ANALYSIS OF THE TRUNK/SHOULDER COMPLEX MOTION DURING THE GOLF DRIVES USING A 5-SEGMENT TRUNK/SHOULDER MODEL

Ki Hoon Han, Christopher Como, Kunal Singhal, Sangwoo Lee, Jemin Kim, Jaewoong Kim, and Young-Hoo Kwon
Biomechanics Laboratory, Texas Woman's University, Denton, Texas, USA

The purpose of this study was to quantify detailed trunk/shoulder complex motions during the golf drives using a new 5-segment trunk/shoulder model (pelvis, abdomen, thorax, and right/left shoulder girdles) and to describe the patterns of the relative motions of the trunk/shoulder segments. Fifteen male golfers were divided into two groups: skilled (n=8, 3-handicap or better) and less skilled (n=7, 13- to 18-handicap). The ranges of the orientation angles of the segments during the downswing were computed. In addition to the dominant rotation of the thorax, substantial frontal plane motions of the trunk segments (abdomen and thorax) and transverse plane motions of the shoulder girdles were observed. Only the frontal plane motion of the left shoulder girdle (elevation/depression) was identified as the factor which differentiated the groups.

KEYWORDS: orientation angles, shoulder girdle, abdomen, thorax.

INTRODUCTION: Human trunk/shoulder complex can potentially have a large number of degrees of freedom due the motions of the spine and the scapula-thoracic complex and development of a sufficiently detailed trunk/shoulder model is essential for an in-depth analysis of the trunk/shoulder motion in golf swing. Since Cochran and Stobbs (1968) first introduced the double-pendulum model, a substantial number of research studies have been conducted based on the double-pendulum model or its triple-pendulum sibling (e.g. Jorgensen, 1994; Pickering & Vickers, 1999; Sprigings & Neal, 2000). In the multi-pendulum models, the golfer/club system is reduced to two or three linked rigid levers moving in a single inclined plane with the 'hub' and the clubhead being the proximal and distal ends of the chain, respectively. As a result, the motions of the trunk segments (and the shoulder girdles) have been practically ignored in these studies.

The golfer/club system during a golf swing presents a unique mechanical challenge: while the golfer's upper body and club overall forms an open chain, there exists a closed chain within the open chain, formed by the arms and the shoulder girdles. In the popular literature, moreover, the golf swing has often been depicted as a combination of the simple rotation of the trunk about its longitudinal axis and the up-down motion of the arm about the shoulder (Hardy & Andrisani, 2005). The motions of the individual trunk segments (pelvis, abdomen, and thorax) and shoulder girdles in conjunction with the motions of the arms make the system substantially more complex than a set of levers moving on in a single inclined plane or a simple combination of trunk rotation and arm motion. While the trunk (thorax) rotation (e.g. X-factor) has received some attention (e.g., McLean, 1992; McTeigue, Lamb, Mottram, & Pirozzolo, 1994; Cheetham, Martin, Mottram, & St. Laurent, 2001; Lindsay, Horton, & Paley, 2002; Egret, Vincent, Weber, Dujardin, & Chollet, 2003; Myers, Lephart, Tsai, Sell, Smoliga, & Jolly, 2008), the projected angle to the ground was used in most cases. This simple planar perspective has become a major obstacle to an in-depth understanding of the complex trunk/shoulder motion and a multi-segment approach (Joyce, Burnett, & Ball, 2010) is substantially overdue.

The purpose of this study was to scrutinize the trunk/shoulder complex motion during the golf drive using a new 5-segment trunk/shoulder model and to describe the patterns of the relative motions of the trunk/shoulder segments. It was hypothesized that (1) substantial frontal plane and transverse plane motions of the trunk segments and shoulder girdles would be observed during the downswing phase of the golf drive in addition to the thorax rotation and (2) skilled golfers would exhibit more frontal plane and transverse plane motions than the less skilled golfers.

METHODS: Fifteen healthy male golfers were recruited into two groups: skilled (n=8; 3-handicap or less; 79.2 ±8.5 kg; 180.8 ±7.2 cm; 26.3 ±7.6 y) and less skilled (n=7; 13- to 18-handicap; 88.8 ±7.5 kg; 176.1 ±4.7 cm; 32.8 ±10.1 y). Each golfer performed five successful drives using his own driver.
A 250-Hz 10-camera VICON motion capture system (Centennial, CO, USA) was used in an indoor motion analysis laboratory to capture the motion trajectories of the reflective markers attached on the golfer's body, club, and the ball plate. A total of 25 reflective markers were used in four different types of trials: ball plate, club, static posture, and motion trials. Golfers were asked to wear black spandex shorts and black swimming cap for motion analysis purposes. Foam balls were used instead of the actual golf balls.
The captured three-dimensional coordinates of the markers were imported into Kwon3D Motion Analysis Suite (Version XP; Visol, Seoul, Korea) for subsequent processing and analysis. The trunk/shoulder complex was divided into five segments: pelvis, abdomen, thorax, and right/left shoulder girdles. The abdomen was defined as the section between the pelvic plane formed by the ASIS (anterior superior iliac spine) and PSIS (posterior superior iliac spine) markers and the thorax line defined by the xyphoid process (XP) marker and the 12th thoracic vertebra (T12) marker. The thorax was defined as the section between the thoracic line and the cervical line formed by the suprasternal notch (SN) marker and the 7th cervical vertebra (C7) marker. The right and left shoulder girdles were defined by the cervical line and respective shoulder joints.
Segmental reference frames were defined for each trunk/should complex segment: the X-axes were aligned with the medio-lateral axes of the segments while the Y-axes were along the antero-posterior axes. In the pelvis, the vector drawn from the left ASIS to the right ASIS was used as the X-axis and the Z-axis was defined perpendicular to the pelvic plane. In the abdomen, the Z-axis was aligned to the vector drawn from the mid-pelvis point (centroid of the ASIS and PSIS markers) to the mid-trunk point (mid-point of the thoracic line) and the Y-axis was defined perpendicular to the frontal plane (formed by the Z-axis of the abdomen and the X-axis of the pelvis). In thorax, the Z-axis was aligned to the vector drawn from the mid-trunk point to the mid-shoulder point (mid-point of the cervical line) while the X-axis was defined perpendicular to the sagittal plane (formed by the Z-axis and the cervical line). In the shoulder girdles, the plane formed by the cervical line and each shoulder joint was used as the transverse plane of the girdle (perpendicular to the Z-axis) with the shoulder line (mid-shoulder to shoulder joint) was used as the positive X-axis for the right side and the negative X-axis for the left side.
Twelve degrees of freedom were assigned to the trunk/shoulder complex: abdomen motion (relative to pelvis; X-flexion/extension, Y-lateral flexion, Z-rotation), thorax motion (relative to abdomen; X-flexion/extension, Y-lateral flexion, Z-rotation), shoulder girdle motions (relative to thorax; X-tipping, Y-elevation/depression, Z-protraction/retraction). The orientation angles (Cardan) were computed among the segmental reference frames using the XYZ rotation sequence in all cases.
Three downswing events were identified for the analysis: Top of Backswing (TB), Mid Downswing (MD), and Ball Impact (BI). The ensemble-average patterns of the orientation angles were obtained for each participant group using the TB-BI time as 100% (Figure 1). The ranges of the orientation angles (maximum - minimum) during the TB-BI phase were extracted from each trial. The mean values of the five trials were used as the representative range values of each golfer. The standard deviations of the five trials were used as the measures of intra-golfer variability of each golfer. T-test was used to compare the ranges of the orientation angles and the intra-golfer variabilities between the skilled and less skilled groups (Table 1). An alpha level of 0.05 was used in all tests.

RESULTS: Figure 1 shows the ensemble average patterns of the trunk segment and shoulder girdle orientation angles. Among the segments, the right shoulder girdle was characterized by consistent depressed and retracted position while left shoulder showed transition from elevated to depressed and protracted to retracted position during the downswing.

Among the relative motions of the trunk segments and shoulder girdles, the rotation of the thorax revealed the largest mean range (~30°) (Table 1). The lateral flexion of the thorax and the winging motion (protraction/retraction) of the right shoulder girdle also showed substantial motion ranges (16-22°) followed by the lateral flexion of the abdomen and elevation/depression and winging motion of the left shoulder girdle (~12°). Among the range variables, only the elevation/depression of the left shoulder girdle revealed a significant difference between the golfer groups (skilled >less skilled). Large inter-golfer variability values were observed in both groups and substantially smaller mean intra-golfer variability values (≤ 1.8°) were observed in all variables.

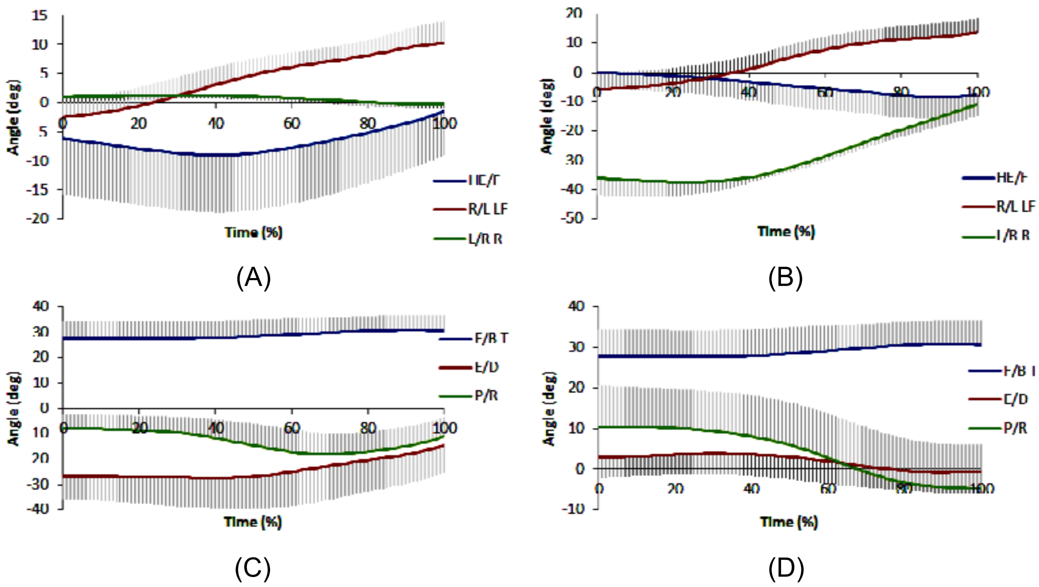

Figure 1: Ensemble average patterns of the orientation angles of the trunk/shoulder complex (skilled group; n=8): (A) abdomen, (B) thorax, (C) right shoulder girdle, and (D) left shoulder girdle. Gray lines show the standard deviations. Motion abbreviations (+/-): HE/F (hyperextended/flexed), R/L LF (laterally flexed right/left), L/R R (rotated left/right), F/B T (tipped forward/backward), E/D (elevated/depressed), and P/R (protracted/retracted).

Table 1: Ranges of the orientation angles during the Downswing (Top of Backswing to Impact) and intra-golfer variabilities (IGV) (M ±SD; in °).

Segment	Axis	Less Skilled		Skilled	
		Range	IGV	Range	IGV
Abdomen	X (FE)	5.7 ±1.7	0.8 ±0.6	8.4 ±3.6	0.4 ±0.2
	Y (LF)	11.0 ±3.0	1.8 ±3.0	12.6 ±1.4	0.6 ±0.2
	Z (R)	2.0 ±1.1	0.3 ±0.5	1.8 ±0.7	0.2 ±0.1
Thorax	X (F/E)	8.8 ±5.4	0.8 ±0.6	9.2 ±1.7	0.6 ±0.4
	Y (LF)	21.6 ±6.5	1.2 ±0.5	19.6 ±3.7	0.7 ±0.4
	Z (R)	30.1 ±4.8	1.5 ±0.7	27.7 ±4.8	0.9 ±0.4
Right SG	X (T)	2.8 ±0.8	0.2 ±0.2	3.5 ±0.8	0.2 ±0.1
	Y (ED)	5.3 ±2.4	0.6 ±0.3	6.1 ±1.7	0.5 ±0.2
	Z (PR)	17.3 ±6.0	0.8 ±0.2	16.1 ±1.9	0.7 ±0.3
Left SG	X (T)	2.8 ±0.8	0.2 ±0.2	3.5 ±0.8	0.2 ±0.1
	Y (ED)	7.1 ±3.5	1.0 ±0.7	12.1 ±4.7*	0.7 ±0.3
	Z (PR)	9.5 ±3.7	1.0 ±0.3	11.6 ±4.0	0.7 ±0.5

*Significantly different from the less skilled group ($p<.05$). Abbreviations: FE=flexion/extension, LF=lateral flexion, R=rotation, T=tipping, ED=elevation/depression, PR=protraction/retraction.

DISCUSSION: In general the sagittal plane motions were characterized by the smallest motion ranges during the downswing while the transverse plane motions revealed the largest motion ranges (Table 1). Substantial frontal plane motions of the trunk segments were also observed. The torsional motion of the shoulder line relative to the pelvis line mainly came

from the rotation of the thorax but the contribution of the winging motions of the shoulder girdles was not negligible either. The combined lateral flexion of the abdomen and thorax exceeded 30° in both groups. Between the shoulder girdles, the right side was characterized by relatively larger winging motion while the left side revealed stronger elevation/depression.
The motion ranges of the trunk segments and shoulder girdles were highly individual-specific with large inter- but small intra-golfer variability values. No significant inter-group difference was observed in all variables except the elevation/depression of the left shoulder girdle. Among the variables, the elevation/depression of the left shoulder girdle revealed the largest mean inter-group difference (~5°).
From the findings of this study, it was evident that substantial frontal plane motions of the trunk segments and transverse plane motions of the shoulder girdles were observed during the downswing phase of the golf drive, which justified the use a sufficiently complex trunk/shoulder model.

CONCLUSION: It was concluded that: (1) in addition to the dominant rotation of the thorax, substantial frontal plane motions of the trunk segments (abdomen and thorax) and transverse plane motions of the shoulder girdles were observed during the downswing phase of the golf drives; (2) only the frontal plane motion of the left shoulder girdle (elevation/depression) was identified as the factor which differentiated the skilled group from the less skilled.

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