exerted by the feet when using a driver, and reported similar mean values for lead foot internal rotation (22 Nm).

Gatt et al. (1998) studied the torque generated at the knee joint during the golf swing and found that maximum external moments of the lead knee were higher than in the trail knee (27.7 Nm and 19.1 Nm respectively), but that maximum internal rotation torque of the lead knee was slightly lower than the trail knee (16.1±4.8 Nm and 19.6±8.1 Nm respectively).

These studies give an insight into the kinetics of the lower extremities, however as the hips play an important role in the transfer of angular momentum from the legs to the upper body, and in pelvic stabilisation, this needs to be examined and quantified in more detail. The purpose of this study was therefore to quantify the internal and external hip moments during the golf swing, and to determine if increased hip joint moments are related to peak club head angular velocity.

Swing kinematics

The golf drive has been defined as having three distinct phases, the backswing, downswing and follow through, and the seven key positions are defined as: address (A), mid backswing MBS), top of the backswing (TBS), mid downswing (MDS), impact (I), mid follow through (MFT) and top of the follow through (TFT). (Hume et al. 2005, Robinson, 1994, McLaughlin & Best, 1994).

Initiation of the backswing involves the club head being taken away from the target "on plane", which Maddalozzo (1987) define as the inclination angle running from the golf ball to the shoulders (Lowe,1994). This is achieved by the trunk and pelvis rotating to the right (for right handed golfers), causing the right hip to internally rotate, and the left hip to externally rotate (Hume et al. 2005), Figure 1. Once the desired pelvic rotation has been achieved, the right hip resists further internal rotation, and there is a build up of eccentric muscle action to maintain a stable hip-pelvis relationship as the trunk and shoulders continue to rotate. On the downswing the reverse is true, the pelvis turns back towards the target causing the left hip to internally rotate and the right hip to externally rotate (Myers et. al. 2007).

During the follow through the left hip then continues to internally rotate resisted by eccentric muscle action in order to decelerate the pelvic rotation; to achieve a balanced and stable end position (Hume et al. 2005). The focus of these movements is to ultimately achieve maximum club head angular velocity, ball displacement and accuracy (Maddalozzo, 1987).

Summary

After reviewing the literature it can be noted that there is a lack of research on rotations of the lower limbs during the golf swing, despite the fact that restricting hip turn to increase resistance between the trunk and pelvis has been shown to improve club head speed, and is a common coaching theme (Cheetham et al, 2000; Hume et al. 2005, McTeigue et al. 1994). The aim of this study was to investigate the nature of the relationship between internal and external hip moments and club head angular velocity in driver swings in golf.

Method

Ethical clearance for this study was sought and obtained from the Institutional Ethical Committee, and all participants gave their informed consent before taking part.

This was a single group repeated measures study design.
The independent variable was defined as swing angular velocity at impact; at each of three swing intensities; an easy paced swing, defined as a swing the player would use if they needed to exercise care to keep the golf ball on the fairway or to “lay up”, a medium strength swing, defined as a typical driver swing if there was little trouble located on the fairway, and a full strength swing, defined as a swing the player would use when trying to hit the golf ball as far as possible.

The kinetic dependent variables were the maximum internal and external rotation moment generated in the right and left hip joints for each swing intensity, the right and left hip moment as a function of time throughout the golf swing, and at each key position.

The kinematic dependent variables were the maximum club head angular velocity, the club head angular velocity as a function of time throughout the golf swing, and at each key position for each swing intensity.

Participants

Eight healthy, right handed, male participants took part in the study. The participants had a mean (± standard deviation) age, mass, height and handicap of 21 (± 1.1) years, 85.3 (± 19.3) kg, 1.80 (± 0.06), and 3 (± 1.5) respectively. All participants were free from injury at the time of testing.

Participant anthropometric data, including: height, mass, leg length, knee width, ankle width, elbow width, wrist width and hand width, were obtained. The club length and mass was also measured (m and kg, respectively). Reflective markers were attached to 39 surface anatomical landmarks, using double sided adhesive tape, according to a customised golf model data set (Gay, 2010). Reflective tape and one reflective marker were also used to define four additional markers on the golf club; at the proximal end adjacent to the grip, the middle of the club shaft, at the distal end of the shaft close to the club head and on the distal end of the club head.

Motion Capture

A Vicon motion capture system (Vicon, Oxford, UK) was used to capture the participants' golf swings in three dimensions. Twelve infrared cameras (MX T20, 2 megapixels) were positioned around two slimline force plates (Kistler Instrument Corporation, Amhurst, NY). The frame rate was set at 200 Hertz (Hz) with a calibration accuracy of < 1.5 millimetres (mm). Static calibration and dynamic calibration of the Vicon system were completed using the wand calibration method according to manufacturer's guidelines. Calibration of the force plates was completed in accordance with the manufacturer's guidelines. The force plates were set flush within the flooring, and the sampling rate was set at 1000 Hz.

Internal and external hip rotation moments were calculated using inverse dynamics based on the angular algorithm developed by Purdom (1970) in the Vicon Nexus 1.4 Polygon software (Vicon, Oxford, UK); using estimated segmental masses from cadaveric data (Dempster & Gaughran, 1967), the anthropometric data obtained from the participants, and the X, Y and Z components of the GRF measured by the force plate. Positive moments were derived during counter clockwise rotations, such as left hip internal rotation during the downswing in golf (when viewed from above), and negative moments were derived during clockwise rotations, such as right hip external rotation during the downswing (when viewed from above) (Figure 1).

Joint centres (ankle, knee, hip, trunk, shoulder, elbow and wrist) were calculated in accordance with Davis et al. (1991).

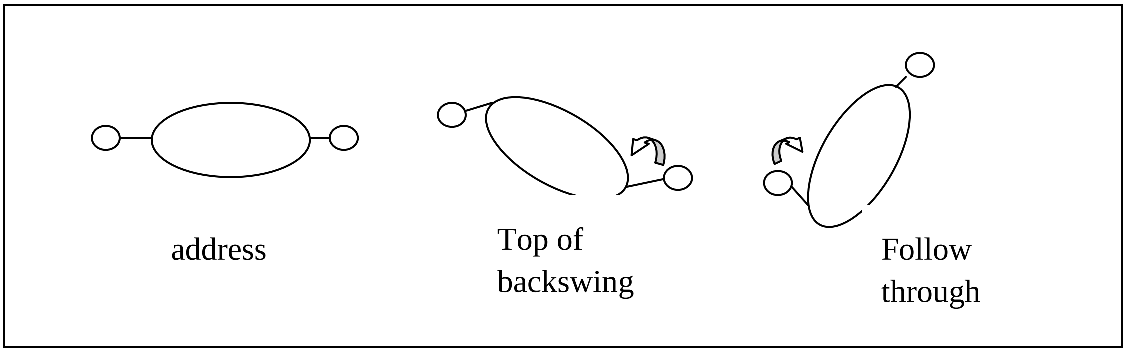

Figure 1. The internal and external rotation of the hips relative to the pelvis

Protocol

The participants performed their normal warm up routine and completed a number of practice driver swings to become habituated with the marker set, and the laboratory environment

Each participant then completed six light, medium, and full strength swings.

An 'airflow' golf ball (The Masters Golf Company, Weston Super Mare, UK) was used during the testing, placed on a rubber golf tee mounted within a standard artificial turf golf practice mat.

Motion Analysis

The spatial model used was customised by Vicon (Oxford, Ltd) for the purpose of golf analysis (Gay, 2010).

Raw data of marker positions and trajectories, and hip internal and external moments were captured in the Vicon Nexus software, and smoothed using a Butterworth (4^{th} order) smoothing algorithm, and then transferred into a Microsoft Excel (Microsoft, USA) spreadsheet for further analysis.

Maximum club head angular velocity, and club head angular velocity as a function of time and at key positions were calculated for all participants and swing intensities.

The maximum and minimum hip moments, and the hip moments as a function of time, were also derived for all participants and all swing intensities.

Parametricity was checked for all data sets (PASW Statistics 17). All variables were tested for normality of distribution using a Kolmogorov-Smirnov test ($p > 0.05$). Overall differences between swing intensities were assessed using one way analysis of variance. If a significant main effect was found, LSD post hoc was used to determine between which pairwise comparison the differences existed. Pearson's correlation coefficient was used to examine the significance of any relationships between hip moments and club head velocity. A 95%

confidence level was used throughout. Effect size (ES) was calculated according to Cohen (Cohen, 1998), where under 0.2 is a small effect, above 0.5 is a moderate effect, and above 0.8 a large effect.

Results

Table 1 presents the mean maximum internal moment of the right and left hip and the mean maximum club head angular velocity (N=8).

Table 1 - Mean maximum club head angular velocity of each swing condition and the mean maximum magnitude of the right (clockwise) and left hip (anti-clockwise) Internal rotation moments.

Swing Intensity	Right Hip Mean Maximum Magnitude (Nmm)	Left Hip Mean Maximum Magnitude (Nmm)	Mean Maximum Club Head Angular Velocity ($deg.s^{-1}$)
Easy	-154.99	186.12	1473.55
Medium	-170.71	242.61	1715.33
Hard	-132.24	344.16	1583.91

Maximum internal and external hip moments were recorded at 350 Nmm and -240 Nmm.

No significant relationship was found between either the mean maximum right internal hip moment (r = -.452, P = .351, one tailed) or the mean maximum left internal hip moment (r = .305, P = .401, one tailed), and mean maximum club head angular velocity.

No significant overall differences were found between intensities for the right hip ($P > 0.05$) at any of the key positions, however one significant difference was found between the easy and medium intensity golf swings at mid follow through ($P = 0.048$, ES = -0.30, one tailed).

The left hip moments on the other hand showed a number of significant differences at key positions during the golf swing, top of backswing ($F_{2,12} = 7.028$, $P < 0.05$), and mid downswing ($F_{2,12} = 15.257$, $P < 0.05$). More specifically significant differences occurred between the easy and hard intensity golf swings at top of backswing ($P = 0.001$, ES = -0.49, one tailed), the easy and medium swing intensities at mid downswing ($P = 0.002$, ES = -0.87, one tailed), the easy and hard swing intensities at mid downswing ($P = .003$, ES= -1.63, one tailed) and the medium and hard swing intensities at mid downswing ($P = 0.028$, ES = -0.61, one tailed).

Interestingly, although no overall significant difference was found between the three swing intensities at impact, a significant difference was found between the easy and medium swing intensities ($P = 0.03$, ES= 0.57, one tailed)

Figures 2 and 3 show the mean magnitudes of the right and left hips during the golf swing.

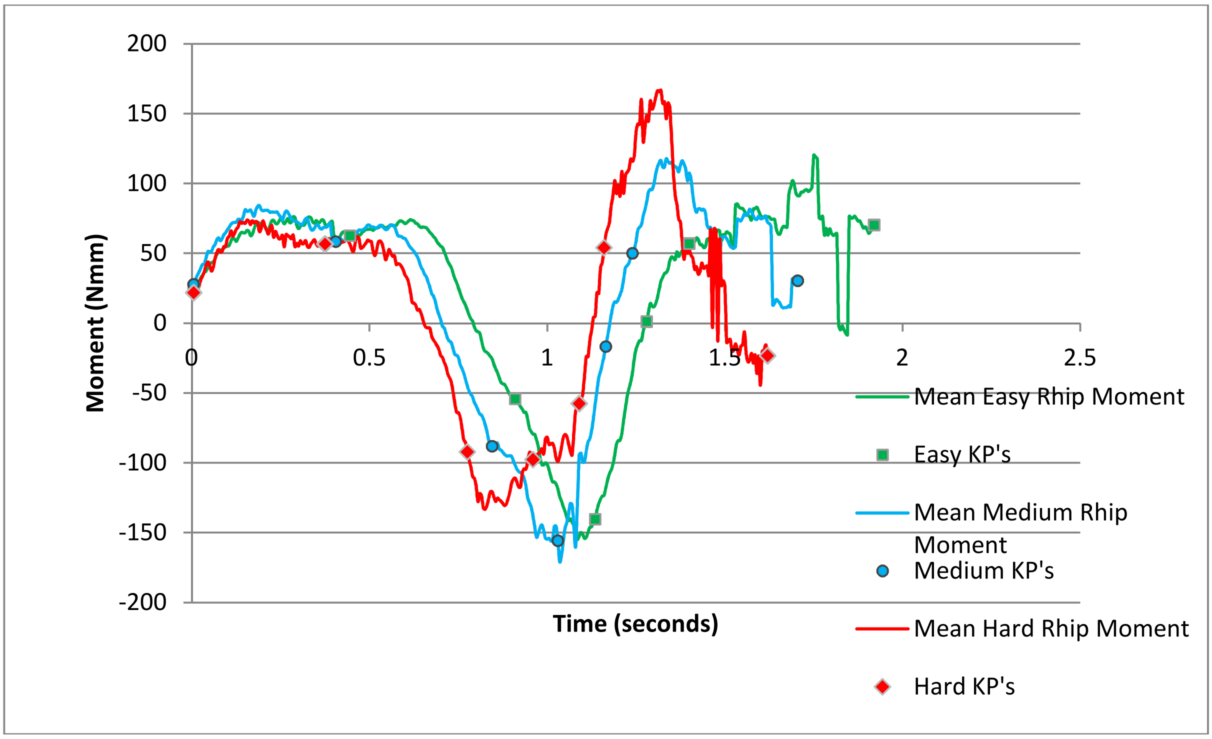

Figure 2 - Mean magnitudes of the right hip moments during the three swing intensities, plotted as a function of time with mean key positions marked

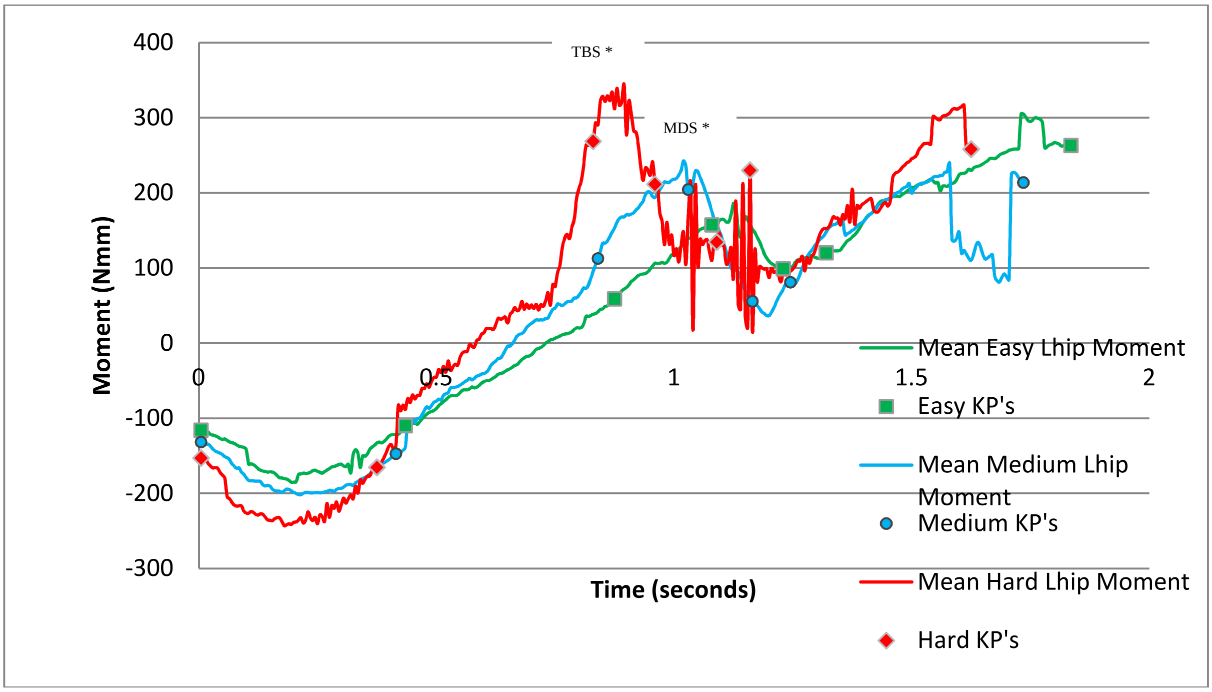

Figure 3 - Mean magnitudes of the left hip moments during the three swing intensities, plotted as a function of time with mean key positions marked

Significant Correlations

Significant correlations were found between the mean right and left hip moments at impact and maximum club head velocity. The mean right hip moment was positively correlated to maximum club head angular velocity (r = .999, P = .017) and the mean left hip moment was negatively correlated to maximum club head angular velocity (r = -.996, P = .028).

Discussion

The significance of correlations between hip moments and club head velocity were examined, and differences between the right and left hip moments were compared. The left hip was found to have higher internal moments (clockwise) than right hip internal (counter clockwise) moments, however no significant correlations were found between mean maximum hip moments and mean maximum club head angular velocity for any of the three different swing conditions ($p > 0.05$). Nesbit (2005) supports these findings by stating that torque about the z axis of the club was not related to club head velocity but was more representative of the individual's swing style. The non significant correlations found between the mean maximum hip moments, and mean maximum club head angular velocity, may therefore reflect differences in the swing styles of the individuals who took part in the study. Some of the participants may utilise the lower body for force and angular velocity generation, to a greater extent than others who may predominantly use the upper body.

The magnitude of the moments experienced within the lead hip (left) were notably higher than those measured in the right, or trail hip, this corresponds with previous literature on lower limb moments during the golf swing. Gatt et al. (1998) found that the lead (left) knee has significantly higher tibial internal rotation than the trail (right) knee (27.7 Nm and 19.1 Nm, respectively). Similarly, Hellstrom (2009), suggests that initiating the downswing from the distal segments nearest the ground and moving to more superior segments as the downswing continues, benefits maximal club head velocity.

Worsfield et al. (2008) also support the findings that the lead leg experiences greater moment values as it was reported that the front (left) foot experienced greater internal rotation torques compared to the rear (right) foot when using a driver (19.7 Nm and 7.8 Nm, respectively).

Hip moments at key positions

A significant ($p < 0.05$) positive correlation was found between the right hip moment at impact, and a significant ($p < 0.05$) negative correlation was found between the left hip moment at impact, when compared to maximum club head velocity.

Nesbit (2005) found that the alpha (x axis) torque on the club reached its maximum value close to mid downswing which was also the case for the right and left hip moments (see figures 2 and 3).

These findings can help explain the change from the lower body dominating the downswing movement to the upper body taking control, because after mid downswing the magnitude of the hip moments starts to reduce and shift towards zero which suggests a reduction in the force applied to rotate the pelvis and stabilise the hips, as angular momentum is transferred to the trunk and the upper body and out towards the club, which is in accordance with the summation of speed principle. (Lowe, 1994, Burden et al. 1998, Hume et al. 2005, Marshall, and Elliott. 2000, Milburn. 1982, Myers et al. 2008).

Previous literature (Nesbit, 2005, Nesbit & Serrano, 2005) suggests that as the golf club passes through zero torque maximum angular work occurs, therefore achieving a left hip torque closer to zero at impact would result in maximum angular work being produced by the hips and a greater force being transferred through the segments to the club head which is a characteristic of the swings of elite golfers (Nesbit & Serrano, 2005).

Recommendations and Conclusions

It is suggested that the moments around the hip joints are an important link in the kinetic chain, and implicated in driving distance as there were significant correlations ($p < 0.05$) between the mean right and left hip moments and mean maximum club head velocity at impact. The findings suggest that the left hip is also influential in initiating and driving the downswing as it achieves its maximum moment magnitude during the downswing for all swing intensities.

Future research is needed to quantify the importance of the role of the hips during the golf swing, to gain a clearer picture of the association between the hip moments and pelvis and shoulder rotation. Research should utilise larger sample sizes to reduce type II errors.

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