ANALYSIS OF TRUNK ROTATION PATTERNS WHEN SWINGING AT DIFFERENT SPEEDS: A PILOT STUDY

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As the trunk plays a vital role during the golf full swing, it is important to understand how body movements affect the golf swing. The purpose of this study was to determine how golfers increase club head speed through trunk rotation. Trunk rotation patterns were captured by 3D motion capture system at 250 Hz. To investigate the effective factors of increasing club head speed, we compared two situations, swing at normal club head speed and at accelerated club head speed, via the trunk rotation angles at three dimensions through six temporary events. The results showed that subtle differences between normal club head speed and accelerated club head speed. To increase club head speed, golfers might optimize the separation between shoulder and pelvic in the early downswing.

KEY WORDS: golf, motion analysis, X Factor.

INTRODUCTION: To improve performance the golf ball should be driven increasing distances. Club head speed is one of the major factors that affects distance of a drive (Hume, Keogh, & Reid, 2005) and is a vital element to differentiate the skill level of golfers. A faster club head speed is usually associated with better performance (Fradkin, Sherman, & Finch, 2004). As a result, it is important to understand how the golfer increases club head speed during the swing phase. An essential factor for developing maximum club head speed at impact is the body segment sequence (Lindsay, Mantrop, & Vandervoort, 2008). Approximately 70% players began the downswing, rotated their hips first and then followed with shoulder rotation (McTeigue, Lamb, Mottram, & Pirozzolo,1994). This sequencing between body segments has been previously assessed by the variable called "X-Factor". The "gap" means the separation between shoulder rotation angle and pelvic rotation angle on the horizontal plane, which is called "X-Factor". The sequence of this movement results in those muscles surrounding the hip and trunk being extended before executing a concentric contraction at the early downswing, which is known as the stretch-shorten cycle (Cole & Grimshaw, 2009). It is believed that actively stretching a muscle (eccentric) prior to shortening it (concentric) results in a much more positive work than concentric contraction alone (Enoka, 1994). In order to maximize ball driven distance, it's important to "widen the gap" at the top of the backswing and to have "closed the gap" at the ball impact (McLean, 1992, 1993). In the past few years, many studies have already validated that X-Factor was one of major elements could affect club head speed (Cheetham, Martin, E.Mottram, & Laurent, 2001; Fletcher & Hartwell, 2004; Cole & Grimshaw, 2009; Chu, Sell, & Lephart, 2010; Okuda, Gribble, & Armstrong, 2010; Healy, Moran, Dickson, Hurley, Smeaton, O'Connor, Kelly, Haahr, & Chockalingam, 2011). The purpose of this study was to discover how golfers' used their trunk to develop club head speed.

METHODS: One amateur golfer (age: 17y; height: 148cm; mass: 45kg; handicap: 9) was recruited for this pilot study. The participant has been playing golf for 3 years. She was free of any musculoskeletal injury in the last 6 months prior to the experiment. Trunk rotation motion during the golf swing was captured by a three-dimensional motion capture system consisting of 10 cameras operating at 250 Hz. (Vicon Motion Capture System, Oxford Metrics, UK). Fifty-one retroflective markers were placed on the bony landmarks of the participant, modified by a previous research (Hahn & Chou, 2004). The landmarks consisted of: bilaterally on the side of the head (approximately to the temples), back of the head, acromio-clavicular, scapula, sacral, lateral epicondyle of elbow, writs, hand (head of third metacarpal), anterior superior iliac spine, medial and lateral femoral epicondyle, medial and lateral malleolus, second metatarsal head and calcaneus. Additionally, 2 markers were placed on the shaft of the golf club (under the grip and club neck). Club head speed was measured by Auditor speed check (Golf Mechanix, US). The target was set at the left side to make the target line (line between ball position and target) parallel to the X-axis of the lab coordination system. The participant was asked to perform 20 swing shots at two different club head speeds by using their own club (iron 7). The experimental set up for this study is demonstrated in figure 1.

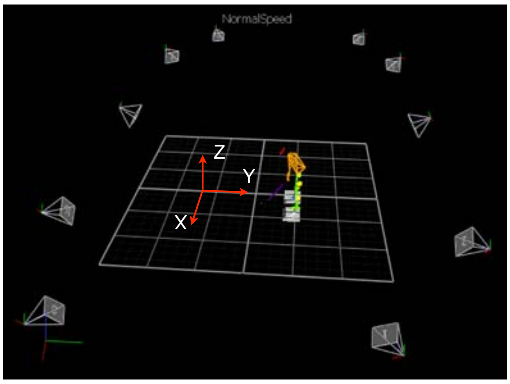

Figure 1: Experimental set up and lab coordination system.

Before the experiment, the participant was asked to swing at two club head speed for five times each with the same club: normal club head speed and accelerated club head speed. Those speed values were used to differentiate success and failed trials. In the experiment, the participant performed a series of 10 full shot golf swings for each club head speed. The sequence of the trial would change every 5 shots in turns, for example: performed 5 normal club head speed shots after 5 accelerated club head speed shots. The average rest time between trials was 60 seconds. Five successful trials were chosen from each situation for data analysis.
The independent variable for this study was the club head speed of full shot golf swing. The dependent variables were selected from the trunk motion patterns, which were: upper trunk rotation, pelvic rotation, upper trunk side-bend, pelvic side-bend, trunk tilt and X-Factor (Okuda et al., 2010). Dependent variables of trunk rotation patterns are demonstrated in figure 2.

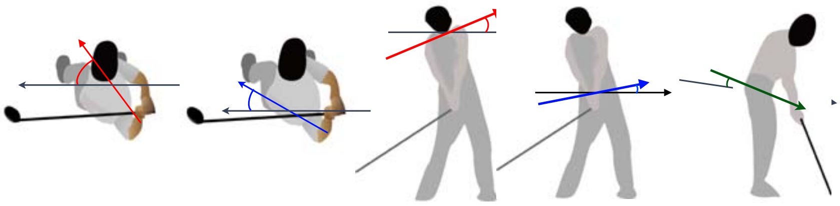

Figure 2: Five trunk rotation parameters, from left to right: upper trunk rotation angle, pelvic rotation angle, upper trunk trunk side-bend, pelvic side-bend and trunk tilt. (Okuda et al., 2010).

According to Okuda et al (2010), there are six temporal events throughout the golf full swing: Address (AD: 0.1 seconds before the initial motion of the club head), Backswing (BS: when the club head reaches the farthest position away from the target), Top of Backswing (TBS: when the club head reaches the closest position toward the target before Downswing), Downswing (DS: when the left wrist reaches the farthest position away from the target), Ball Impact (BI: when the club head makes contact with the ball), Follow Through (FT: when the club head reaches the closest position toward the target). Matlab (Math-Works Inc., USA) was used to calculate all kinematic data and temporal events occurring time. Since it was a pilot study, only descriptive statistic analysis method was employed in this study.

RESULTS: The normal club head speed was 30.38±0.18 m/s, and the accelerated club head speed was 33.36±0.79 m/s. According to the previous research, key kinematic activities occurred between top of the backswing and ball impact (Chu et al., 2010). X-Factor was found greater at accelerated club head speed than normal club head speed at TBS event. Variables occurred between top of backswing and ball impact were demonstrated in table 1.

In the current study, the maximum X-Factor was 66.09±0.57° at normal club head speed, 67.00±2.27° at accelerated club head speed.

Table 1: Means (±SD) of the trunk rotation variables. n= 5.

	Normal club head speed			Accelerated club head speed		
Variables	**TBS**	**DS**	**BI**	**TBS**	**DS**	**BI**
Upper trunk rotation (°)	102.16 ±2.13	57.45 ±3.04	15.59 ±0.58	103.05 ±1.29	52.80 ±1.32	19.06 ±1.86
Pelvic rotation (°)	42.25 ±1.80	3.57 ±2.34	60.54 ±0.60	40.92 ±2.54	7.47 ±3.30	65.54 ±3.34
X-Factor (°)	59.91 ±0.81	53.88 ±5.34	-44.95 ±1.09	62.13 ±2.58	45.32 ±4.57	-46.48±1.82
Upper trunk side-bend (°)	111.62 ±3.77	38.99 ±3.44	23.66 ±0.83	113.28 ±1.99	33.73 ±0.67	26.52 ±0.90
Pelvic side-bend (°)	17.02 ±1.41	5.38 ±0.28	6.57 ±0.52	16.36 ±0.47	4.38 ±0.51	8.32 ±2.02
Trunk tilt (°)	16.97 ±0.75	10.49 ±0.50	5.28 ±1.04	16.10 ±1.03	9.51 ±0.42	5.49 ±1.11

X-Factor= upper trunk rotation angle - pelvic rotation angle

DISCUSSION: The purpose of this study is to examine trunk rotation movement during an accelerated swing shot. Since the results were only gathered from one subject, the data could only provide limited information. However, we can still observe the fact that trunk rotation movement affects the club head speed. First of all, the upper trunk rotation angle was similar in both club head speeds (normal club head speed: 102.16 ±2.13°, accelerated club head speed: 103.05 ±1.29°). Yet pelvic rotation angle was constrained and was smaller in accelerated club head speed (40.92 ±2.54°) than in normal club head speed (42.25 ±1.80°). This resulted in greater X-Factor in accelerated club head speed (62.13 ±2.58°) than in normal club head speed (59.91 ±0.81°). It also showed that the separation was subtly greater in accelerated club head speed than in normal club head speed. According to Okuda et al (2010), which measured the X-Factor between skilled golfers and low skilled golfers, there were no significant differences in either upper trunk or pelvic horizontal rotation angles at the top of the back swing. In a similar previous study, Myers, Lephart, Tsai, Sell, Smoliga, & Jolly (2008) examined 100 golfers from different levels, and found no significant differences in both upper trunk and pelvic horizontal rotation angles at the TBS and the BI. It suggested that the separation of shoulder and pelvic rotation angle might be a minor factor in creating an accelerated club head speed swing shot.

Secondly, to overhaul the X-Factor profile from the full shot golf swing, the X-Factor maximum did not occur at the TBS event. The X-Factor maximum ~~was~~ occurred after the TBS event. In addition, the X-Factor maximum was greater in accelerated club head speed (67.00±2.27°) than in normal club head speed (66.09±0.57°). This implied that after the TBS event, accelerated club head speed created more separation between shoulders and pelvic than normal club head speed. Correspondingly, McLean and Andrisani (1996) indicated a phenomenon that describes the pelvic rotated back towards the impact position while the upper torso was still rotated to top of the backswing, creating maximum separation between two segments, upper torso and pelvic. Our study was supported by a previous statement of the importance of creating the separation between shoulders and pelvic rotation angle at TBS and early the downswing, which would store energy in trunk muscles (Myers et al., 2008). The release of stored energy resulted in more impulse and increased club head speed, ball initial velocity, and therefore driven distance (Cheetham et al., 2001). Our study was consistent with the previous study that muscle around the trunk would be stretched passively then shortened with greater work and would result in greater power output (Myers et al., 2008). The phenomenon that described the change during the early downswing was called "X-Factor stretch" (Cheetham et al., 2001). To accelerate club head speed, golfer utilized the advantage of the stretch-shortening cycle (Fletcher et al., 2004). This suggested that although there was no difference between the separations of shoulder and pelvis at the

TBS event, it is important to create a greater separation at the early downswing and to optimize the X-Factor stretch.

CONCLUSION: The aim of this study was to estimate how golfers speed up club head linear speed by alternating the trunk rotation patterns. Although it was a pilot study, the result was consistent with earlier studies. The result showed that X-Factor stretch could be a vital parameter. To improve ball driven distance, it is important to utilize SSC by using X-Factor stretch.

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