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The Effect of an 8-Week Plyometric Exercise Program on Golf Swing Kinematics

Mark Bull and Matthew W. Bridge
University of Birmingham

Previous research on conditioning in golf has looked at the effect of physical training programs on outcome measures of golf swing performance, namely club head speed and ball displacement. The current study examined the effect of an 8-week golf specific plyometric training program on the kinematics of the golf swing. Sixteen skilled golfers were randomly assigned to either an experimental or control group. Three-dimensional swing kinematic data were collected on shots with a 6 iron pre and post the training intervention. Statistical analyses were used to identify any changes in swing kinematics after the training intervention. Results showed that the experimental group increased lead arm and hand speeds in the downswing after training. This was accompanied by increases in maximum X-factor during the downswing and maximum rate of recoil of the X-factor. In conclusion, a program of golf specific plyometric training can potential lead to improvements in variables related to club head speed and ball displacement.

Keywords: golf, plyometrics, kinematics, exercise

There are numerous factors that influence the ability of a golfer to achieve the desired outcome of any chosen shot (Langdown, Bridge, & Li, 2012). Primary aims of the full swing are to produce maximum ball displacement, accuracy, control and consistency for each shot (Burden, Grimshaw, & Wallace, 1998). When considering maximum ball displacement the golfer must produce maximum speed at the most distal end of the kinematic sequence, the club-head (Neal & Sprigings, 1999). However, this is not the only factor that must be considered as eventual ball displacement will also be influenced by the five impact factors between the club and ball (Langdown et al., 2012). Key to the success of achieving all the aims of the selected shot is a golfer's physical competence (Smith, 2010) and when specifically considering club-head speed—muscular power (Hellström, 2008; Yoon, 1998). A golfer requires strong lower body muscles to generate high forces and torques against the ground and alongside this, high rotary power in the torso, and powerful movements in the chest and arms (Hellström, 2009). As a result a golfer's physical preparation must use a program of athletic development that produces golf-specific power during the dynamic movement of the swing (Newton, 2007). Within any such

The authors are with the School of Sport and Exercise Sciences, University of Birmingham, Birmingham, UK.

program it is important to train the initial and maximal rates of force development which are more important in golf than maximal strength (Hellström, 2009). The speed of movement of exercises should be fast to replicate the short movement time of the downswing (0.2–0.3s).

Previous work examining the effect of physical conditioning on golf performance has examined the effects of concurrent strength and flexibility (Hetu, Christie, & Faigenbaum, 1998; Larkin, Larkin II, Larkin, & Larkin, 1990; Lennon, 1999; Westcott, Dolan, & Cavicchi, 1996) or concurrent strength and power (Doan, Newton, Kwon, & Kraemer, 2006; Fletcher & Hartwell, 2004) programs on various outcome measures. The difficulty with this approach is that is does not allow the separation of the effects of each on golf performance. In addition some work has not incorporated a control group (Hetu et al., 1998; Lennon, 1999; Westcott et al., 1996) and so any changes seen may be the result of a diurnal variation in performance. Many of the above studies have focused on the simple outcome of ball displacement (Fletcher & Hartwell, 2004; Lennon, 1999) or club-head speed (Fletcher & Hartwell, 2004; Hetu et al., 1998; Jones, 1999; Westcott et al., 1996) without consideration of any changes in golfers' swing kinematics. Doan and colleagues (2006) found significant increases in strength, power and flexibility after 8 weeks of training and an increased club-head speed. The authors also qualitatively analyzed participants' swings using a video camera with a frame rate of 60Hz. However, this methodology is limited in that it only provides a 2D representation of the swing when many of the key kinematic variables such as the order of peak segmental rotational velocities or kinematic sequence (Cheetham et al., 2008) and X-Factor (Cheetham, Martin, Mottram, & St Laurent, 2002) are best assessed in three-dimensions (3D) (Joyce, Burnett, & Ball, 2010). There is currently little knowledge on the effects of training interventions on 3D swing kinematics and further research is needed in this area (Hellström, 2009). To address this need the purpose of this study is to examine any effect that a plyometric training intervention may have on a golfer's swing kinematics.

Method

Participants

Skilled golfers (category one—handicap <5 shots) were chosen as the sample population for the study as they have been shown to have a reduced variability in their swing mechanics and would therefore produce more reliable swing mechanics increasing the internal validity of the results. Participants were recruited from local golf clubs, by word of mouth and from the clientele of local professional golf coaches. Individuals expressing an interest in the study were given written information about the study covering its purpose and commitment required from them should they participate. They were also given the opportunity to question the investigators about the study. Sixteen males who had not previously completed any plyometric training volunteered to participate in the study. Each participant provided written informed consent before participation. Post consent, but before being accepted on to the study participants were screened for injury, asked to complete a training history questionnaire and were assessed for their physical literacy and their physical suitability for plyometric exercises. This was assessed by asking participants to demonstrate the ability to back squat 60% of their body weight for five repetitions with good form. Participants were then randomly assigned to either the control group ($n = 8$) or experimental group ($n = 8$). Within the control group, all of the golfers were members of an English County Golf Union team, with a mean handicap of 3.3 ± 1.6 shots and mean age of 24.4 years ± 8.8 years. This group continued with any existing exercise program that they were performing while the experimental group followed an 8-week plyometric exercise program outlined below. Existing exercise programs in the control group comprised of endurance and weight training, consistent with "conventional" gym programs or no training at all. In the experimental group, two members were professional golfers, six were skilled category one golfers (<5 handicap). The participants mean handicap was 3.8 ± 1.6 shots (2 professionals excluded) and mean age was 21.5 ± 5.5 years.

Procedure

A between groups repeated measures design approved by the University Ethics Committee was used to assess the impact of an 8-week program of plyometric exercises on golf swing kinematics.

Testing. Subjects were asked to hit five 6 iron shots onto an open air driving range. Each golfer wore typical golf attire and golf shoes. Times of pretest trials were recorded to follow the exact testing protocol for the post intervention testing. Each participant went through their normal warm up routine before both the pre and post testing. Once fully warmed up, the participants hit five 6 iron shots from a driving range mat at full speed toward a designated target at a distance on the range using a full compression ball. The target was located so that a line drawn between it and the position of the ball on the driving range mat was parallel to the x-axis of the global frame. The testing conditions for both pre and post training were dry, mild and overcast.

Apparatus & Calibration. Three-dimensional kinematic data were collected using a Polhemus Liberty electromagnetic tracking system (Polhemus Inc., Colchester, VT, USA), sampling at 240 Hz. A transmitter, which contains three orthogonal coils (solenoids), generates three different electromagnetic fields in the region of 1–4000 × 10–9 T. Sensors, which also contain three orthogonal coils, record 3magnetic flux in the three different fields. Magnetic flux generates proportional currents used to calculate a vector signifying the direction and strength of the magnetic field at the site of the sensor. According to the manufacturer, the static accuracy is 0.076 mm RMS for sensor position and 0.15° RMS for sensor orientation. The orientation of the right-handed orthogonal global frame was such that the positive x-axis pointed parallel to the direction of the target line, the positive z-axis pointed vertically upwards, and the positive y-axis pointed forward from the right-handed golfer. The performance area was a synthetic golf mat positioned adjacent to the transmitter. The experimental setup yielded a measurement space where the distance from transmitter to sensors ranged from 0.164 m to 1.41 m during recordings. Sensors were secured to the golfer by using a Velcro body harness, which offered little or no resistance or interference to the golfer during their swing. Sensors were placed on the participants on selected body landmarks; middle of second metacarpal on dorsal side left hand, lateral and proximal section of left humerus, center of forehead, third vertebrae thoracic spine and lumbo-sacral joint (pelvis).

A static calibration using a 20 cm pointer pen was carried out according to the manufacturer's instructions. The following anatomical landmarks were calibrated so the sensors could be located within the magnetic field created by the transmitter, lateral Head of second Metacarpal on the left hand, medial wrist at the head of the Ulna, lateral wrist at the head of the styloid process of the radius, (both left hand), medial head at the medial epicondyle of the humerus on the left arm, center of the left shoulder joint, center of the right shoulder joint, right lateral ribs, high on midline just below the armpit, right lateral ribs, on the midline of the rib cage, distal-Medial (left side) of the head at the external auditory meatus, distal-lateral (right side) of the head at the external auditory meatus, vertex of the head, right greater trochanter, left greater trochanter and the superior point (mid coronal plane) of the left iliac crest

Variables. Raw sensor data were converted to the local anatomical coordinate system for each body segment defined during the calibration. The following kinematic variables were calculated for each shot from the 3D swing data using commercially available software (Golf Biodynamics Ltd): maximum rate of X-factor stretch (MROS), maximum rate of X-factor recoil (MROR), maximum X-factor (mXF), X-factor stretch (XFs), peak hip speed (hip_{peak}), peak upper torso speed ($torso_{peak}$), peak lead arm speed (arm_{peak}), peak lead hand speed ($hand_{peak}$), upper torso tilt and bend, pelvic tilt and bend, head rotation, shoulder rotation, pelvic rotation, head lift, head thrust, pelvic lift, pelvic thrust. Total swing time, down swing time and back swing time were also measured alongside the timing lags between peak segmental speeds. Segmental position and movement were defined as follows: Tilt—the angle between a segment's frontal axis and the horizontal plane; Bend—the angle between a segment's longitudinal axis and the horizontal plane; Sway—the linear translation along the x-axis of the center of a segment; Lift—the linear translation of the center of a segment along the z-axis; Thrust—linear translation of a segment along the y-axis. Top of the back swing was defined as that point when the hips first reach their maximum turn on the backswing.

Calculations. The following calculations were used by the Golf Biodynamics software to compute the variables (with thanks to R. Neal, personal communication, July 20, 2010). The angular velocity of the pelvis and the upper torso segments was the axial rotational velocity about the z-axis of the local (anatomically referenced) coordinate systems. This axis was normal to the plane of the medial-lateral and anterior-posterior unit vectors that run from left to right greater trochanters (for the pelvis) and from posterior to anterior. The centers of the two shoulder joints define the medial-lateral axis for the upper torso. It has an approximate vertical orientation when the body is in an erect posture. The angular velocity of the hand and the lead arm was calculated by determining the plane of best fit for the origin of the local coordinate system (separately for arm and hand) between halfway down (club horizontal) and halfway through (club horizontal post impact). This plane was represented by a unit vector that was normal to the plane. The angular speed was then calculated by taking the dot (scalar) product of this vector with the instantaneous angular velocity vector of the arm/hand respectively. The angular speed is therefore the speed about this normal vector or the angular speed in the plane of best fit. This meant that for the hand it was very close to what in golf terms would be described as the “lag” of the club (the angle made between the club and the lead forearm).

It should be noted that this variable did not include the axial rotational velocity because that lies within the plane. X-factor was calculated as the difference between the instantaneous upper torso (UT) rotation and the instantaneous pelvis rotation. That is, X-factor = θ_{UT}—θ_{pelvis}. Each of these angles (θ_{UT} and θ_{pelvis}) is calculated as the arc tangent of the angle between the y-unit vector of the anatomically based local coordinate system as projected on to the ground. The y-unit vector runs approximately in the anterior-posterior direction when the body is in the anatomical position. The benefit of using this method was that it includes the lateral movement of the pelvis toward the target at the start of the downswing as this changes the plane of the pelvis and therefore a measure of the total separation of the pelvis and torso in the measurement.

Training Intervention. Each participant within the experimental group undertook two plyometric sessions a week, for eight weeks of plyometric training. At least 48 hours rest was taken between sessions and all participants were asked to continue their normal levels of golf play and practice however, they were asked not to undertake in any golf lessons or make any conscious technique changes. They were instructed not to embark in any other forms of exercise, whereas the control group continued with their normal routines.

Before each training session, each participant undertook a full ballistic warm up, consisting of drills relevant to the plyometric training and preparing them for the demands of the forthcoming exercises. Warm up drills consisted of forward and backward walking lunge, running backward, skipping, carioca, and heel flicks/knee raises. These warm up drills were consistent with the suggestion of (Hamill & Knutzen, 2003) who advised that such warm up drills aid the ability of the muscle to stretch faster, thus increasing the stretch reflex. On completion of the training session, each participant undertook a warm down, which comprised of a short walk followed by a static stretching session. The stretches given were targeted at the main muscle groups used within the exercises. As with the exercises, each participant was shown how to correctly and safely stretch, to optimize the benefits of the stretch, with minimal risk of injury.

Each participant within the experimental group was given instruction as to how correctly perform the exercises. One training session a week was supervised by the instructor and researcher, primarily to check exercise form and technique. The participant carried out the remaining session of that week in an unsupervised manner. To complete the exercises, all participants were provided with a 4KG medicine ball and five 12-inch high hurdles. The participants were instructed to carry out bounding, hopping and squat jump exercises on grass, as opposed to hard surfaces.

Central to the selection of exercises employed within this study, was a short review of existing literature on both physical training for golf an plyometrics (Doan et al., 2006; Gordon, Moir, Davis, Witmer, & Cummings, 2009; Hellström, 2002; Newton, 2007; Potach & Chu, 2000; Sáez-Sáez de Villarreal, Requena, & Newton, 2010). These studies highlighted the use of hopping, jumping, bounding and medicine ball throws for plyometric-golf specific exercise. The intensity and volume of the exercises was based on recommendations of from Piper and Erdmann (1998), Potach and Chu (2000), and McNeely (2005). When completing the medicine ball exercises, participants were informed to throw the ball against a wall and not to be concerned with catching the ball once it struck the wall. This was designed to allow the participant to focus fully on being explosive and powerful, as suggested by Newton (2007). The exercises used are shown in Table 1. To encourage greater ground reaction forces, bounding, lateral hurdle hops, multidirectional hurdle hopping, overhead medicine ball throws and squat jumps were employed. This was done with a view to improving, angular velocity/peak segment rotational velocities, X-factor stretch, stretch shortening cycles and more powerful eccentric-concentric muscle contractions, frontal rotation medicine ball throws, squat rotational medicine ball throws, lunge medicine ball throws were chosen. On completion of the program, the participant's undertook the warm down as described above.

Data Analysis and Statistics

The effects of the intervention on swing kinematics were analyzed using mixed factorial MANOVAs with a repeated factor of test (pretest, posttest) and a between-groups factor of group (control, experimental). MANOVAs were carried out on the following groups of variables; peak segmental speeds, individual body segment positions at address/top of the back swing/impact, swing timings, lags between segmental peak speeds, and variables related to X-Factor. Where significant effects were found follow-up mixed factorial ANOVAs were performed to identify significant effects within individual variables. The overall type I error rate for each analysis was set at α=0.05. Post hoc comparisons were carried with-in group on all variables where significant effects were identified from an ANOVA. The overall type I error rate for each analysis was set at α=0.05. All data and reported as mean ± *SD* unless otherwise stated.

Results

Pelvis Position

There were no significant main effects of trial on golfers' pelvic positions at address, top of the backswing or impact (Wilks's λ =0.05, $F_{14,1} = 1.51$, $p = .57$, $\eta^2 = 0.96$). Nor was there an interaction effect with group (Wilks's λ =0.04, $F_{14,1} = 1.97$, $p = .51$, $\eta^2 = 0.97$).

Upper Torso Position

There were no significant main effects of trial on golfers' upper torso positions at address, top of the backswing or impact (Wilks's λ =0.53, $F_{9,6} = 0.60$, $p = .77$, $\eta^2 = 0.47$). Nor was there an interaction effect with group (Wilks's λ =0.41, $F_{9,6} = 0.95$, $p = .55$, $\eta^2 = 0.59$).

Head Position

There were no significant main effects of trial on golfers' head positions at address, top of the backswing or impact (Wilks's λ =0.83, $F_{5,10} = 0.42$, $p = .83$, $\eta^2 = 0.17$). Nor was there an interaction effect with group (Wilks's λ =0.53, $F_{5,10} = 1.76$, $p = .21$, $\eta^2 = 0.47$).

Table 1 Plyometric Exercise Intervention

Exercise	Equipment	Sets/Repetitions	Intensity	Rest Period
Multidirectional Hops*	Hurdles × 4	3 sets, 1 set = 1 complete circle	Low/medium	3 min between sets
Bounding	N/A	3 sets 8 hops on each leg	Low/medium	3 min between sets
Lateral hops*	Hurdles × 1	3 sets, 1 set = 4 jumps left then 4 jumps right	Low/medium	3 min between sets
Squat Jumps	N/A	3 sets × 5 reps	Medium/high	3 min between sets
Overhead Throws	4kg Medicine ball	3 sets of 6 reps	High	3 min between sets
Squat Ball rotational throws*	4kg Medicine ball	3 sets, 1 set = 4 throws clockwise, 4 throws anti clockwise	High	3 min between sets
Kneeling lunge Rotations	4kg Medicine ball	3 sets, 1 set = 8 throws 2 left leg, 2 right leg clockwise, 2 left leg and 2 right leg anti clockwise	High	3 min between sets
Frontal rotation throws*	4kg Medicine ball	3 sets, 1 set = 4 throws clockwise, 4 throws anti clockwise	High	3 min between sets

*Indicates exercise was carried out in golf posture throughout.

X-Factor Variables

There was no main effect of time (Wilks's λ =0.68, $F_{4,11}$ = 1.3, p = .34, η^2 = 0.32) but a significant interaction effect between test and group was found for MROR, MROS, mXF, XFs (Wilks's λ =0.32, $F_{4,11}$ = 5.9, p = .009, η^2 = 0.68). Follow-up ANOVAs showed the interaction to be present for MROR (F_1 = 5.0, p = .04, η^2 = 0.27), XFs (F_1 = 7.2, p = .02, η^2 = 0.34) and mXF (F_1 = 7.0, p = .02, η^2 = 0.33) with pairwise comparisons showing significant increases in MROR and mXF for the experimental group post training (Table 2).

Peak Segmental Speeds

There was no main effect of time (Wilks's λ =0.61, $F_{4,11}$ = 1.8, p = .20, η^2 = 0.39) but a significant interaction effect between test and group was found for peak segmental speeds (Wilks's λ =0.45 $F_{4,11}$ = 3.4, p = .049, η^2 = 0.55). Follow-up ANOVAs showed the interaction to be present for arm_{peak} (F_1 = 5.5, p = .03, η^2 = 0.28) and $hand_{peak}$ (F_1 = 13.5, p = .003, η^2 = 0.49) with pairwise comparisons showing significant increases in arm_{peak} and $hand_{peak}$ for the experimental group post training (Table 2).

Swing Timings

There were no significant main (Wilks's λ =0.82, $F_{2,13}$ = 1.4, p = .27, η^2 = 0.18) or interaction effects (Wilks's λ = 0.84, $F_{2,13}$ = 1.2, p = .33, η^2 = 0.16) on swing times. However, there was a main effect of trial on timings lags between peak segmental speeds (Wilks's λ =0.38, $F_{4,11}$ = 4.5, p = .02, η^2 = 0.62), although this was not accompanied by an interaction effect with group (Wilks's λ =0.93, $F_{4,11}$ = 0.22, p = .92, η^2 = 0.08) suggesting both groups changed in the same manner. Follow-up ANOVAs only found a significant main effect of arm-hand lag time (F_1 = 11.65, p = .004, η^2 = 0.45), with arm-hand lag time reducing significantly after the intervention (46 ± 22ms pre vs 28 ± 22ms post).

Discussion

The purpose of the current study was to investigate any effects of plyometric training on golf swing kinematics. The main finding was that the 8 week training program used here increased the peak speed of the lead arm and hand, and the maximum X-Factor and rate of recoil of the X-Factor during the downswing. Previous work has found combinations of plyometric and strength training to increase golfers' club head speed (Doan et al., 2006) and ball displacement (Fletcher & Hartwell, 2004), while neither was measured here it is reasonable to suggest we would have seen a similar outcome. This is supported by suggestions that increases in lead arm (Healy et al., 2011) and hand segment speeds (Sprigings & Mackenzie, 2002), maximum X-Factor (Hume, Keogh, & Reid, 2005) and rate of recoil of the X-Factor (Neal & Dalgleish, 2008) may all increase club head speed. Swing performance, including club head speed, has been reported to be related to both golf skill (handicap and score) and muscle strength (Torres-Ronda, Sánchez-Medina, & González-Badillo, 2011). It is, therefore, possible that the inclusion of golf specific plyometric in a player's physical conditioning may result in improved scores on the course.

Table 2 Group Mean Stretch and Segmental Speed Data Pre and Post Intervention.

	Control Group				Training Group			
	Pre		Post		Pre		Post	
	Mean ± *SD*	CI	Mean ± *SD*	CI	Mean ± *SD*	CI	Mean ± *SD*	CI
$Pelvis_{peak}$ (°·s^{-1})	443 ± 92	383–503	457 ± 74	408–505	490 ± 63	490–550	513 ± 52	465–561
$Torso_{peak}$ (°·s^{-1})	718 ± 85	661–774	734 ± 67	689–779	745 ± 63	688–802	770 ± 50	725–815
Arm_{peak} (°·s^{-1})	905 ± 157	803–1007	908 ± 147	819–998	868 ± 108	766–970	930 ± 79*	840–1020
$Hand_{peak}$ (°·s^{-1})	1438 ± 115	1356–1520	1404 ± 126	1315–1493	1483 ± 101	1401–1565	1562 ± 109*	1473–1651
mXF (°)	57 ± 7	51–63	56 ± 9	48–64	61 ± 8	56–67	68 ± 11*	60–76
XFs (°)	15.5 ± 8.0	10.4–20.5	13.4 ± 6.2	8.7–18.0	14.9 ± 5.1	9.8–20.0	17.0 ± 6.0	12.4–21.6
MROS (°·s^{-1})	72 ± 20	44–100	67 ± 21	49–84	91 ± 48	63–119	99 ± 26	81–117
MROR (°·s^{-1})	651 ± 160	533–770	651 ± 124	490–812	771 ± 153	652–889	929 ± 273*	769–1090

* Indicates significant difference from pre training value in same group, $p < 0.05$. CI shows the 95% confidence interval for the mean.

Golfers' body positions throughout the swing did not change suggesting that the training intervention did not alter technique and that the effects seen are the result of changes in rotational power of the body which is important in conditioning programs for golf (Gordon et al., 2009). We qualitatively inspected kinematic sequence curves of golfers in both groups but found no obvious changes in sequencing which was supported by the lack of change in time between peak segmental speeds in the post testing. The only exception to this was the significant decrease in the time between peak arm and hand speeds in both groups in the post test. As there was no difference in the time between hand peak speed and impact it is possible that this represents a later peaking of the arm speed rather than an earlier release of the "lag" angle of the club, although this cannot ruled out. Equally, given the absence of any changes in positional kinematics it may be the result of diurnal variation in swing kinematics, something which is not currently well understood (Langdown et al., 2012). The finding of no change in positional kinematics was unexpected as our work with individual golfers has previously shown plyometrics to alter kinematics, the difference being that this was in combination with swing technique instruction. It would therefore be informative to examine if there is an effect of swing technique instruction in combination with plyometrics on swing kinematics.

The exercises in the current study were specifically selected to increase trunk rotational power and ground reaction force as these have been found trunk rotational power has been shown to be related to swing speed (trunk rotational power, Yoon, 1998) and ball carry (vertical jump performance, Wells, Elmi, & Thomas, 2009) in low handicap golfers. A standard external loading (4kg medicine ball) was used for selected exercises in the training program (Table 1) and it is possible that this was not optimal for participants (Cormie, McGuigan, & Newton, 2011). Future studies should investigate the optimal upper body loading for golf specific plyometric exercises. In addition the retesting post intervention was immediately after week 8, it has previously been found that additional recovery can lead to further increases in power after 4 weeks (Luebbers et al., 2003). The program consisted of a mixture of lower body specific and whole body exercises, which were a mixture of open and closed kinetic chain for the lower body but the upper body was only in an open kinetic chain. Closed kinetic chain exercises have been shown to improve throwing performance and it is possible that the inclusion upper body closed kinetic chain exercises may potentially improve the current exercise program (Prokopy et al., 2008).

A limitation of the current study is that we have no data on the club or ball and as such can only make inferences about changes that may have occurred in these. The generalization of the findings to female or less skilled golfers is limited as the current sample consisted of only male skilled golfers. In terms of skill level we would suggest that plyometric training may only be suitable for golfers who have established swing techniques and should certainly not be used for golfers who do not have the necessary physical competency to complete the exercises safely.

In conclusion, an 8-week plyometric training program consisting of lower and whole body exercises can alter the swing kinematics of skilled male golfers increasing distal segmental speeds and other variable that may be related to club head speed and ball displacement. Future research should consider the optimal loading for golf specific plyometrics and the potential for combined plyometric and swing technique interventions.

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