PELVIS SWAY: COM vs. SENSOR

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Abbreviations

COM – center of mass
TB – top of backswing

Introduction

In December 2017 on 'Golf Biomechanists' Facebook forum (https://www.facebook.com/groups/golfbiomechanists/), there was a discussion on different methods of pelvis sway measurement. Figure 1 is one of the photos posted to the forum in the threads which shows the average pelvis sway value of professional golfers reported by GOLFTEC®. There are two points of interest in this photo: 1) an average sway value of 3.9 inches (9.9 cm) toward the target from initial setup to TB reported, and 2) the corresponding body posture at TB. In this technical note, two different methods of sway measurement will be compared and the sway values obtained from these methods will be compared. Also regression equations will be derived to relate the values from the two methods. The TB postures that typically come with the mean sway values will be also explored.

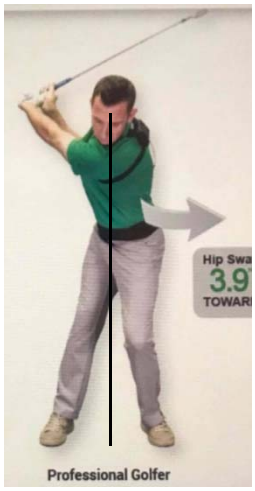

Figure 1. Average pelvis sway and corresponding posture of professional players reported by GOLFTEC®

Pelvis COM Sway vs. Sensor Sway

The key aspect of the discussions on Facebook was the point of interest with which the pelvis sway was measured: pelvis COM and a motion sensor placed on the back side of the pelvis. Figure 2 shows the overall motions of the pelvis COM and the sensor during the backswing (i.e. initial setup to TB). The Y-axis is parallel to the target direction. Points 1 and 2 in the figure are the positions of the pelvis COM and the sensor at initial setup, while points 3 and 4 are those at TB. (Also see the video posted by Jon Sinclair: https://www.facebook.com/jon.sinclair.7/videos/1617004475022280/.) Note in Figure 2 that, at initial setup, the pelvis is slightly opened toward the target (left-rotated) as depicted by the broken line connecting the two points in this particular example.

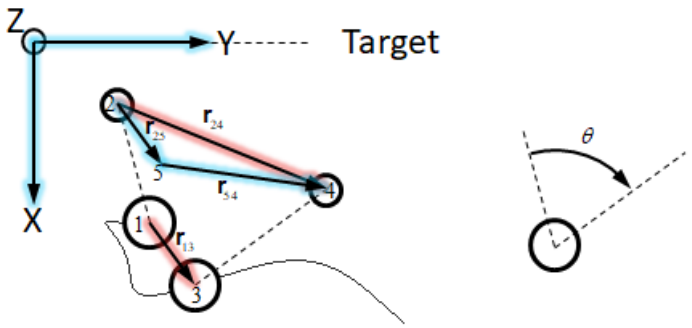

Figure 2. Displacements of the pelvis COM and the pelvic sensor (horizontal view; driver)

$\mathbf{r}_{13}$ and $\mathbf{r}_{24}$ in Figure 2 are the displacement (change in position) vectors of the points from position 1 to 3 (pelvis COM) and 2 to 4 (sensor), respectively. $\mathbf{r}_{25}$ is displacement of the sensor due to the linear motion of the pelvis COM while $\mathbf{r}_{54}$ is that due to the angular motion of the pelvis (rotation in particular; θ in Figure 2) about its COM. So

$$\mathbf{r}_{24} = \mathbf{r}_{25} + \mathbf{r}_{54}, \quad [1]$$

where

$$\mathbf{r}_{25} = \mathbf{r}_{13}. \quad [2]$$

The sway value measured from the motion of the sensor has two parts: sway of the pelvis COM + sway due to the rotation of the pelvis:

$$y_{24} = y_{25} + y_{54}. \quad [3]$$

The sway value measured based on the sensor motion must be larger than that measured based on the pelvis COM motion.

Measured Sway Values

Figure 3 shows the ensemble average pelvis sway patterns of 63 male elite golfers for the driver condition. The green line is the sway pattern of the pelvis COM while the gray line is that of the sacrum marker (approximated sensor position). Event 6 is TB in the graph. As shown in the figure, the pelvis COM initially moves away from the target and then starts moving toward. Obviously, sacrum marker's sway increases more rapidly than that of the pelvis COM.

Figure 4, on the other hand, is the scatter plot of the two sway parameters (driver). As shown in the figure, the two sway parameters are highly (significantly) correlated. The trend line along with the regression equation shows a linear relationship between the two parameters rather well. The red dot in the scatter plot represents the mean sway values. The variance in the scatter plot is due to individual differences in pelvis angular motion, pelvis size, etc.

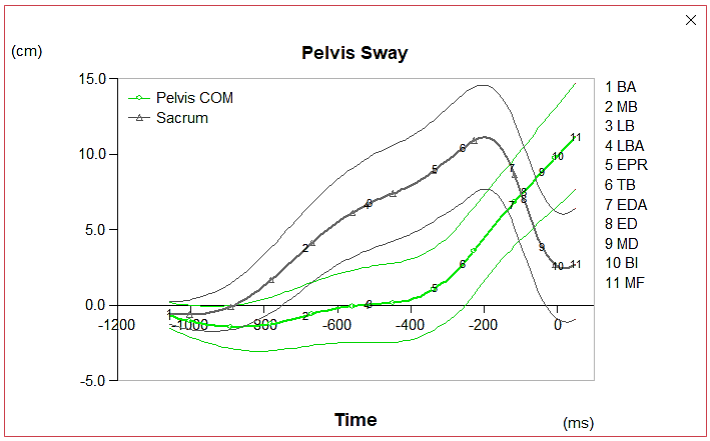

Figure 3. Pelvis sway patterns of male elite golfers (n = 63; driver)

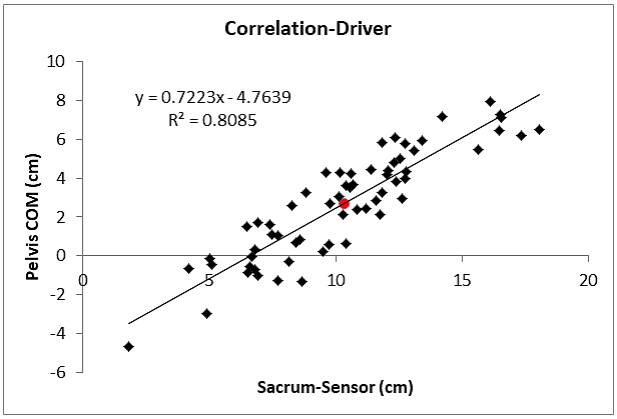

Figure 4. Linear relationship between the two pelvis sway measures (*r* = 0.899)

Table 1 summarizes the mean (and standard deviation) sways and pelvis rotation values of 62 elite male golfers in three club conditions (driver, 5-iron, and PW). As club gets shorter (drive to PW), mean values of both sway measures tend to increase. The mean sacral sway values are comparable (slightly larger) to the value reported by GOLFTEC (i.e. 4.1-4.3 in vs. 3.9 in). The correlation coefficients close to 0.9. The mean pelvis rotation angle tends to decrease as club gets shorter.

Table 1. Mean pelvis sway and rotation values of elite male golfers in three club conditions

Club	Pelvis COM (Mean ± SD)	Sacrum-Sensor (Mean ± SD)	COM-Sac Correlation	Pelvis Rotation (Mean ± SD)
D	2.7 ± 2.8 cm 1.06 ± 1.09 in	10.3 ± 3.5 cm 4.06 ± 1.36 in	*r* = 0.899*	40 ± 8°
5-I	3.3 ± 2.6 cm 1.29 ± 1.03 in	10.7 ± 3.3 cm 4.20 ± 1.29 in	*r* = 0.904*	38 ± 7°
PW	3.7 ± 2.4 cm 1.46 ± 0.94 in	10.9 ± 3.1 cm 4.30 ± 1.22 in	*r* = 0.896*	37 ± 7°

*Significant at 95% confidence level

Table 2 presents linear regression equations which can be used in predicting the expected mean COM sway from a given sacral sway value. Converting a sensor sway value to a roughly matching pelvis COM sway value can be beneficial as the pelvis COM sway should be what golfers actually feel as their pelvis sway.

Table 2. Linear Regression Equations

Club	Models	R^2
D	COM = -4.767 + 0.723 * SAC	0.808
	COM = -0.570 + 0.742 * SAC – 0.038 * HSIN	0.870
5-I	COM = -4.448 + 0.724 * SAC	0.819
	COM = -1.306 + 0.743 * SAC – 0.030 * HSIN	0.859
PW	COM = -4.872 + 0.603 * SAC	0.801
	COM = -2.741 + 0.639 * SAC – 0.043 * HSIN	0.843

Abbreviations: COM = Pelvis COM sway, SAC = Sacral sway, HSIN = height * $\sin\theta$

As a result of stepwise regression, two models emerged as significant at 95% confidence level in all three club conditions:

$$\text{COM sway} = a + b * \text{sacral sway}, \qquad [4a]$$

$$\text{COM sway} = a + b * \text{sacral sway} + c * (\text{height} * \sin\theta) \qquad [4b]$$

where COM and sacral sways and height of the golfer are all in cm and θ is the pelvis rotation angle from initial setup to TB.

In Equation 4a, COM sway was predicted by sacral sway only and over 80% of the variance was explained by the regression (see R^2 values in Table 2). In Equation 4b, COM sway was predicted by not only sacral sway but also golfer's height and pelvis rotation angle during the backswing (initial setup to TB). Height of the golfer was used instead of the actual distance from the pelvis COM to the sacrum marker in this model. Over 84% of the total variance was explained by this model. The residuals (the differences between the actual pelvis COM sway values and the predicted) were less than 2.5 cm in all club conditions.

Interpretation

Figure 5 presents TB postures of five golfers who show sacral sway values close to the mean value in the driver condition along with their pelvis rotation angles. Although their sacral sway values are similar (10.2-10.4 cm), the pelvis COM sway values are quite different (0.7 - 4.3 cm). The more the pelvis rotates, the larger the difference between the two sway measures is. Therefore, there is an ample room for subjective interpretation when the mean sway value is associated with an actual TB posture. For example, those who promote shifting of the pelvis toward the target during backswing tend to choose the posture shown in Figure 1 which is characterized by almost upright lead leg (ankle to hip). Those on the other end of the spectrum may choose the posture shown in Figure 5E. This gets even more exaggerated when the initial pelvis position is brought into play. Since the pelvis sway is measured from the initial position at setup, different pelvis positions at setup yield very different pelvis positions at TB. A player who tends to place the pelvis closer to the lead foot at setup will end up with a posture in which the pelvis is significantly shifted toward the target at TB, vice versa.

Figure 6 presents the TB postures of five golfers whose pelvis COM sway values (2.4 - 3.0 cm) are similar to the mean value. All postures are fairly centered. Figure 7 shows the TB postures of those who scored the largest combined sway (simple sum of the COM sway and the sacral sway) values. The sacral sway values of these golfers range from 16.1 to 18.1 cm (9.26 - 9.67 in). The postures in Figures 7D and 7E are similar to that shown in Figure 1 but the actual sacral sway values are substantially larger than 3.9 in.

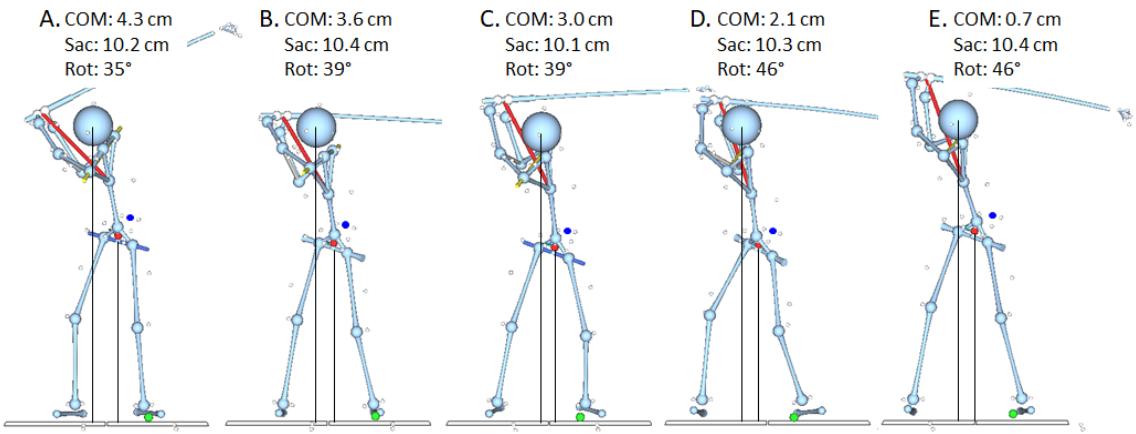

Figure 5. Golfers showing sacral sway values similar to the mean value. Depending on the pelvis rotation angle, the corresponding pelvis COM sway can vary substantially. 'A' shows the largest COM sway while 'E' does the smallest.

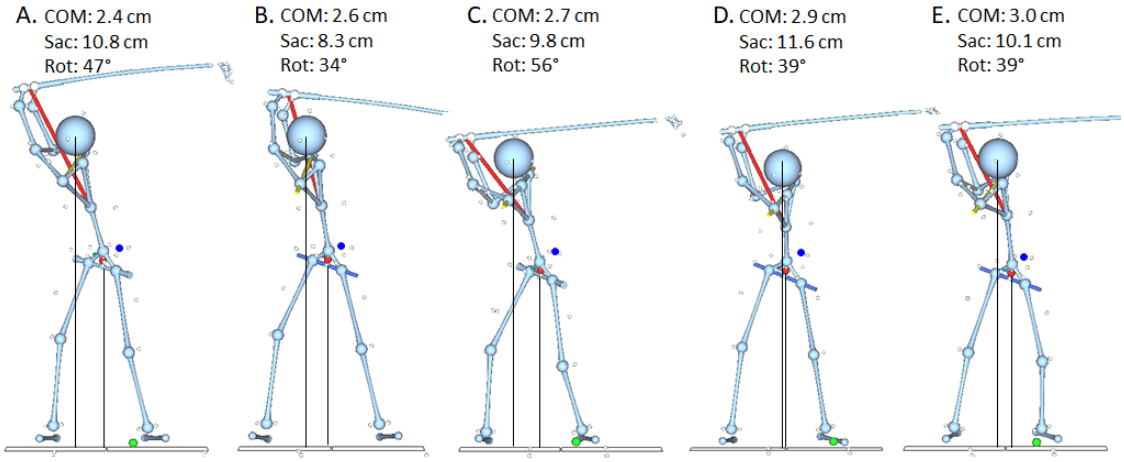

Figure 6. Golfers showing COM sway values similar to the mean value. 'A' shows the smallest COM sway while 'E' does the largest.

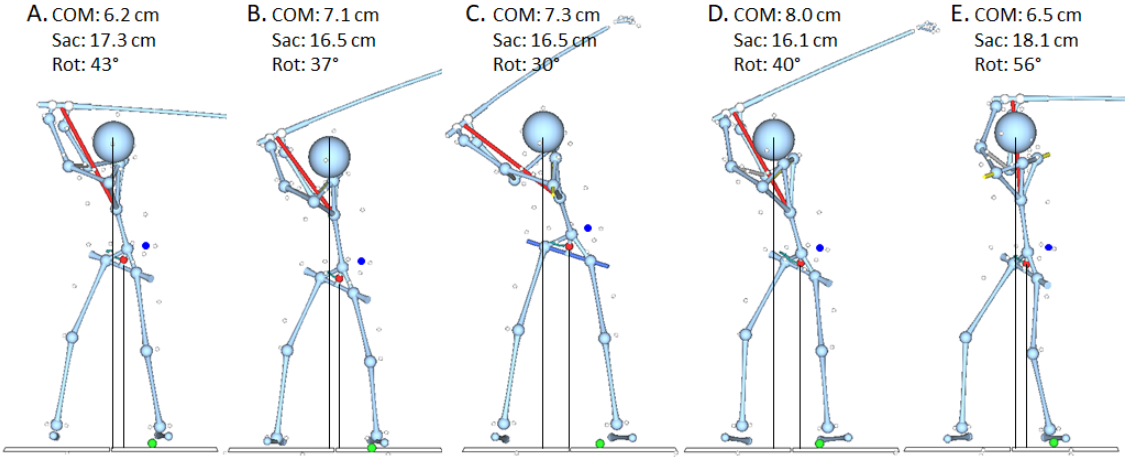

Figure 7. Golfers showing the largest combined (COM + sacral) sway values. The sacral sway values range from 9.26 to 9.67 in which is substantially larger than 3.9 in.

Summary

It is clear from Figures 5-7 that caution must be used when an actual TB posture image is attached to a given sacral sway value as the posture varies substantially depending on the initial pelvis position/orientation and amount of pelvis rotation (among all angular motions) during the backswing. The actual pelvis position at TB is individual-specific and generalization of a posture at TB for a given sway value is at best misleading.

The regression (prediction) equations presented in Table 2 could be useful in getting a more realistic feel of a given sacral sway value.

Related Dr. Kwon's Golf Biomechanics Webpages

Swing Events and Phases: http://drkwongolf.info/biom/events-phases.html
Scalar vs. Vector: http://drkwongolf.info/biom/scalar_vector.html

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