The Influence of an 8-Week Strength and Corrective Exercise Intervention on the Overhead Deep Squat and Golf Swing Kinematics

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<u>Disclosure Statement:</u> The authors report no conflict of interest or financial disclosures.

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ABSTRACT

It has previously been suggested that performance of the overhead squat (OHS) is a useful predictor of loss of posture in the golf swing. Using an eight-week intervention to improve OHS performance, this study assessed this suggestion and analysed the impact of any resultant physical adaptations on golf swing kinematics. Thirty-seven golfers (hcp=14.8±13.3) were randomly split into a control group (n=16) and an intervention group (n=21) – who completed an eight-week strength and flexibility programme. Pre- and post-intervention OHS assessments and 3D six-iron swing kinematics were captured. The level of significance set for the study was $p < .05$. Despite the intervention group's significant improvement in OHS thigh angle ($p<.001$), there were no significant changes in 3D swing kinematics between groups and over pre- and post-testing for address ($p=.219$), top of the backswing ($p=.977$) and impact ($p=.994$). In addition, regression analysis revealed that the four measured OHS variables were significant and small predictors of swing kinematic variables at the top of backswing and impact (ranging from $R^2=.109$ to $R^2=.300$). These may, however, be spurious relationships as swing changes could be expected following the intervention if they were indeed true predictors of the postural variables. The use of the OHS to understand the cause of loss of posture during the golf swing is therefore not recommended as many other variables could influence swing kinematics. It may, however, be a useful assessment tool for strength and range of movement, provided that any motor learning issues are resolved prior to results influencing conditioning programmes.

Keywords

Movement assessment; Golf Coaching; TPI; Strength and Conditioning; Musculoskeletal

INTRODUCTION

Over the past couple of decades, golf has become a sport in which individuals have prioritised increased distance as a route to save shots around the course. A 20-yard increase can save 0.75 shots per round resulting in greater prize money (8). This has led to a rise in engagement with strength and conditioning (S&C), with golfers seeking to gain muscle strength and speed through training interventions provided by suitably qualified practitioners (42). Being able to safely perform multi-joint and multiplanar movements at high velocity and under high loads, such as in the golf swing, is essential for increased performance and reduced risk of injury (33). Unsurprisingly, and with the risk of injuries remaining a concern for athletes and coaches alike, S&C coaches and other golf fitness professionals have been seeking and applying tools to functionally assess, monitor and train athletes within their coaching remit (e.g., Functional Movement Screening; (12,13)). Musculoskeletal screening techniques are a staple method of assessment for physiotherapists and other manual therapy professionals to test range of movement (ROM), strength, stability etc., before providing results-led interventions to their clients. The use of screening to specifically assess golfers has been popularised by the promotion of a 'golf-specific functional movement screening' (35). This aims to equip S&C coaches and other golf fitness professionals with methods of assessing physical capacities (e.g., ROM, strength, power) and has led to the popular notion that an understanding of test results can provide insight on the individual golfer's possible swing 'faults' (where desired ball flight is compromised) or characteristics.

One such swing characteristic is a loss of posture during the golf swing. This has been hypothesised to relate to many other swing characteristics (or 'faults') such as a flat shoulder plane (26), changes in swing plane, angle of attack, timing, balance and rhythm (27) among others. A lack of core mobility and strength, or instability in the lower body have been cited as possible physical causes of loss of posture (34). It is plausible that a loss of posture can lead to ‘thin shots’ (where the bottom of the clubhead strikes around the centre of the golf ball) or a ‘topped shot’ (where the bottom of the clubhead strikes the top of the golf ball) which will both cause a significant loss of distance and control over ball flight (34). Since 2006, it has been advocated that a loss of posture during the backswing or the downswing and through impact, can be predicted through the observed results of an overhead squat (OHS) test, commonly used to assess golfers’ ROM (28,36). However, to date, little robust evidence has been provided to corroborate this association.

The OHS is, however, an important functional screening tool, appearing in many published screening methods (see (4)), and has been proposed as an effective initial overarching test to dictate whether an individual needs further functional movement screening (11). The OHS is used to assess both the upper and lower body through the closed kinetic chain of the bilateral, symmetrical functional mobility of ankle dorsi-flexion, knee and hip flexion through the lowering of the pelvis towards the floor, thoracic spine extension, shoulder flexion and abduction through the maintenance of posture and arms vertical above the shoulder joint (12) and strength of the lower body (6,7) to include the gluteals and quadriceps. Golf literature suggests that a failure to complete a full OHS indicates generalised stiffness and asymmetry in the musculature of the lower body (e.g. 26,40).

The crossover from the electromyography evidence (24) to the muscles involved in the OHS may imply that increases in the strength and flexibility of specific muscles could influence the kinematics of the swing. Various studies have analysed the effect of exercise interventions on the outcome measures of the golf swing (e.g., clubhead speed (CHS) & ball speed (BS)), with both home- and gym-based programmes prescribed (5,14,16,23,29). Intervention session frequency ranged from once per week (55% adherence over a seven-week period; (29)) to three-four sessions per week (for an eight-week period; (23)). However, more frequent engagement was associated with greater improvements in the OHS (29). It is important for coaches to consider the lag time between increased physical capacity (e.g., strength) and the actualisation of this into performance (39). Findings in golf research support this claim with significant improvements in muscle strength and power reported after six weeks of training, but golf measures only significantly improved after 12 weeks (1). Despite all these papers demonstrating the positive impact that S&C can have upon the golfer, the difficulty of a purely outcome-based approach is the lack of consideration for changes in swing kinematics and separation of the effects of each training method on golf performance (9). Previously, Hellström (19) stated that there was little research on the effect of physical conditioning on 3D swing kinematics. Indeed, only a handful of studies have shown changes in swing kinematics following S&C programmes (9,10,23,30).

To date, three studies have attempted to assess the 'golf specific functional movement screening tests' with only two assessing the relationship to swing faults (18,20,38). Gulgin et al. (18) and Speariett & Armstrong (38) reported that of those who presented a limited OHS, 54% and 90% respectively, exhibited loss of posture in the backswing and that 67% and 60% respectively, showed a degree of early hip extension in the downswing. With all three investigations presenting various significant methodological limitations (e.g., subjective screening ratings, violations in statistical analysis, 2D swing analysis and a lack of kinematic measures for loss of posture, etc.), it would be misleading to suggest that the findings these papers report should be applied in S&C/golf coaching settings.

One further study (17) has assessed the relationships between the OHS on swing kinematics, specifically the control of the spine, pelvis and X-factor. While robust 3D analysis took place, the OHS was reliably, but subjectively rated a pass or fail without breaking the OHS movement into specific digitised measurements. Results highlighted a moderate and small relationship with spine rotation and spine side bend at the top of the backswing respectively. Those who 'passed' the OHS demonstrated increased rotation and spine side bend at this point in the swing (i.e., less loss of posture). No results suggested a significant relationship between the OHS and early extension characteristics (e.g., pelvic thrust or thorax lifting).

This study aimed to continue testing the suggestions that restrictions in the OHS test can translate to a loss of posture and early hip extension (pelvic thrust) in the backswing and downswing of an individual's golf swing respectively (25,27). Furthermore, the study aimed to use an intervention to alter the ROM in the OHS test to examine the relationship between changes in OHS physical capacity and swing kinematics.

METHODS

Experimental Approach to the Problem

A between group repeated measures procedure was employed to assess the effect of an eight-week strength and flexibility intervention on the 3D kinematics in the golf swing. Kinematic variables were calculated for each shot using the 3D golf biomechanics software (AMM 3D-

Golf™ system). Variables were selected based on the suggested link between possible physical restrictions in the OHS and their impact upon posture within the golf swing (25,27).

Subjects

After local ethics committee approval (University of Birmingham), a convenience sample of 41 golfers (29 males; 12 females) were recruited via advertising of the research at a golf club. Subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. All golfers were randomly assigned to an intervention group (*n*=21) or a control group (*n*=16). Thirty-seven of the original 41 golfers completed both baseline and post-testing, with the final control group consisting of 16 participants (four participants withdrew due to non-attendance at post-testing). All participants completed consent forms and indicated they were pain/injury free and fit to participate in the study. The participants were of mixed ability, but all possessed a CONGU handicap (See Table 1 for participant characteristics).

Table 1 Participant characteristics

	Overall	**Control**	**Intervention**
n	37	16	21
Male n	26	14	12
Female n	11	2	9
Handicap	14.8±13.3	13.0±12.0	16.1±14.3
Male	10.2±10.0	12.3±10.6	7.7±9.2
Female	25.7±13.9	18.0±25.5	27.4±12.0
Age, y	39.7±11.6	39.7±12.7	39.7±11.1
Male	38.2±11.6	40.9±12.8	35.2±9.6
Female	43.1±11.5	31.5±10.6	45.7±10.6
Height, m	1.78±0.1	1.81±0.1	1.76±0.1
Male	1.83±0.1	1.83±0.1	1.83±0.1
Female	1.67±0.1	1.67±0.0	1.67±0.1
Weight, kg	81.05±15.2	82.78±13.1	79.73±16.8
Male	87.2±13.2	85.5±11.5	89.2±15.3
Female	66.5±7.9	63.5±2.4	67.1±8.6

Note. Participants who withdrew from the study were not included in the statistics. Professionals (*n*=5) were assigned a handicap of 0 for statistical purposes.

Procedures

OHS Assessment

Prior to any analysis of the golf swing all participants undertook a musculo-skeletal screening assessment. The OHS screening test was conducted and recorded using a Canon 60D DSLR camera fitted with a Canon 18-200mm f/3.5-5.6 IS Telephoto Lens. Calibration frames were filmed, and high-contrast markers were placed upon eight anatomical landmarks for digitisation purposes. Markers were placed on the acromion process, greater tubercle of the humerus, lateral condyle of the humerus, styloid process of the ulna, greater trochanter of the femur, lateral epicondyle of the femur, lateral malleolus of the fibula and on the shoe directly above the distal phalanx of the 5th toe.

All participants were asked to assume a comfortable stance with the feet remaining parallel and slightly wider than shoulder width apart, aligned side on to the camera. Hand width was set by placing a bar on the head and adjusting the elbows to 90° before fully extending the arms to an overhead position. As per recommendations from Vidal et al. (41), verbal cues and demonstrations were provided and familiarisation time was allowed prior to participants completing an OHS. While squatting to as low a position as possible, participants were instructed to try and maintain a parallel position with the feet, with heels on the floor and the arms fully extended at the elbow with the hands remaining overhead and not moving past the toe line. Each OHS was digitised and all four variables (see Table, Supplemental Digital Content (SDC) 1, which defines the measurement of each OHS variable) were measured using Tracker software (version 4.72).

Swing kinematic analysis

All participants executed a minimum of 15 shots (M = 15.49±2.48) with their own six-iron for both pre- and post-testing. These shots were captured at 240Hz using a Polhemus Liberty electromagnetic tracking system (Polhemus Inc., Colchester, VT, USA), a real-time, six degrees of freedom motion capture system that, according to the manufacturer, has a static accuracy of .76mm root mean square (RMS) for the sensors' X, Y and Z position and .15° RMS for their orientation (32). A Velcro body harness was used to attach sensors to each participant and to ensure any wires offered no interference to their swing. Sensors were attached to selected body landmarks: middle of second metacarpal on dorsal side left hand, lateral and proximal section of left humerus, centre of forehead, third vertebrae thoracic spine and lumbo-sacral joint (pelvis). A static calibration of a further 13 anatomical landmarks, using a 20 cm pointer pen, was carried out according to the manufacturer's instructions. This was done to allow the sensors to be located within the magnetic field created by the transmitter. Six 3D swing kinematic variables were analysed (see Table, Supplemental Digital Content 2, which defines the static kinematic variables measured at address, top of the backswing and impact).

Ball flight and impact analysis

Ball flight and impact data were collected (i.e., CHS and BS) using a TrackMan® 2.0 launch monitor and participants were instructed to use 'a normal swing for consistent ball flight, with maximum accuracy and distance towards a specified target'. These instructions were used to limit task related variability (i.e., strategic variability) so that any variability seen would be of a within movement nature (22). The TrackMan® launch monitor was positioned on the ball to target line and participants were informed of the specified target prior to testing. Each golf ball was placed on a marked spot on the golf mat to allow variability at address to be solely down to the participant's set up position rather than the position of the ball on the mat. Following calibration participants performed a self-selected warm-up which also acted as a familiarisation period towards the motion analysis system, harness, sensors, range set-up and specified target.

Definition of key positions in the swing

Address was defined as the first point at which angular speed of the shaft was less than 10 deg/s (i.e., the time point before the shaft begins moving into the backswing). Top of the backswing was defined as the point at which the angular speed of the club shaft was at a minimum after the address position. This represents the moment of change from backswing to downswing in terms of the club, but the authors acknowledge that the pelvis and torso may have already begun their transition into the downswing. Impact was defined as the frame where the clubhead was closest to the original address position before impact with the ball (2).

Training Intervention

Each participant in the intervention group undertook three-four strength, myofascial release, and flexibility sessions per week for an eight-week period (compliance: mean = 25 sessions; range = 15-36 sessions; mode = 24). For the duration of the eight weeks both groups of participants were asked to refrain from golf lessons and were to continue with their normal practice and playing routine. Prior to completing each session, the intervention group were instructed to complete a 15-minute dynamic warm-up. Participants then followed the strength exercise intervention (see Table, Supplemental Digital Content 3, which details the strength exercise intervention) followed by the myofascial release and flexibility intervention (see Table, Supplemental Digital Content 4, which details the myofascial release and flexibility intervention).

Selection of Exercises

Exercises were selected to focus on the goals of increasing gluteal strength, thoracic extension, shoulder mobility and scapular stability, stability around the lumbopelvic area and overall flexibility required to complete an OHS. It has previously been shown that the OHS demands optimisation of these physical qualities to allow for a full range of movement during this test (3,6,12).

Statistical Analyses

All data were checked for approximation to the normal distribution, and group and individual means and standard deviations were calculated. Mixed-factorial multivariate analysis of variance (MANOVA) tests were used to assess if there was a significant difference in the pre- and post-intervention swing kinematic variables at address, top of the backswing and at impact and between groups. Dependent t-tests were used to assess changes between pre- and post-intervention OHS variables for each group. A backward stepwise multiple regression analysis assessed whether the four OHS variables (SDC 1) could be used to explain the variance in the 3D kinematic variables (SDC 2) at each key position in the golf swing. This was repeated for each 3D kinematic variable at address, top of the backswing and impact. For all tests, alpha levels were set to $p<.05$, all data analyses were carried out using SPSS 20.0 and data are reported as mean and standard deviation unless otherwise stated.

RESULTS

The intervention group achieved a significant decrease in OHS thigh angle following the eight-week programme (i.e., golfers obtained lower squat positions; Table 2) ($p<.001$).

A mixed-factorial MANOVA showed there to be no significant changes in 3D swing kinematics between groups and over both pre- and post-testing for address (Wilk's λ=.88, p=.219, $\eta\rho^2$=.12), top of the backswing (Wilk's λ=.98, p=.977, $\eta\rho^2$=.02) and impact (Wilk's λ=.99, p=.994, $\eta\rho^2$=.01) (Table 3).

Table 2 Mean values for the overhead squat variables for each group pre- and post-intervention

Variable	**Whole Group**		**Intervention Group**		**Control Group**	
	Pre	Post	Pre	Post	Pre	Post
Torso Angle (°)	36.72±10.69	37.58±8.56	39.44±10.02	39.08±8.58	33.14±10.79	35.62±8.40
Thigh Angle (°)	103.65±20.71	88.14±19.21**	108.96±18.78	84.15±19.20**	96.67±21.63	93.37±18.51
Shin Angle (°)	55.60±5.51	55.95±6.22	55.33±5.57	56.21±5.88	55.95±5.59	55.60±6.82
Arm Angle (°)	35.23±19.58	34.75±17.12	37.32±21.87	36.27±18.47	32.49±16.37	32.75±15.53

Note. Symbols indicates a significant difference between overhead squat variables within groups between pre and post testing **($p<.001$).

Table 3 Mean values for the swing kinematic variables for each group pre- and post-intervention

Variable	**Address**				**Top**				**Impact**			
	Intervention		Control		Intervention		Control		Intervention		Control	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Spine Axis Forward Tilt (°)	35.86 ±5.00	35.14 ±5.28	37.63 ±4.40	36.84 ±5.81	33.67 ±7.72	34.44 ±7.12	35.17 ±5.38	36.97 ±6.42	28.66 ±4.57	28.85 ±5.53	28.33 ±5.19	28.99 ±5.42
Spine Flexion/Extension (JCS) (°)	29.19 ±10.38	26.14 ±14.86	32.21 ±13.35	31.93 ±10.85	-4.82 ±9.89	-12.12 ±16.66	-2.88 ±18.67	-5.01 ±13.02	38.18 ±11.42	35.79 ±13.37	38.00 ±10.80	38.52 ±9.67
Pelvic Thrust (in)	(calibrated position) 0.00 ±0.00				2.13 ±1.49	1.84 ±1.20	1.88 ±0.91	1.55 ±1.00	1.86 ±1.10	1.99 ±1.09	2.26 ±1.34	2.01 ±1.54
Pelvic Lift (in)	(calibrated position) 0.00 ±0.00				-0.83 ±0.81	-0.95 ±0.80	-1.15 ±0.68	-1.21 ±0.81	0.06 ±0.83	0.00 ±0.89	0.10 ±1.06	0.03 ±1.09
Upper Body Thrust (in)	(calibrated position) 0.00 ±0.00				1.38 ±1.19	1.56 ±1.09	1.05 ±1.19	1.48 ±1.43	-0.82 ±1.61	-0.46 ±1.60	-0.95 ±1.03	-0.75 ±1.27
Upper Body Lift (in)	(calibrated position) 0.00 ±0.00				-0.60 ±1.37	-0.88 ±1.52	-0.76 ±0.97	-1.30 ±1.53	0.65 ±1.16	0.55 ±1.04	1.42 ±1.25	1.09 ±1.31

A backward stepwise multiple regression analysis revealed the following at the three selected phases of the swing for whole group analysis (Table 4 provides a summary of the regression models; See Tables, Supplemental Digital Content 5-10, which provide the full regression models for each result presented):

At address, no significant predictors of the address posture variables were found using the OHS. At the top of the backswing, the OHS Torso Lean is a significant predictor of Upper Body Lift (R^2=.300, p<.001), Pelvic Lift (R^2=.109, p=.046) and Spine Axis Forward Tilt (R^2=.164, p=.013). OHS Arm Angle is a significant predictor of Pelvic Thrust (R^2=.187, p=.007). At impact, the OHS Arm Angle is a significant predictor of Spine Flexion/Extension (R^2=.119, p=.037) and OHS Shin Angle is a significant predictor of Upper Body Lift (R^2=.119, p=.037).

TrackMan® data showed there to be no significant change to CHS (Whole Group p=.820; Intervention p=.873; Control p=.850) or BS (Whole Group p=.786; Intervention p=.890; Control p=.750). CHS reduced post intervention by 0.88% for the whole group, by 0.95% for the intervention group and by 0.79% for the control group (Table 5).

Table 4 A Summary of all Regression Models (Final Step (4)) Assessing the use of OHS Variables to Predict Swing Kinematic Variables

Step 4 from each Model	**Variable**	R^2	***B***	***SE B***	**β**	**95% CI**
Upper Body Lift at top of the backswing	Constant		-4.713	.965		[-6.671, -2.755]
	OHS Torso Angle	.300	.097	.025	$.548^{***}$	[.046, .148]
Pelvic Lift at top of the backswing	Constant		-2.230	.577		[-3.401, -1.060]
	OHS Torso Angle	.109	.031	.015	$.330^{*}$	[.001, .061]
Spine Axis Forward Tilt at top of the backswing	Constant		47.722	4.767		[38.045, 57.400]
	OHS Torso Angle	.164	-.324	.124	$-.405^{*}$	[-.576, -.073]
Pelvic Thrust at top of the backswing	Constant		.742	.382		[-.033, 1.517]
	OHS Arm Angle	.187	.028	.010	$.433^{**}$	[.008, .048]
Spine Flexion / Extension at impact	Constant		54.866	8.453		[37.706, 72.026]
	OHS Arm Angle	.119	-.476	.219	$-.344^{*}$	[-.922, -.031]
Upper Body Lift at impact	Constant		-2.866	1.692		[-6.301, .569]
	OHS Shin Angle	.119	.065	.030	$.345^{*}$	[.004, .126]

Note. *** $p < .001$, ** $p < .01$, * $p < .05$.

Table 5 TrackMan® Data for Pre- and Post-Intervention Testing

Kinematic Variable at Impact	Mean ± SD					
	Whole Group		Intervention Group		Control Group	
	Pre	Post	Pre	Post	Pre	Post
Clubhead Speed (m/s)	34.4±5.8	34.1±5.5	33.0±6.5	32.7±6.0	36.2±4.3	35.9±4.1
Ball Speed (m/s)	44.6±8.5	44.1±8.3	42.8±9.6	42.4±9.5	47.0±6.2	46.3±5.9

DISCUSSION

The eight-week intervention significantly altered the OHS assessment results with the lower squatting pattern demonstrating a significant improvement in flexibility and strength through those muscles that are involved (e.g., through gluteal strength, latissimus dorsi flexibility, and possible improvements in calf flexibility and thoracic extension etc.).

Although significant OHS ROM changes were achieved by the intervention group, they were unable to directly use these new physical capacities in their golf swings. It is possible that despite these results, they have not had the time to translate the physical adaptations into technical performance in their swing, or that these physical adaptations are not an important factor for the swing kinematics. Therefore, it is likely they will need extensive coaching to incorporate new ROM and strength within their golf swing. Previous research has also found similar patterns where successful interventions have resulted in little or no performance changes (37) or have been delayed until several weeks later (1).

Alongside this study's finding that no post-intervention swing kinematic changes occurred, there was also no significant impact upon the CHS and BS. This result is similar to the results from Lamberth et al. (21) who conducted a 6-week strength and functional training programme with five golfers (additional five in control group) and reported no significant changes in CHS following significant improvements in strength. However, it is contradictory to other previous research which has shown significant CHS increases (e.g., 14,16,23). A possible explanation for this discrepancy in findings could be that this is the only research study to take place in a driving range studio that faces out onto a range. The first testing took place in the summer with the second testing taking place in colder autumn conditions. It is possible that there may be seasonal influences that can affect golf performance that has prevented increases in CHS in this study even though the golfers were able to warm-up adequately prior to testing. Another plausible explanation exists around the focus of the intervention to improve the OHS ROM rather than generate significant maximal strength gains.

The OHS assessment test has been made popular within golf and links between the results of this test and the swing characteristics of golfers have been emphasised. It has been suggested that if the golfer cannot perform a full OHS then there will be some loss of posture during the backswing and/or downswing (25,27). The results of the current study suggest that a small, but reliable percentage of the variance in swing posture variables can be explained by aspects of the OHS (e.g., 30% of the variability in upper body lift at the top of the backswing can be predicted by OHS torso angles). However, when the OHS mechanics had been manipulated through the intervention, no significant change in postural swing kinematics was seen, therefore this relationship does not exist once manipulation has taken place. This suggests any relationship is a spurious one and within the context of the study’s limitations, leads to the argument that the OHS is not a good predictor of loss of posture in the golf swing and that other variables will also have an influence on whether posture can be maintained. These results cannot, therefore, be termed a predictive relationship between the OHS and the postural kinematics of the golf swing.

Strength and conditioning coaches should be encouraged to look for a lack of thoracic extension which would lead to increased anterior lean in the OHS and an inability to extend through the spine into the top of the backswing position during the golf swing. Lifting the upper body and the pelvis, and thrusting the pelvis forward leads to a loss of posture but may allow the golfer to compensate for a possible lack of thoracic extension and possible tightness in the latissimus dorsi (especially through the lead side). Flexibility in the latissimus dorsi was shown, through OHS arm angle, to be a very small but significant predictor of pelvic thrust (Table 4). Results show that, with no swing kinematic changes after increasing this physical constraint, the OHS arm angle is not a good predictor of pelvic thrust and that other variables may be influencing this movement pattern. From a physical perspective this pelvic thrust combined with the lifting of both the pelvis and the torso could lead to a reduction in the stretch on the lats but also a loss of posture as discussed previously. Any lag effect must, however, be considered when interpreting results. Once again, the OHS remains a useful assessment tool for S&C coaches to understand the limitations on ROM and strength within a golfer's body in order to provide systematic and targeted conditioning programmes. It should be noted that there is no evidence to suggest that the OHS should be used by golf coaches to predict loss of posture during the golf swing. Other significant results presented a very small impact so further, longitudinal, research is needed with larger samples to fully establish the influence of the OHS on posture kinematics and indeed the nature of these relationships when coaching can take place during a lag period.

There were limitations to this study that need to be considered for future research. Seasonal differences could have influenced the results from pre- to post-testing. However, it is important that research is conducted that is representative of the on-course situation that golfers will compete in (31). Lab based experiments, although controlled, provide the golfer with an artificial situation in which to perform with very little ball flight to observe and no real target to play towards. The analysis of most variables in this study were underpowered compared to the value of .8 which is deemed an appropriate level of confidence (15). However, post-hoc analysis of power revealed that to achieve 80% confidence in the analysis of pre-post swing kinematic variables would have required a sample size of n=1232 and for the significant backward stepwise regression results a sample of at least n=101 was required. The use of a backward stepwise regression minimises suppressor effects and allowed all OHS variables to be considered in each model. Other small predictors may have emerged had the sample size been considerably larger. Results should therefore be interpreted within the context of these limitations.

The inconsistency of total sessions completed (range 15-36 sessions across the eight-week intervention) may have led to less adaptation for some participants. However, with a significant change in OHS thigh angles for the intervention group it is possible that all managed the minimum dose to achieve an adaptive response.

No kinematic swing changes through golf tuition were allowed during the intervention period which must be considered in future research of this nature. With controlled tuition alongside and following the intervention it may allow for the actualisation of new physical capacities in strength, stability around joints and flexibility to positively affect the swing kinematics. This may also result in increased performance benefits within the outcome data of CHS and BS as well as other impact factors and launch conditions.

This study has shown that it is possible to improve the squat mechanics of golfers through a targeted physical intervention. Future research now needs to establish how golf coaches can work with golfers to ensure positive manipulation of swing kinematics to utilise gains in strength and flexibility where appropriate pre- and post-intervention tests are in place. Only then will the golfer’s performance truly benefit from an S&C intervention programme.

PRACTICAL APPLICATIONS

Systematic S&C interventions are critical for physical adaptations; however, it should not be assumed that swing kinematics or even performance outcomes will alter automatically following increases in ROM, flexibility, and strength. Results from this study indicate the importance of coaches using 3D analysis and measurement of OHS angles to assess the relationship between technical and physical limitations, as opposed to drawing conclusions based upon 2D video analysis and subjective screening observations (without any measurement).

S&C coaches should continue to perform assessments of the OHS with their golfers to understand whether there are physical restrictions or weakness to inform their interventions. However, caution should be exercised when using the results to allow any OHS motor learning issues to be addressed prior to drawing conclusions from this assessment tool (41). Loss of posture during the swing may still be due to learnt movement behaviour or physical constraints. Coaches, however, should be aware that, within the context of this study's limitations, the OHS is not a useful predictor of these postural kinematics. Where deterioration of posture occurs with golfers who can already achieve a full OHS it becomes the coach's role, alongside the S&C coach, to establish if there are other variables affecting golf swing kinematics and subsequent ball flight. As long as no other physical restrictions are identified, the golf coach should begin to implement technical corrections to reduce loss of posture if deemed appropriate due to a negative impact upon ball flight.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the funding contribution made to assist with the data collection by The Professional Golfers' Association.

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LIST OF SUPPLEMENTAL DIGITAL CONTENT

- Supplemental Digital Content 1. Table which defines the measurement of each OHS variable. pdf
- Supplemental Digital Content 2. Table which defines the static kinematic variables

measured at address, top of the backswing and impact. pdf

- Supplemental Digital Content 3. Table which details the strength exercise intervention. pdf
- Supplemental Digital Content 4. Table which details the myofascial release and flexibility intervention. pdf
- Supplemental Digital Content 5-10. Tables which provide the full regression models for each result presented. pdf