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**Research article**

# Trunk rotation and weight transfer patterns between skilled and low skilled golfers

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**Abstract**
The purpose of this study was to examine trunk rotational patterns and weight transfer patterns that may differentiate swing skill level in golfers. Thirteen skilled golfers (mean handicap = 0.8 ± 2.6) and seventeen low skilled golfers (mean handicap = 30.8 ± 5.5) participated in this study. Kinematic and kinetic data were obtained through high-speed 3-D videography and force plates while the participant performed a full shot golf swing with a driver. Data at six temporal events during the swing were selected for the analysis. The results indicated that significant differences existed between the groups in the multiple events, as the skilled golfers showed the following motion patterns when compared to the low skilled golfers; 1) An earlier trunk horizontal rotation with a rapid weight transfer to the trail foot during the backswing; 2) An earlier pelvic horizontal rotation accompanied with an earlier weight transfer to the lead foot during the downswing motion; and 3) Less upper trunk horizontal rotation and more posterior pelvic rotation at the follow through. Collectively, these finding may be useful for instruction of golfers to improve their swing mechanics on a full shot golf swing.

**Key words:** Golf, kinematic, kinetic, skill level.

## Introduction

Previous scientific golf studies have identified several major key elements in the golf swing that can differentiate the skill level of golfers. In kinematic studies, it has been suggested that a sequential movement of the body segments is one of the most important factors for the successful motion pattern in the golf swing. This sequential pattern has been examined over a period of 40 years (Burden et al., 1998; Cochran and Stobbs, 1968; Milburn, 1982). Bunn (1972) described that the proximal body segments theoretically should reach their peak speed first, followed by more distal segments to execute an efficient and powerful motion during the golf swing. Thus, a proper golf swing should be initiated by motion of the pelvis, followed by that of the upper trunk, upper extremity, and then the golf club, in order to transfer momentum from proximal parts of the body to the distal segments. Results of previous scientific golf studies have supported this theory (McTeigue ea al., 1994). A kinematic golf study, using a portable motion analyzer, reported that approximately 70 percent of PGA tour professionals initiated the downswing motion from their pelvic segment (McTeigue et al., 1994). Burden et al. (1998) reported that 75 percent of sub-10 handicap golfers produced shoulder rotation that continued away from the flag while the pelvis began turning back toward the flag. It demonstrated that the skilled golfers initiated the down swing motion from the pelvic segment. Similarly, a series of studies describing the muscle-firing patterns of professional golfers' scapular muscles (Kao et al., 1995), hip and knee muscles (Bechler et al., 1995) and trunk muscles (Watkins et al, 1996), suggested that this sequential activation of segments occurred in skilled or professional golfers.

Kinetic studies of the golf swing have revealed the magnitude and direction of force applied to the ground (Budney and Bellow, 1979; Barrentine et al., 1994) and the weight transfer pattern during the golf swing motion (Richards et al., 1985). Barrentine et al. (1994) reported the difference in the timing of maximum torque in the trail foot depending on the golf skill level, and also suggested a correlation between the golf club velocity and the time of the maximum torque on the trail foot. Weight transfer, from the trail foot to lead foot, has been identified as a key element in hitting the ball a long distance. The amount of weight shift, and its timing with regard to active trunk rotation, may be critical in optimizing club head velocity (Richards et al., 1985). Previous studies in weight transfer patterns of skilled or professional golfers revealed that approximately 80 percent of the weight shifted onto the trail foot at the end of back swing; followed by a transfer to the lead foot during the down swing, reaching 81 to 142 percent of the golfer's weight at ball impact (Richards et al., 1985; Williams and Cavanagh, 1983).

Despite the fact that a number of studies have investigated the mechanics of the golf swing, there are a limited number that have examined kinematic and kinetic factors in combination. The control of weight transfer is a factor that typically differentiates skilled golfers and their counterparts. Since the body segments above the hip joints comprise the majority of the body mass, motion of these segments significantly affects weight transfer pattern during the swing. Additionally, the trunk is the body segment that connects the lower extremity to the upper extremity affecting the transfer of momentum from the legs to the arms. Examining the kinematics and kinetics of the trunk may provide useful information to understand differences in the skill level of golfers. Therefore, the purpose of this study was to examine the trunk rotational patterns and weight transfer patterns that are associated with the fullshot golf swing between skilled and low skilled golfers.

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**Table 1. Anthropometric and golf performance data. Data are means (± SD).**

| | Low skilled (n=17) | Skilled (n=13) |
|---|---|---|
| Height (m) | 1.77 (.06) | 1.81 (.08) |
| Mass (kg) | 76.0 (16.0) | 81.4 (10.7) |
| Gender | 14 males/3 females | 11 males/2 females |
| Age (year) | 23.9 (3.1) | 26.3 (4.9) |
| Years of experience (year) | 5.4 (3.6) | 14.1 (4.9) |
| Handicap (strokes) | 30.8 (5.5) | .80 (2.6) |

## Methods

### Participants

Thirteen skilled golfers (SG: inclusion criteria; handicap less than 5) and seventeen low skilled golfers (LSG; inclusion criteria; handicap between 20 and 36), ranging in age from 19 to 35 years participated in this study. All participants were right-handed golfers, and none had any history of orthopedic problems that restricted his/her golf swing. A summary of anthropometric data and golf performance data is presented in Table 1. A written informed consent approved by the University of Toledo Human Subjects Research Review Committee was obtained from each participant to insure that he/she understood the purpose of the study as well as the possible risks of being a participant.

### Instrumentation

Trunk rotational motion was measured using a three-dimensional video analysis system, consisting of eight high-speed cameras operating at 240 Hz, and the associated hardware and software (Motion Analysis Corporation, Santa Rosa, CA). The motion of retroflective makers, placed on the participant, was recorded by these cameras and transmitted to a video processor/computer system (MIDAS) for tracking, further reduction and processing (EVa software, Version 6.1.5, Motion Analysis Corporation, Santa Rosa, CA). After being processed by the EVa software, the data were then transmitted to Kintrak software (KinTrak version 6.2.2., Motion Analysis Corporation, Santa Rosa, CA) for final data analysis.

Ground reaction forces data during the golf swing were measured using a two-plate force platform system (Advanced Mechanical Technology, Inc, Model OR 6-3 and SGA 6-4, Watertown, MA). This system consisted of two separate force plates to individually record the ground reaction forces acting on each foot. Only the vertical component of ground reaction force (VGRF) data was used to analyze the weight transfer pattern of the golfers, because the study was interested in how trunk position affected the vertical force acting on the two feet. The force plates were synchronized with the three-dimensional motion analysis system so that specific points in the ground reaction force data could be identified by visually viewing the kinematic data. The VGRF data were sampled at 960 Hz, and converted to units of bodyweight and analyzed in KinTrak. Figure 1 demonstrates the experimental set up for this study.

### Data collection procedure

The participants were provided with an opportunity of warm-ups including stretch exercises and practice hitting before the testing began. Thirty-three reflective markers were placed over specific anatomical landmarks on the

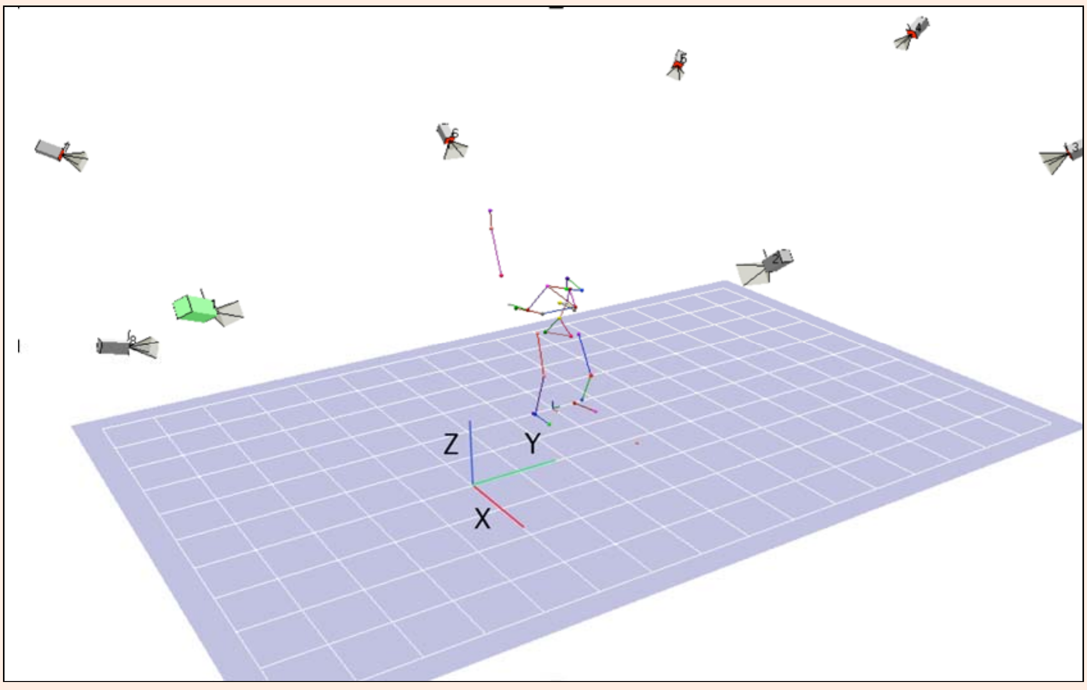


**Figure 1. Experimental set up for the study.**

**Figure 2. Marker configurations for data collection.**

participant's body as well as on the golf club to define the kinematic model and to create a stick figure that was used for visualization. The landmarks consisted of: forehead, side of the head (right/left), C7 spinous process, acromion process (right/left), sacrum, ASIS (right/left), lateral condyle of humerus (right/left), styloid process of ulnar (right/left), greater trochanter (right/left), lateral condyle of femur (right/left), medial condyle of femur (right/left) toe of the foot (right/left), heel of the foot (right/left), lateral malleolus (right/left), medial malleolus (right/left), at the head of the golf club, on the shaft of the golf club (at 10 cm and 70 cm proximal from the distal end of the shaft). An additional marker was placed on the top of the golf ball, and used to visually identify the time of ball impact during the data analysis. The markers on the medial side of the lower extremity (the medial condyle of femur and the medial malleolus of the tibia) were removed after the static trail for the data collection. Figure 2 demonstrates the marker configuration for this study.

During data collection each participant was allowed to establish a preferred foot position on each force plate; however they were asked to select a position that would allow them to hit the golf ball as parallel as possible to the Y-axis of the lab's coordinate system (designated by a target in the center of the golf net). The participants performed a series of five full shot golf swings with a driver provided by the investigators while the kinematic and kinetic data were collected. The participants wore a pair of their own sport shoes during the data collection. The average rest time between trials was approximately 90 seconds.

## Statistical analysis

The independent variable for this study was the skill level of the golfer; (SG or LSG. The dependent kinematic and kinetic variables were selected from the trunk motion pattern and the weight shift pattern. Specific kinematic variables consisted of the following and illustrated in Figure 3. The variables are: a) Horizontal rotation angle of the upper trunk segment on XY plane of the lab coordinate system, where the segment was identified between the right acromion to left acromion markers, b) Horizontal rotation angle of the pelvic segment on XY plane of the lab coordinate system, where the segment was identified between the right ASIS to left ASIS markers, c) Side bending angle of the upper trunk segment relative to the XY plane of lab coordinate system, where the segment was identified between the right acromion to left acromion markers d) Side bending angle of the pelvic segment relative to the XY plane of lab coordinate system, where the segment was identified between the right ASIS to left ASIS markers, e) Antero-posterior tilting angle of the pelvis relative to the neutral position of the pelvis, where the segment was identified using the right ASIS, left ASIS, and sacrum markers. To calculate this last variable of interest, the obtained angle in the each event were compared to the angle of the neutral position obtained at the static trial. The kinetic variables included the VGRF at the six temporal events for each foot and the maximum VGRF of each foot throughout the entire swing. For each participant, all dependent variables were based on the average of five of the participant's trials. Independent t-tests (significance level of $p < 0.05$) were used for each dependent variable to identify those variables for which a significant difference existed between the two groups.

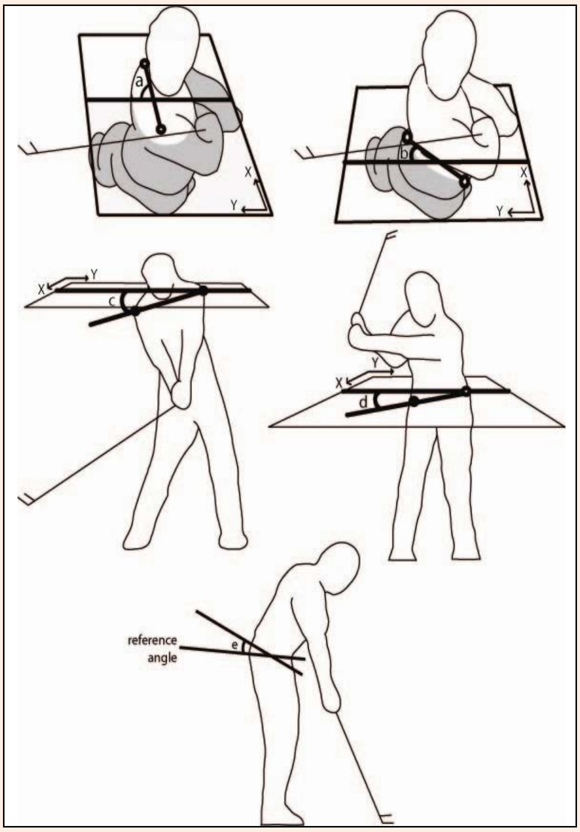


**Figure 3. Definitions of the joint angles.**

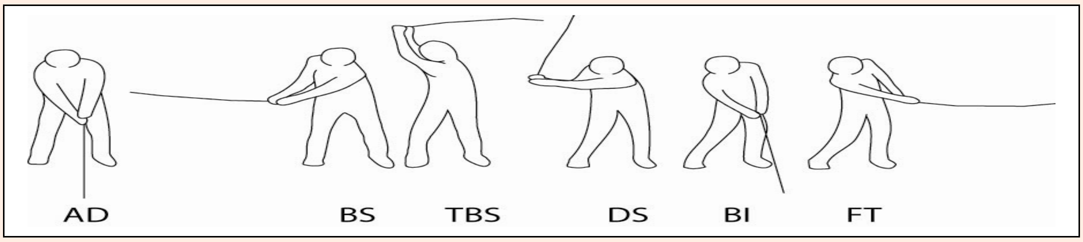


**Figure 4. Six temporal events for data analysis.**

In order to examine the dependent variables across the entire golf swing, six temporal events in the golf swing were identified as reference points to effectively represent the characteristics of the swing. These six temporal events were; 1) Address (AD: 0.1 second before the initial motion of the club head for the backswing, 2) Back Swing (BS: when the club head reached the farthest position from the target along the Y axis of lab coordinate system), 3) Top of the Back Swing (TBS; when the club head reached either the lowest position along the Z axis of lab coordinate system or the closest position toward the target on Y axis of lab coordinate system after the BS event), 4) Down Swing (DS: when the left wrist reached the farthest position from the target along the Y axis of the lab coordinate system), 5) Ball Impact (BI: when the club head contacted the ball by visual inspection of the video data ), 6) Follow Through (FT: when the club head reached the closest position toward the target along the Y axis of the lab coordinate system). These temporal events are illustrated in Figure 4.

## Results

### Kinematic data

Kinematic data revealed a different motion pattern between the two groups. The results of kinematic data are presented in Table 2. A significant difference was found in the horizontal rotation angle of upper trunk at the BS

**Table 2. The results of kinematic variables. Data are means (±SD).**

| | | Low skilled (n=17) | Skilled (n=13) |
|---|---|---|---|
| **Upper trunk horizontal (°)** | **Address** | -6.3 (4.4) | -3.9 (5.4) |
| | **Backswing** | 40.7 (10.4) | 47.8 (6.3) * |
| | **Top of back swing** | 97.8 (19.8) | 102.3 (12.6) |
| | **Downswing** | 62.3 (13.5) | 56.6 (6.5) |
| | **Ball impact** | -12.9 (11.0) | -12.2 (8.3) |
| | **Follow through** | -55.2 (12.1) | -43.3 (10.5) ** |
| **Pelvic horizontal (°)** | **Address** | -3.1 (4.4) | .4 (1.5) ** |
| | **Backswing** | 21.8 (10.8) | 28.8 (8.9) * |
| | **Top of backswing** | 51.5 (16.9) | 47.9 (11.5) |
| | **Downswing** | 20.7 (13.7) | 10.1 (7.9) * |
| | **Ball impact** | -33.7 (14.9) | -38.1 (9.6) |
| | **Follow through** | -44.6 (14.3) | -46.7 (11.1) |
| **Upper trunk side-bending (°)** | **Address** | 12.4 (5.0) | 15.1 (3.3) |
| | **Backswing** | -18.9 (7.5) | -17.1 (6.9) |
| | **Top of backswing** | -29.3 (7.5) | -25.7 (8.6) |
| | **Downswing** | -25.0 (10.5) | -20.0 (4.6) |
| | **Ball impact** | 30.0 (6.1) | 28.7 (5.0) |
| | **Follow through** | 45.2 (5.8) | 40.7 (6.1) * |
| **Pelvic side-bending (°)** | **Address** | -.9 (1.7) | .2 (3.0) |
| | **Backswing** | -10.4 (3.3) | -8.1 (3.9) |
| | **Top of backswing** | -15.3 (5.1) | -14.6 (5.3) |
| | **Downswing** | -11.7 (4.0) | -7.6 (3.6) ** |
| | **Ball impact** | 6.5 (3.7) | 8.7 (4.6) |
| | **Follow through** | 9.1 (4.0) | 9.1 (4.7) |
| **Pelvic anterior-posterior (°)** | **Address** | -10.0 (9.5) | -11.2 (6.5) |
| | **Backswing** | -8.4 (6.9) | -8.7 (4.2) |
| | **Top of backswing** | -4.6 (9.1) | -8.1 (6.9) |
| | **Downswing** | -9.7 (8.8) | -8.9 (7.1) |
| | **Ball impact** | .0 (8.1) | 6.6 (5.2) * |
| | **Follow through** | 4.2 (7.9) | 10.5 (5.8) * |

* and ** denote $p < 0.05$ and 0.01 respectively between the groups. Note: The positive values in the horizontal rotation angles represent that the segment was positioned in the clockwise direction, relative to the Y-axis of lab coordinate system viewing from above, while the negative numbers represent that the segment was positioned in the counter-clockwise direction. The positive values in the side bending angles represent the segment tilts down toward the right side of the body from the XY plane while the negative values represent the segment tilts down to left side of the body. The positive values in the pelvic antero-posterior rotation represent posterior rotation while the negative values represent anterior rotation.

**Table 3.** The results of kinetic variables. Data are means (±SD).

| | | Low skilled (n=17) | Skilled (n=13) |
|---|---|---|---|
| Lead foot VGRF(%BW) | Address | .50 (.06) | .48 (.08) |
| | Backswing | .35 (.11) | .25 (.09) * |
| | Top of backswing | .20 (.14) | .24 (.10) |
| | Downswing | .33 (.19) | .59 (.28) ** |
| | Ball impact | 1.05 (.23) | .90 (.28) |
| | Follow through | .78 (.17) | .68 (.21) |
| Trail foot VGRF(%BW) | Address | .51 (.05) | .52 (.11) |
| | Backswing | .76 (.13) | .92 (.12) ** |
| | Top of backswing | .83 (.14) | .74 (.12) |
| | Downswing | .67 (.18) | .60 (.15) |
| | Ball impact | .25 (.16) | .38 (.20) |
| | Follow through | .25 (.14) | .36 (.19) |
| Maximum VGRF(%BW) | Lead | 1.13 (.25) | 1.09 (.32) |
| | Trail | .89 (.12) | .98 (.09) * |

* and ** denote $p < 0.05$ and 0.01 respectively between the groups.

and FT events. A group difference in the horizontal rotation angle of pelvis was found at the AD, BS and DS events. The upper trunk side bending angle showed a significant difference only at the FT event, while the significant difference was only found at the DS event in the pelvic side bending angle. A significant difference in the antero-posterior tilting angle of the pelvis existed at the BI and FT events with the skilled group demonstrating larger angles.

### Kinetic data

The VGRF for each force plate was expressed in units of percent body weight for each participant. The results of this data are presented in Table 3. When compared to the counterpart, the VGRF for the skilled group was significantly smaller in the lead foot and significantly larger in the rear foot at the BS event. At the DS event, the lead foot VGRF was significantly larger in the skilled group than that of low skilled group. The Maximum VGRF showed a significant difference between the two groups for the right foot; but no significant differences existed for the left foot.

## Discussion

Golf coaching literature has emphasized the importance of the backswing motion (Haney, 1999; Leadbetter, 1993); however the scientific studies examining kinematic variables in this phase are limited. In our study, the skilled group showed significantly greater horizontal rotation angle in the pelvic segment at the BS event. This angle changed 28.4 degrees from the AD to the BS event, and that was larger than the angle change of 19.1 degrees between the BS and TBS event. A change in the horizontal rotation angle for the upper trunk was 51.7 degrees between the AD and BS event, and 54.7 degrees between the BS and TBS event, respectively. This implies that the pelvic rotation diminished after the BS event in the skilled group, while their upper trunk segment displayed a continuing motion.

This relationship is likely to create tension in the trunk and hip muscles. It has long been believed that the Stretch-Shortening cycle is one of the most important elements involved in the generation of power in sport activities (Finni et al., 2003). This movement pattern in the skilled group seems to indicate the presence of the conditions that would optimize the Stretch-Shortening cycle. It may be suggested that the skilled group utilized this effective Stretch-Shortening mechanism to produce a powerful force during early downswing motion. Relative to this, a significantly larger VGRF at the BS event in the trail foot was found in the skilled group. More interestingly, the skilled group showed 18% of decrease in the trail foot VGRF from the BS event to the TBS event (0.92%BW at the BS, 0.74%BW at the TBS), while the low skilled group showed 7% increase at the same period. The skilled group completed the back swing weight transfer onto the trail foot before the TBS event, while the low skilled golfers were still engaged in the backswing weight transfer motion at the BS event then completed it at the TBS event. Richards et al. (1985) reported that the VGRF were remarkably similar between skilled and less skilled golfers at the top of the back swing and the ball contact. Our study revealed that the difference existed during the middle of the backswing motion rather than the key events in the backswing motion (top of the backswing).

No significant group differences were found in both upper trunk and pelvic horizontal rotation angles at the top of the back swing and at the ball impact, which was consistent with previous studies (Burden et al., 1998; McTeigue et al., 1994; Myers et al, 2008) The presence of abbreviated horizontal rotation of the upper trunk, an error commonly associated with low skilled golfers, was not confirmed in our study. This suggests that although inadequate horizontal rotation of the upper trunk segment at the top of the back swing has been subjectively observed in some low skilled golfers, it may not actually be a common error for them.

Another common error in low skilled golfers, a large side bending of the trunk toward the target at the top of the swing was not evidenced in the present study. This reverse spine angle motion pattern could be a major cause of reverse weight transfer pattern in low skilled golfers. McTeigue et al. (1994) reported that low skilled amateur golfers (average handicap 17.5) had a significantly larger side bending angle of the trunk (leaning toward the left side of the body for right handed golfers) at the top of the swing, and it became significantly smaller at ball impact when compared to those of professional golfers. The results of our study showed the same tendency with the McTeigue's findings, but a statistical difference between the groups was not found.

Previous golf studies revealed the importance of sequential movement of the body segments in the downswing motion by examining a sequence of motion pattern (Burden et al., 1998) or a separation angle of the pelvis and torso (Myers et al., 2008). In our study, the skilled golfers demonstrated a significantly larger pelvic horizontal rotation angle back toward the target than that of the low skilled golfers at the DS event. Additionally, the side bending angle of the pelvis toward left side of the body was significantly lesser in the skilled group. This result suggests that skilled golfers had an earlier down swing motion pattern with their pelvic segment, as it rotated back toward the address position. Our study supports a previous study stating the importance of this lower segment leading motion pattern at the beginning of the down swing (Neal and Wilson, 1985). Relative to this, an EMG analysis of a professional golfer also found that the down swing motion was initiated with the golfer's leg and hip muscles followed by his upper body muscles (Okuda et al, 2002).

Relative to the DS event, a significant difference between the groups was also evident in the lead foot VGRF, while no significant difference was found for the trail foot VGRF. This is most likely due to a rapid weight transfer from the trail foot to the lead foot in the skilled group. This weight transfer pattern was supported by Barrentine et al. (1994) reporting that PGA professional golfers applied larger shear force in earlier timing with the trail foot after the top of the back swing when compared to low- or high-handicap amateur golfers. Burden et al. (1998) suggested that the speed of the swing is benefited by the center of mass shifting exclusively in the intended direction of the ball flight during the ball impact. This motion pattern was evident in both groups in our current study, but appeared to occur earlier in the skilled golfers. The maximum VGRF in the lead foot generally appears in the late down swing motion, and it can represent how much force is transferred from the golfer's body to the ground. Results of our study for this value showed no significant difference between the groups while both groups reached more than one body weight. Since the center of mass of golfer generally moves in the vertical direction during the down swing motion, this value could exceed one body weight by gravitational acceleration acting on the golfer's body. Our results agreed with Richards et al. (1985) stated that the timing and the magnitude of the transfer of the body weight were more important than simply the magnitude of the VGRF.

Relative to the FT event, the skilled golfers showed significantly less upper trunk horizontal rotation than low skilled golfers. Three theories may explain this observation. First, the low skilled golfers may have attempted to vigorously rotate the upper trunk segment even after the ball impact, in an effort to maximize club velocity. Secondly, the skilled golfers may have intentionally slowed down the upper trunk horizontal rotation earlier in the swing motion, in order to optimize transfer of momentum to the club. Lastly, the acceleration of the club automatically slows the upper trunk segment by transfer the momentum to the distal segment (Cochran and Stobbs, 1968). Putnam (1993) described a theoretical interaction in the motion of two segments, in which a decrease in the speed of a proximal segment is largely due to the motion-dependent effect of the distal segment. The proximal segment slowed down primarily by the interactive moments resulting from the angular velocity and acceleration of the distal segment. As a conclusion, differences in the upper trunk horizontal rotation angle at the FT event may be due to a purposeful intention of the golfers or automatic interaction of the involved segments. A significant difference was also found in the pelvic antero-posterior tilting angle after the BI event. The difference in the motion pattern during the down swing, as described earlier, may have contributed to the difference in the antero-posterior tilting angle of the pelvic segment that was observed. The skilled golfers had an earlier downswing motion pattern with their pelvic segment and a slight sway toward the lead foot. As the motion continued and reached ball impact, this movement pattern led to an extension of the right hip as well as a flexion in left hip, and ultimately led to the posterior rotation of the pelvis. Since the lower segment rotated earlier and its center of mass shifted toward the lead foot while the upper segment remained toward the trail foot, this compensatory motion of the pelvis was necessary to maintain balance. Although not statistically significant, the skilled golfers showed a noticeably larger trail foot VGRF at the ball impact and follow through events. This could be attributed to the posterior tilting angle of the pelvis in the skilled golfers, not due to a hanging back swing fault.

## Conclusion

Specific characteristics of trunk rotation and weight transfer patterns during the golf swing were found between two different skill levels of golfers. The significant difference in the kinematic and kinetic variables existed mostly in the transition phase of the swing, such as in middle of back swing, in the middle of down swing, and in the middle of follow through. Earlier horizontal rotation of the trunk accompanied with earlier weight transfer to the trail foot in the middle of the backswing was evident in the skilled golfers when compared to the low skilled golfers. Similarly, the pelvic horizontal rotation in the downswing motion occurred significantly earlier with a rapid weight transfer to the lead foot in the skilled golfers while the low skilled golfers showed a delay in these motions. As a consequence of the motion pattern leading up to the ball impact, less horizontal rotation of the upper trunk and more posterior pelvic tilt were evident in the middle of follow through motion for the skilled golfers. Collectively, the results of this study may be beneficial for the golf swing instruction for low skilled golfers to improve their skill in a full shot golf swing.

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## Key points

- Different trunk rotation and weight transfer patterns were found between skilled and low skilled golfers.
- Earlier trunk rotation accompanied with earlier weight transfer to the trail foot during the back swing was evident in the skilled golfers.
- Earlier pelvic horizontal rotation with a rapid weight transfer to the lead foot during the downswing was evident in the skilled golfers.

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