

An Analysis of X-Factor, Triple X-Factor, and the Center of Pressure (COP) according to the Feel of the Golf Driver Swing

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Objective: The aim of this study was to analyze X-factor, triple X-factor, and the center of pressure (COP) according to the feel of golf driver swing.

Method: For this research, 9 golfers from the Korea Professional Golfers' Association (age: 30.11±2.98 yrs, height: 178.00±8.42 cm, weight: 76.22±8.42 kg, experience: 10.06±3.11 yrs) were recruited to participate in the experiment. Twelve Motion Analysis Eagle-4 cameras were installed and an image analysis was conducted by using the NLT (non-linear transformation) method, and 2 units of Kistler type 5233A dynamometer were used to measure ground reaction force. The sampling ratio was set at 1000 Hz. The golfers each took 10 swings by using their own driver, and chose the best and worse feel from among 10 shots. A paired-sample *t*-test was used to analyze the results.

Results: In regard to feel, no change in head speed, X-factor, and the triple X-factor's X-factor stretch, hip rise, and head swivel, was observed ($p>.05$). Regarding ground reaction force, a difference was observed between the top of the backswing ($p<.05$) and impact ($p<.05$) in the vertical force of the left foot. For COP, a difference was also observed between the mid backswing ($p<.001$), late backswing ($p<.001$), and top of the backswing ($p<.05$) for the right foot X-axis and Y-axis mid follow through ($p<.01$).

Conclusion: It can be reasoned that, irrespective of feel, the head speed, X-factor and triple X-factor's X-factor stretch, hip rise and head swivel did not have an effect on drive distance for domestic golfers, and the vertical reaction force of the left foot and left-right movement span's pressure dispersal of the right foot had an increasing effect on drive distance.

Keywords: X-factor, Triple X-factor, X-factor stretch, Hip rise, Head swivel, COP

INTRODUCTION

A golf swing is a movement that requires highly technical and scientific analyses, and is comprised of a complex and continuous rotational movement that involves body segments and joints. Moreover, because it involves supporting the anatomical axis by using the lower body and generating a large rotational movement of the upper body, timing and coordination must be well executed to achieve good head speed, accuracy, and consistency (Burden, Grimshaw & Wallace, 1998; So, 1998; Egret, Vincent, Weber, Dujardin & Chollet, 2003; Lee & So, 2004).

An effective golf swing is established through accuracy and consistency from keeping the lower body and rotational axis of the body firmly fixed. When the difference between shoulder rotation, which represents upper body rotation, and hip rotation, which represents lower body rotation, increases, the accumulated force becomes great enough to increase the efficiency of energy use (Cheatham, Martin, Morttram & St Laurent, 2001; Horton, Lindsay & Macintosh, 2001; Lindsay & Horton, 2002). This results in a large amount of tension being stored, allowing maximum club head speed to be achieved by rotation, similar to uncoiling of a

spring (Hardy & Andrisani, 2008). Efficient use of the large segments involved in the golf swing is one of the factors that can increase head speed, which requires expression of the lower body muscle group, followed by use of the upper body muscle group (McTeigue, Lamb, Mottran & Pirozzolo, 1994; Okuda, Armstrong, Tsunozumi & Yoshiike, 2002). Moreover, by creating a large difference in angle between the shoulders and hips during the back swing, and then generating shoulder rotation after hip rotation during the downswing, greater elasticity is generated from eccentric contraction (McTeigue et al., 1994; Hardy & Andrisani, 2008).

Weight transfer is essential in effectively transferring momentum in a golf swing. To increase flight distance, proper weight transfer must be performed with generation of a large ground reaction force (GRF) (Hume, Keogh & Reid, 2005). Proper weight transfer is an essential part of maintaining the ideal balance, achieving natural upper body rotation, and delivering maximum momentum to the ball (Zumerchik, 2002). In other words, an effective golf swing can be viewed as proper weight transfer using GRF and upper body rotation with the lower body as the base. For proper balance, weight transfer starts from the center of the

body, followed by movement to the right and then back to the left (Gluck, Bendo & Spivak, 2008).

One of the most well-known studies on flight distance, and upper and lower body rotation during golf swing is that by McLean (1992), which was published in *Golf Magazine* with the title, "Widen the gap", and reported on an X-factor that demonstrates the difference in rotational angle between the shoulders and hip at the top of a backswing. The author reported that having a larger difference in rotational angle between the shoulders and the hip at the top of a backswing contributed significantly to increasing flight distance. Moreover, McLean (2008) also introduced triple X-factor as factors that increase flight distance, in the *Golf Digest* under the title, "Triple x-factor: your key to power". The triple X-factor consist of X-factor stretch, hip rise, and head swivel. X-factor stretch refers to the angle at which the value of the X-factor appears largest in going from the top of a backswing to downswing. Hip rise refers to the difference in the height of the left hip from addressing the ball to the actual impact, and head swivel refers to the difference in head angle from looking at the ball during address to post-impact follow through. Another study reported that these three variables affect the increase in flight distance (Mann, 2008).

Precedent studies on X-factor and the X-factor stretch of the triple X-factor (Cheetham et al., 2001; Kim, 2004; Chang, 2005a, b; Kim, 2009) reported that the X-factor value increased in going from the top of a backswing to downswing and that increased X-factor stretch value affected the increased flight distance. Studies similar to those on hip rise of the triple X-factor reported on changes in hip sway, height difference between the left and right hips, rotational angle distance of the hip, and rotational and angular hip speeds during a golf swing (Evans & Oldreive, 2000; Marshall & Elliott, 2000; Cheetham et al., 2001; Kwon & Lee, 2005; Lee & Nam, 2005; Sung, 2005; Myers et al., 2008), but content related to the movement of hip rise was difficult to find. Studies on head movement similar to head swivel have examined head position and height at address, top of the backswing, impact, and finish (Cochran & Stobbs, 1999; Kwon & Lee, 2005; Sung, 2005), with studies on the movement of head swivel being rare.

X-factor and the X-factor stretch of the triple X-factor have been reported to be effective in increasing flight distance, but studies on the hip rise and head swivel of the triple X-factor are still lacking. Moreover, as clear interpretations have not been obtained yet, the hip rise and head swivel factors of the triple X-factor should be analyzed. However, it was determined that if the ball does not accurately contact the "sweet spot" on the face of the clubhead at the moment of impact or proper weight transfer is not executed, then it would be difficult to explain increased flight distance based on bodily movements alone.

In a golf swing, weight transfer refers to the change in the center of pressure (COP) and distribution of force on both feet, and weight transfer plays a role in maintaining proper balance during the golf swing and delivering the maximum momentum to the ball by having the ball contact the sweet spot on the face of the clubhead under an optimal condition (Richards, Farrell, Kent & Kraft, 1985; Wallace, Grimshaw & Ashford, 1994; Zumerchik, 2002; Shin, 2007; Song, 2009). The outcome of weight transfer has an effect on the flight, direction, distance, and trajectory of the ball, which are essential elements of a successful golf

swing (Hur, Moon & Lim, 2005; Sung, 2010), and a good shot cannot be executed without proper weight transfer during the swing (Sung, 2010). Accordingly, a golf swing is affected by the reaction force generated on the ground according to the movement of body segments (Williams & Cavanagh, 1983). Therefore, the changes in GRF and COP should be analyzed for observation of proper weight transfer during golf swings.

The present study examined Korean professional golfers with the objective of investigating the changes in head speed, X-factor, and the triple X-factor's X-factor stretch, hip rise, and head swivel, along with changes in GRF and COP according to their feel of the golf driver swing.

METHODS

1. Participants

The participants in the present study consisted of 9 professional golfers who are members of the Korea Professional Golfers' Association (KPGA; age: 30.11 ± 2.98 yrs, height: 178.00 ± 8.42 cm, weight: 76.22 ± 8.42 kg, experience: 10.06 ± 3.11 yrs). All the participants received explanation on the study procedures prior to their participation, and a written participation consent form was received from all the participants.

2. Equipment

Twelve Eagle 4's infrared cameras (Motion Analysis, USA) were used with a sampling rate of 250 Hz/s and resolution of $1,280 \times 1,024$ pixels to acquire the images. Two GRF measurement systems from Kistler (type 5233A) were used to collect GRF data at a sampling rate of 1,000 Hz. Coordinates were calculated by using the EVaRT 5.0 program from Motion Analysis to obtain the positional coordinate and GRF data, while smoothing was performed by using Matlab 7.1.

3. Procedures

Forty markers (35 on the body, 3 on the clubhead, 1 on the shaft, and 1 on the golf ball) were attached to obtain the three-dimensional (3-D) coordinates of the golf driver swing motion. The 3-D spatial coordinates were calculated by using the non-linear transformation (NLT) method, while GRF was measured by using 2 units of the Kistler type 5233A dynamometer. Each participant used his own driver to make 10 shots each. The best swing feel was defined as having the golf ball accurately contacting the sweet spot on the clubhead face at the moment of impact with proper weight transfer. Each participant self-assessed the feel of the swing for each of his shot, with 1 point for the worst swing feel and 5 points for best swing feel. The mean head speed from the 10 driver shots was calculated for each participant. For the worst swing feel, the shot that showed the lowest head speed in comparison with the mean head speed was used, while for the best swing feel, the shot that showed the highest head speed in comparison with the mean head speed was used for the analysis.

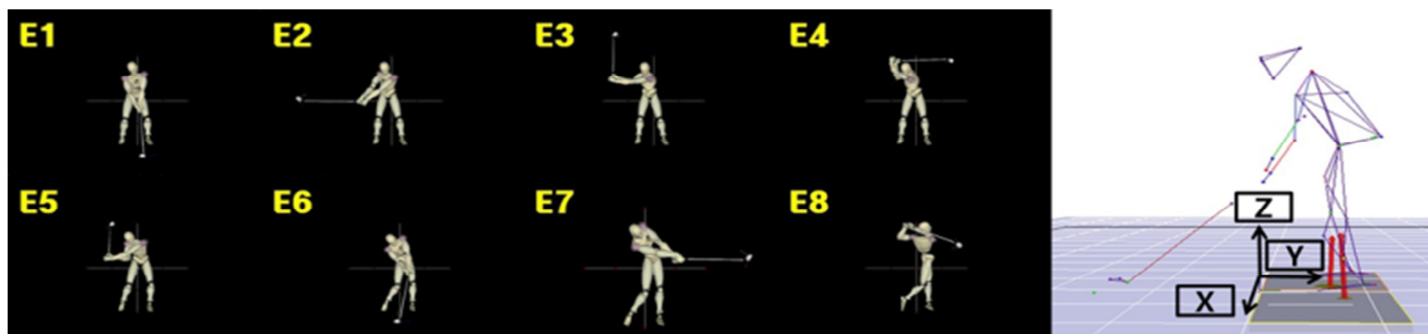


Figure 1. Events and definitions of the axis.

4. Data processing

1) X-factor

As an orthogonal projection on a the XY plane, the difference in angle between the shoulder and hip was calculated.

2) Triple X-factor

(1) X-factor stretch

By using the X-factor value obtained, the highest X-factor value from the initial stage of downswing was set as the X-factor stretch value.

(2) Hip rise

After defining the coordinate of the left hip at address as "0" point, the value was calculated as change in the value of the Z-axis length, that is, the vertical length.

(3) Head swivel

As an orthogonal projection on the XY plane, the difference in head angle between the point of address and mid follow through was calculated.

3) GRF

$$BW (\%) = \frac{\text{ground reaction force (N)}}{\text{weight (kg)} \times 9.8 (\text{N})} \times 100 (\%)$$

4) COP

$$X_{\text{cop}} = -\frac{M_y + F_x \times dz}{F_z}, \quad Y_{\text{cop}} = -\frac{M_x + F_y \times dz}{F_z}$$

5) The events in the present study were defined as E1 (AD: address), E2 (MB: mid backswing), E3 (LB: late backswing), E4 (TB: top of the backswing), E5 (ED: early downswing), E6 (IM: impact), E7 (MF: mid follow through), and E8 (FN: finish). The axes were defined as follows: X-axis, the left and right direction relative to the participant; Y-axis, the front and back of the participant; and Z-axis, the vertical direction (Figure 1).

5. Statistical analysis

Statistical analysis was performed by using SPSS 14.0 (IBM, USA). A paired *t*-test was performed to analyze the differences in the two test conditions based on swing feel, with the significance level set to $\alpha = .05$.

RESULTS

The results from the analysis of head speed, X-factor, GRF, COP, and the triple X-factor's X-factor stretch, hip rise, and head swivel according to the feel of the golf driver swing by KPGA professional golfers were as follows:

1. Head speed and X-factor

Head speed showed the highest value of 1.44 ± 4.30 m/s when the swing feel was good, but no statistically significant differences were observed ($t = -1.004$, $p > .05$). The X-factor ($t = 0.206$, $p > .05$) also did not show any statistically significant differences (Table 1).

Table 1. Head speed and X-factor

| | Bad | Good | <i>t</i> | <i>p</i> -value |
|------------------|------------|------------|----------|-----------------|
| Head speed (m/s) | 43.50±4.36 | 44.94±1.81 | -1.004 | .345 |
| X-factor (deg) | 48.89±5.81 | 48.77±6.36 | 0.206 | .842 |

2. Triple X-factor

The elements of the triple X-factor's X-factor stretch ($t = -0.084$, $p > .05$), hip rise ($t = -1.679$, $p > .05$), and head swivel ($t = 0.554$, $p > .05$), all did not show statistically significant differences (Table 2).

3. Ground reaction force

The vertical force of the left foot at E4 (TB) was 34.26 ± 10.59 %BW ($t = -2.652$, $p < .05$) when the swing feel was good, showing a statistically significant difference. At E6 (IM), the value was 72.67 ± 18.09 %BW ($t = 2.713$, $p < .05$) when the swing feel was good, also showing a statistically

Table 2. Triple X-factor

| Triple X-factor | Bad | Good | <i>t</i> | <i>p</i> -value |
|------------------------|------------|------------|----------|-----------------|
| X-factor stretch (deg) | 59.55±9.35 | 59.63±7.95 | -0.084 | .935 |
| Hip rise (cm) | 6.55±3.05 | 6.94±3.06 | -1.679 | .132 |
| Head swivel (deg) | 16.62±6.97 | 16.03±6.18 | 0.554 | .595 |

significant difference. The vertical force of the right foot at E4 (TB) was 68.72±12.80 %BW ($t=1.572$, $p>.05$) when the swing feel was good but showed no statistically significant difference. At E6 (IM), the value was 51.33±17.86 %BW ($t=0.686$, $p>.05$) when the swing feel was good but also showed no statistically significant difference (Table 3).

4. Center of pressure

Changes in COP were calculated based on both the left and right feet at E1 (AD), established as "0" point. A lower X-axis value indicates a right direction and a higher X-axis value, a left direction. Meanwhile,

a lower Y-axis value indicates a forward direction and a higher Y-axis value, a backward direction.

The COP of the left foot showed similar changes from E1 (AD) to E4 (BT) regardless of the swing feel. At E5 (ED), when the swing feel was bad, movement was to the left, 3.86±3.64 cm from E1 (AD), whereas when the swing feel was good, movement was to the left, 2.30±3.20 cm from E1 (AD) ($t=1.812$, $p>.05$). However, no statistically significant differences were found. At E8 (FN), the movement direction changed to the left by 2.02±6.74 cm from E1 (AD) when the swing feel was bad and by 0.43±3.17 cm from E1 (AD) when the swing feel was good ($t=1.212$, $p>.05$), but without statistically significant differences (Table 4, Figure 2).

The COP of the right foot showed changes in movement direction to the right by -0.71±0.83 cm from E1 (AD) to E2 (MB) when the swing feel was bad and by -0.24±1.00 cm from E1 (AD) to E2 (MB) when the swing feel was good ($t=-5.548$, $p<.001$), with statistically significant differences. At E3 (LB), movement was to the right at -0.92±1.03 cm from E1 (AD) when the swing feel was bad and at -0.35±1.29 cm from E1 (AD) when the swing feel was good ($t=-5.098$, $p<.001$), with statistically significant differences. At E4 (TB), movement was to the right at -3.03±1.38 cm from E1 (AD) when the swing feel was bad and at

Table 3. Ground reaction force

| | | (unit: %BW) | | | | | | | |
|-----------------|------|-------------|------------|------------|-------------|-------------|-------------|-------------|------------|
| | | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 |
| Left foot | Bad | 51.50±3.48 | 25.63±7.03 | 27.29±7.24 | 30.81±8.22 | 88.11±21.92 | 79.82±13.97 | 56.40±19.57 | 79.15±7.68 |
| | Good | 50.83±4.06 | 26.54±7.24 | 27.47±6.01 | 34.26±10.59 | 89.56±20.06 | 72.67±18.09 | 48.28±25.50 | 80.60±7.87 |
| <i>t</i> | | 0.874 | -0.866 | -0.190 | -2.652 | -0.702 | 2.713 | 0.800 | -0.810 |
| <i>p</i> -value | | .408 | .402 | .854 | .029* | .503 | .027* | .447 | .441 |
| Right foot | Bad | 51.99±3.01 | 80.22±7.55 | 71.18±7.55 | 62.30±12.29 | 49.79±13.16 | 49.13±18.62 | 35.69±7.54 | 27.24±7.71 |
| | Good | 52.66±3.65 | 73.13±8.07 | 71.50±6.30 | 68.72±12.80 | 51.06±8.96 | 51.33±17.86 | 37.20±9.29 | 30.46±8.73 |
| <i>t</i> | | -0.811 | 0.565 | -0.440 | 1.572 | 1.081 | 0.686 | -0.429 | 0.700 |
| <i>p</i> -value | | .441 | .587 | .671 | .155 | .311 | .512 | .679 | .504 |

Note. Significant at * $p<.05$

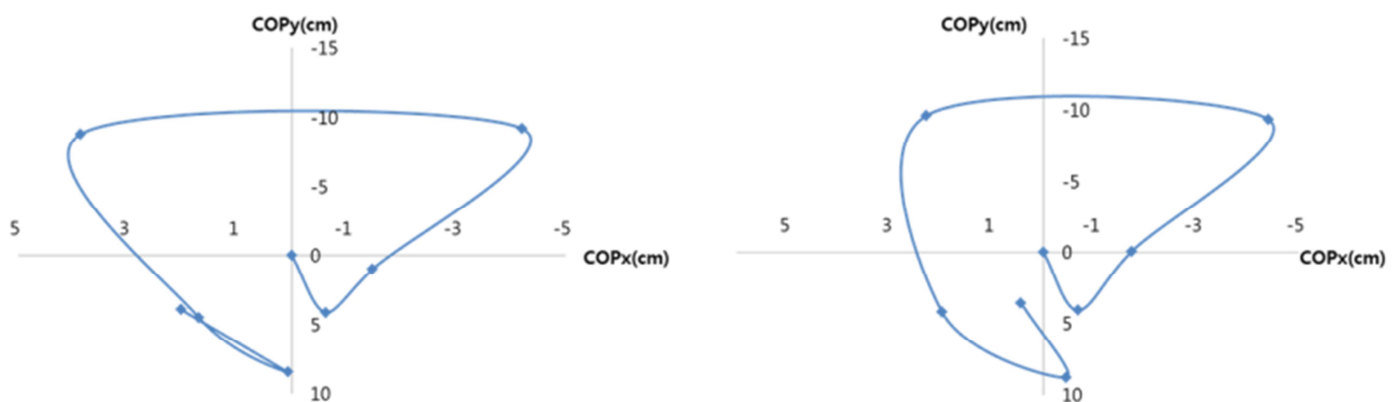
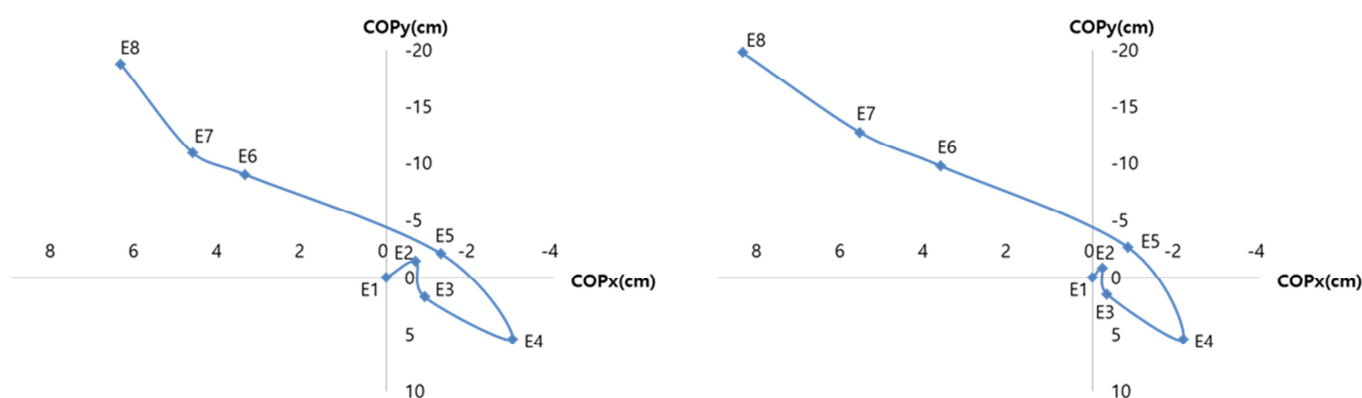
**Figure 2.** COP of the left foot (left: bad, right: good).

Table 4. Center of pressure (COP)

(unit: cm)

| | | Axis | E2 | E3 | E4 | E5 | E6 | E7 | E8 |
|-----------------|------|------|------------|------------|------------|------------|------------|-------------|-------------|
| Left foot | Bad | X | -0.63±1.74 | -0.47±1.29 | -0.21±2.79 | 3.86±3.64 | 1.69±2.36 | 0.07±3.57 | 2.02±6.74 |
| | Good | X | -0.69±1.51 | -0.73±1.60 | -0.41±3.20 | 2.30±3.20 | 1.98±4.29 | -0.45±5.43 | 0.43±3.17 |
| <i>t</i> | | | 0.130 | 0.654 | 0.268 | 1.812 | -0.230 | 0.347 | 1.212 |
| <i>p</i> -value | | | .900 | .531 | .795 | .108 | .824 | .738 | .260 |
| Left foot | Bad | Y | 4.12±5.50 | 1.00±4.00 | -9.20±5.97 | -8.80±6.33 | 4.51±2.98 | 8.45±4.60 | 3.92±5.15 |
| | Good | Y | 4.08±4.88 | -0.06±5.17 | -9.35±6.77 | -9.59±7.55 | 4.20±8.58 | 8.80±9.13 | 3.56±6.81 |
| <i>t</i> | | | 0.060 | 1.679 | 0.154 | 0.690 | 0.125 | -0.162 | 0.426 |
| <i>p</i> -value | | | .954 | .132 | .881 | .510 | .904 | .876 | .682 |
| Right foot | Bad | X | -0.71±0.83 | -0.92±1.03 | -3.03±1.38 | -1.31±1.38 | 3.39±3.85 | 4.65±2.99 | 6.38±4.17 |
| | Good | X | -0.24±1.00 | -0.35±1.29 | -2.18±0.93 | -0.85±1.95 | 3.65±4.07 | 5.58±3.93 | 8.40±6.75 |
| <i>t</i> | | | -5.548 | -5.098 | -2.658 | -1.665 | -0.716 | -1.673 | -1.571 |
| <i>p</i> -value | | | .001*** | .001*** | .029* | .134 | .494 | .133 | .155 |
| Right foot | Bad | Y | -1.40±3.64 | 1.73±3.08 | 5.42±2.08 | -2.08±2.46 | -9.01±2.24 | -10.92±2.30 | -18.75±4.48 |
| | Good | Y | -0.84±2.49 | 1.47±2.46 | 5.45±2.13 | -2.62±3.80 | -9.76±2.06 | -12.74±2.95 | -19.76±3.66 |
| <i>t</i> | | | -0.771 | 0.535 | -0.046 | 0.600 | 1.540 | 3.608 | 1.590 |
| <i>p</i> -value | | | .463 | .607 | .964 | .565 | .162 | .007** | .151 |

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

**Figure 3.** COP of the right foot (left: bad, right: good).

-2.18±0.93 cm from E1 (AD) when the swing feel was good ($t = -2.658$, $p < .05$), with statistically significant differences. At E7 (MF), the forward movement was -10.92±2.30 cm from E1 (AD) when the swing feel was bad and -12.74±2.95 cm from E1 (AD) when the swing feel was good ($t = 3.608$, $p < .01$), with statistically significant differences (Table 4, Figure 3).

DISCUSSION

The present study analyzed head speed, X-factor, vertical force, COP, and the triple X-factor's X-factor stretch, hip rise, and head swivel according to the feel of the golf driver swing by 9 KPGA professional

golfers. Based on the results, the following findings are discussed.

Impact is the most dynamic motion in golf and involves maintaining posture through coordination of the body segments, along with accuracy and appropriate timing for delivering maximum momentum of the head at impact (Plagenhoef, Evans & Abdeinour, 1993), as well as the direction, position, and speed of the club face at the moment of impact (Hay, 1985). In the present study, the head speed was 43.50±4.36 m/s when the swing feel was bad and 44.94±1.81 m/s when the swing feel was good, showing greater head speed by 1.44±4.30 m/s when the swing feel was good, but the difference was not significant.

With respect to the X-factor, the result was 48.89±5.81 deg when the swing feel was bad and 48.89±5.81 deg when the swing feel was good,

showing no significant difference. These values were higher than the 45.33 ± 9.32 deg and 40.95 ± 5.84 deg reported by Kwon and Lee (2005) and Kim (2004), respectively, but lower than the 53.50 ± 5.60 deg and 59.10 ± 8.20 deg reported by Lephart, Smoliga, Myers, Sell and Tsai (2007) and Myers et al. (2008), respectively. However, McLean (1996) indicated that although the angular difference in X-factor is a major factor in increasing flight distance, it is not quantitatively fixed.

The X-factor stretch of the triple X-factor was 59.55 ± 9.35 deg when the swing feel was bad and 59.63 ± 7.95 deg when the swing feel was good. The X-factor stretch values in the present study were lower than the 61.53 deg reported by Kim (2004) and the 65.58-77.81 deg reported by Chang (2005a). Hip rise was 6.55 ± 3.05 cm for bad swing feel and 6.94 ± 3.06 cm for good swing feel. McLean (2008) investigated hip rise in 75 professional tour and 150 amateur golfers (handicap: 17.2) and found that the amateur golfers showed a change of 1.27 cm and the professional golfers showed a change of 11.51 cm. By contrast, the present study showed changes that were lower than these values. Head swivel represents the angular change in head position from the point of address to mid follow through after impact (McLean, 2008). McLean (2008) reported that highly skilled tour golfers such as Jim Furyk, Annika Sorenstam, Joe Durant, Hal Sutton, Robert Allenby, and Carl Pettersson are able to have their head and eyes follow naturally the rotation of the body. This makes it easier to perform upper body rotation and weight transfer, and helps prevent injuries by reducing pressure on the neck and back, while also enabling the player to hit the ball further and straighter by releasing the head and eyes early for a natural head swivel. According to the study by McLean (2008) on head swivel of 75 tour professional and 150 amateur golfers (handicap: 17.2), the angular difference from address to mid follow through was 19.40 deg for the tour professional golfers and 4.40 deg for the amateur golfers. In the present study, the values at mid follow through were 16.62 ± 6.97 deg for bad swing feel and 16.03 ± 6.18 deg for good swing feel, showing no significant changes.

As shown, the present study did not find differences in head speed, X-factor, and the triple X-factor's X-factor stretch, hip rise, and head swivel according to swing feel, which is believed to be the result of performing a within-group analysis of the KPGA professional golfers as one group. Even for subjects with similar skill levels, differences in swing motion and strategy were observed between the subjects (Nesbit & Serrano, 2005). Thus, it is necessary to distinguish such differences in swing motion and strategy through a preliminary study.

The vertical force of the left foot at the top of the backswing was 30.81 ± 8.22 %BW for bad swing feel and 34.26 ± 10.59 %BW for good swing feel. At the moment of impact, the values were 79.82 ± 13.97 %BW for bad swing feel and 72.67 ± 18.09 %BW for good swing feel. With respect to the maximum GRF by each event, the highest values were found at early downswing, with 88.11 ± 21.92 %BW for bad swing feel and 89.56 ± 20.06 %BW for good swing feel. The changes were similar to those reported by William and Cavanagh (1983), Lee (1998), Sung (2005), and Hur et al. (2005), which suggested that as the weight is transferred to the left foot during downswing, the maximum vertical force appears right before the impact.

The vertical force of the right foot at mid backswing was $80.22 \pm$

7.55 %BW for bad swing feel and 73.13 ± 8.07 %BW for good swing feel, which were the highest among all the events regardless of swing feel. Williams, Jones, and Snow (1988) reported that the vertical force loaded on the right foot at mid backswing highly correlated with the flight distance of the ball. Their results were also similar to those reported by Sung (2007), which indicated that force in the right foot increased significantly at mid backswing.

With respect to changes in COP, the overall changes to the left/right and front/back directions of the left foot showed slight changes regardless of swing feel. However, when the swing feel was bad, change in the movement direction to the left appeared at early downswing, while at finish point, the COP position was found to be similar to that at the point of impact. Such phenomenon is determined to be the result of weight being transferred excessively to the left foot in going from the top of the backswing to downswing, which does not allow proper weight transfer to take place after impact. With respect to the COP of the right foot, for good swing feel, the margin of the left/right and front/back movements of the COP appeared narrowly at mid backswing, late backswing, and top of the backswing. The results were similar to those reported by Koenig, Tamres and Mann (1994) that in the early stage of a backswing, both feet move toward the direction of the heels, and then the left foot moves toward the toes at the top of the backswing, while the right foot moves quickly toward the toes as the down swing begins. In addition, they reported that having better golf skills resulted in the COP of the left foot being closer to a circle. COP is a scale that displays the point where the total vertical force is applied on the supporting surface (Teasdale & Simoneau, 2001). Therefore, having a small margin of movement in the COP of the right foot in going for address to the top of the backswing allows greater force to be accumulated, resulting in the start of an effective downswing for proper weight transfer and impact.

CONCLUSION

The objective of the present study was to compare and analyze the head speed, X-factor, GRF, COP, and triple X-factor's X-factor stretch, hip rise, and head swivel according to the feel of the golf driver swing by 9 KPGA professional golfers. As a result, the following conclusions were derived.

Head speed, X-factor, and the triple X-factor's X-factor stretch, hip rise, and head swivel showed no significant differences according to swing feel. The vertical force of the left foot was highest at the top of the backswing when the swing feel was good, whereas it was highest at the point of impact when the swing feel was bad. The COP of the right foot showed a narrow margin of the left/right movement of the COP at mid backswing, late backswing, and top of the backswing when the swing feel was good. At mid follow through, change in movement direction that was slightly more toward the front/back direction was observed when the swing feel was good.

Based on these results, we can conclude that regardless of swing feel, head speed, X-factor, and the triple X-factor's X-factor stretch, hip rise, and head swivel did not influence the variables related to flight distance. By contrast, the vertical force of the left foot and the margin of the left/

right movement of the COP of the right foot influenced the increase in flight distance.

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