

Research article

## Golfing skill level postural control differences: A brief report

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### Abstract

Golfers have better balance than their age-matched counterparts; however, it is uncertain if this persists during the swing as a function of skill level. The purpose of the study was to investigate dynamic postural control (center of mass (COM) motion) measured during different phases of the swing in golfers of varying proficiency. Eighteen healthy golfers were grouped by handicap: novice (no handicap,  $n = 7$ ), intermediate (handicap 15-19,  $n = 7$ ), and advanced (handicap 9-14,  $n = 4$ ). Indoor testing was performed hitting 3 tee shots using a common driver. A five-camera (60 Hz) motion analysis system (9 markers) was used to extract kinematics data. There were no significant group differences in gender, age, or BMI. Advanced players had lower COM displacement with respect to address at the time of maximum arm speed ( $p = 0.001$ ) compared to intermediate (57%,  $p = 0.014$ ) and novice (73%,  $p = 0.023$ ). These changes persisted after COM distance and time normalization. Advanced golfers had improved COM linearity during the downswing ( $p < 0.001$ ) compared to intermediate (30%,  $p = 0.029$ ) and novice (51%,  $p < 0.001$ ). Advanced players had decreased COM displacement at the time of maximum arm speed and a more linear COM path during the early downswing. Further study should focus on these changes during ball launch conditions.

**Key words:** Golf Balance, Body worn sensor, postural compensatory strategy.

### Introduction

Cause and effect in the golf swing has been sought after since its creation. The scientific community is beginning to make contributions in this area. However, picking out isolated positions and events during snapshots of the swing often lead to spurious conclusions for a graceful complex, highly-integrated motor task.

Since its teaching origins, balance during the golf swing has been sought after (Wiren, 1990). Recently, some investigations have focused on the importance of balance and dynamic postural control in golf. Tsang and Hui-Chan (2010) studied 11 male golfers (66.2 +/- 6.8 years old) and 12 control participants (71.3 +/- 6.6 years old). They found the golfing group had significantly longer duration of static single leg stance, less anteroposterior body sway in perturbed single leg stance, and lunged further (Tsang and Hui-Chan, 2010). This same research group studied similar groups with the addition of Tai Chi practitioners and younger university students (Tsang and Hui-Chan, 2004). They found both Tai Chi practitioners (69.6 years old) and golfers (66.2 years old) demonstrated

significantly improved knee proprioceptive acuity over the elderly control group (71.3 years old) and the performance was similar to the younger student group (20.3 years old). They also found the Tai Chi and golfer group had significantly improved reaction time and leaned further without loss of stability, and demonstrated better control of leaning trajectory than the elderly control subjects. (Tsang and Hui-Chan, 2004)

Traditionally, balance control is defined by individual's ability to control deviations of the center of mass (COM) within the base of support (or center of pressure (COP)) (Winter, 1995), and balance deficits defined by deviations that lie outside normal age-matched reference limits. (Allum and Carpenter, 2005; Najafi et al., 2010a) As golfers appear to have better static and dynamic balance than their age-matched counterparts (Tsang and Hui-Chan 2010), it is less clear if static and dynamic balance actually improves golfing performance. It is also difficult to separate out the combined and synergistic effects of overall strength and flexibility, versus the effects of core stability and core strength (Liemohn et al., 2010) and their potential effect on dynamic postural control. In one of the largest studies of its kind, Sell and colleagues (Sell et al., 2007) studied the strength, flexibility, and balance in 257 golfers of varying proficiency based on their handicap index. They found the group with the highest proficiency demonstrated significantly increased hip, torso, and shoulder strength and flexibility as well as improved eyes-open balance compared to the lower proficient golfing group (Sell et al., 2007). Wells and colleagues (2009) studied elite golfers and reported significant correlations between anterior abdominal muscle endurance and sit and reach with driver carry distance. However, Stemm and colleagues (2006) reported no group differences in unilateral and bilateral postural sway during a virtual movement task.

These studies suggest that static and dynamic balance is important in golf. However, it is unclear if it is important in golfing performance. Some of these conflicting findings may stem from the measurements not being taken during the golf swing and the methods may not be responsive enough to detect meaningful differences (Najafi et al., 2010a). Zheng and colleagues (2008) studied pro and amateur-level golfers (low, mid, and high handicap). They found professional players produced greater magnitudes of left shoulder horizontal adduction, right shoulder external rotation, and trunk rotation than high handicap players. They concluded that better players demonstrated higher levels of coordination of distal seg-

ments resulting in maximal velocity closer to ball contact. In a recent review paper on balance and athletic performance, Hrysomallis (2011) suggested that balance training could improve rapid force development resulting in improved power and motor performance. Therefore, the purpose of the study is to investigate dynamic postural control of the body center of mass (COM) during specific sequences of the golf swing amateur golfers of varying proficiency. Our major hypotheses were that better players would have different COM in the medial-lateral ( $COM_{M-L}$ ) and anterior-posterior directions ( $COM_{A-P}$ ) displacement and movement patterns during the swing.

## Methods

### Subjects

In this cross-sectional pilot study, eighteen healthy golfers were recruited at Rosalind Franklin University of Medicine and Science. Before testing, each player signed an IRB approved consent form and indicated their handicap, age, weight and height (Table 1). All golfers were right handed and were stratified into 3 different groups based on handicap index: novice, intermediate, and advanced. The intermediate group included 7 players with handicaps that ranged from 15-19; advanced group included 4 players with handicaps 9-14; and the novice group composed of 7 players without an established handicap.

**Table 1.** Means ( $\pm$ standard deviation) of subject's age, height and weight in each group.

Golf Skill	Advance	Intermediate	Novice
N	4	7	7
#Male	4	4	4
Handicap	9-14	15-19	No handicap
Age (yrs)	40 (16)	38 (13)	38 (13)
Height (m)	1.86 (.05)	1.74 (.09)	1.79 (.10)
Weight (kg)	92 (6)	71 (11)	84 (16)

### Experimental setup

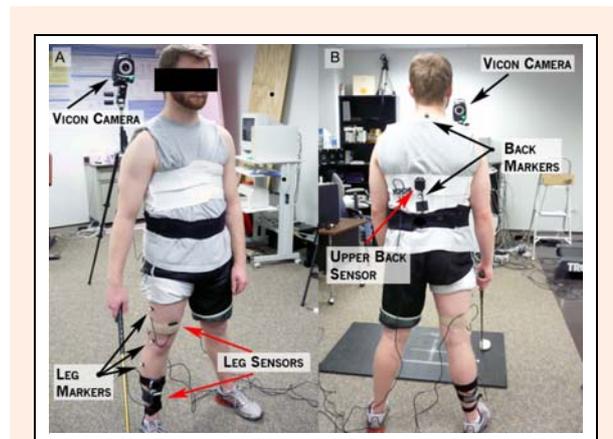
Testing was performed in an indoor facility with each golfer hitting swinging a common driver to hit a practice ball. A five-camera (60 Hz) motion analysis system (VICON®, Oxford, UK) was used to capture each swing.

Nine reflective markers were positioned on the following specific anatomical landmarks ascertained through palpation: acromio-clavicular joint (shoulder), anterior superior iliac spine (hip), 7th cervical vertebra (c7), 10th thoracic vertebra (t10), 3<sup>rd</sup> meta-carpal-phalangeal joint (middle knuckle on the left hand), medial and lateral center of the knee and tibia. Additionally, one marker was located on top of the club head and a wadded up ball of reflective adhesive tape formed the practice ball. The complete configuration of the player and his environment is shown in the Figure 1.

### Protocol of measurement and data analysis

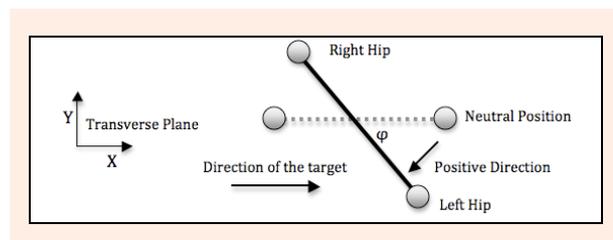
The analysis included an investigation of the hip, shoulder and spine angular segments and a complete balance study using the COM as the reference. Initially, each golfer was asked to stay in a neutral upright standing position to initialize the marker position as the reference position.

The estimated COM during upright position was assumed to be the most postural stable position. The beginning of the swing was defined by the first position change of the club head. A reflective ball was used to define the moment of impact. For the purpose of calculating the 3D kinematic data, the three best swings of the player were captured and reconstructed using VICON cameras and Nexus software. The player confirmed the swing was an adequate representation of their normal swing and the investigator confirmed adequate data capture. Each swing was assumed as an independent sample for the final data analysis. Following the 3D reconstruction, a quintic spline function (MATLAB, The MathWorks, Inc., Natick, MA) was applied to the raw coordinates in order to smooth the data and calculate kinematic quantities.



**Figure 1.** Complete configuration of the player and his environment.

The calculation of the different angles using the 3D location of each marker was done using a simple trigonometric model. Specifically, the hip angle was defined as the angle in the transverse plane between the lines connecting the two hip markers while standing in the neutral position and at any point in time. The same definition was applied for shoulder angles using the two shoulder's markers. For both angles, a positive value was indicative of a rotation from the neutral position away from the imaginary target and a negative value represented a rotation towards the target as illustrated in Figure 2.



**Figure 2.** Definition of the hip (shoulder) angle during the golf swing.

The COM movement during the swing was estimated using a two-link biomechanical model. The details of this model and its accuracy compare to a full body model have been described in our previous publications.

(Najafi et al., 2010b; Marclay et al., 2012) In summary, the position of COM was estimated using the subject's anthropometry data (i.e. height and body mass) and measuring spine and ankle joint angles (respectively using back markers and leg markers). Our previous study demonstrated that this simplified model has a high agreement with the estimated values using the full body model during golf swing trials ( $r = 0.93 \pm 0.05$  for A-P and  $r = 0.95 \pm 0.03$  for M-L directions) (Marclay et al., 2012). In another study, we demonstrated that the range of COM motion estimated using this model has a high correlation ( $r > 0.95$ ,  $p < 0.001$ ) with the range of center of pressure (COP) motion measured using a pressure platform (Najafi et al., 2010a). Reducing the number of reflective markers from 36 (for full body model) to nine, allows us to reduce the time of measurement as well as minimizing the degree of inconvenience for players for performing more natural swing trials. We didn't use COP measurement in this study, since our initial observations suggested that the natural base of support of our golfers exceed the measurable area of a standard pressure/force platform.

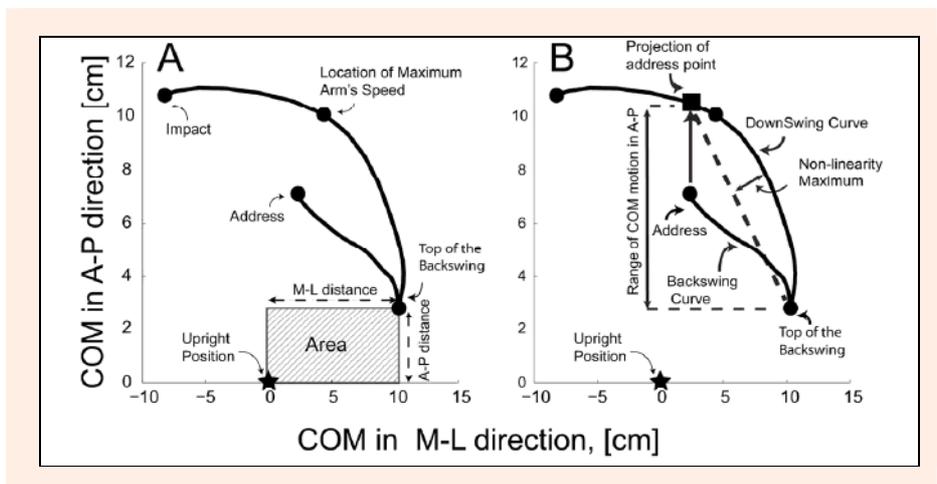
The maximum speed of the arm during the downswing was determined with the markers located on the left arm of each player. For this purpose, the total arm distance from the top of the backswing to the impact of the ball is differentiated and multiplied by the frequency of the system. In a similar way, the speed and acceleration of the COM were also calculated and analyzed.

Based on our initial observations and comparing with the Vicon data, we defined the top of the backswing as the minimum peak of the COM in A-P direction. As far as we know, this represents the first time the backswing has been defined by the COM rather than the club stopping or body rotation stopping (McTeigue et al., 1994). This measure may be unbiased by different swing strategies based on skill level. This peak could be accurately detected using a peak detection algorithm and could objectively discriminate between the backswing and downswing. Therefore, the minimum position of  $COM_{A-P}$  was used as the data point to separate these two phases. Figure 3A demonstrates the different phases of the golf swing, including the COM variability at the top of the backswing and at maximal arm speed during the swing.

COM was estimated at the key instances during swing including the time of upright position ( $t_{UP}$ ), address ( $t_{Add}$ ), top of backswing ( $t_{TBS}$ ), impact ( $t_{Impact}$ ), maximum arm's speed ( $t_{MAS}$ ), and maximum COM acceleration ( $t_{AccMax}$ ). To characterize and analyze dynamic balance for each group, COM distances as well as areas between each two measured instances were calculated and compared. An example of COM distances (A-P and M-L) and COM area (Figure 3A, dashed surface) between  $t_{UP}$  (Figure 3A, star point) and  $t_{TBS}$  is illustrated in Figure 3A.

In a second part of the study, we analyzed the influence of the arm speed during the swing. It stands to reason that arm movement can also influence the motion of the COM and challenge the postural control. For this purpose, the different COM distances and areas were normalized by the maximum arm speed of each golfer.

Finally, a new measure was introduced as part of the balance control of the golfer: the COM's linearity during the early downswing. This measure was intended to correspond to the teaching philosophy that there is a flat and straight trajectory into impact although this philosophy has some controversy. It is based on others work on center of pressure changes in the swing despite different strategies (Ball and Best 2007) and the club following one plane in some despite the body moving in different planes (Coleman and Anderson 2007). We assumed that we may achieve the best energy efficacy if the COM moves on a linear trajectory from the top of backswing toward the address point. Therefore, we calculated the non-linearity of the downswing COM trajectory and assumed it as an outcome to assess the skill level. Based on this definition, a lower non-linearity value indicates a better skill level. Figure 3B demonstrates the interpretation of the linearity for a typical trajectory of the COM. To estimate the non-linearity, first we projected in A-P direction, the position of COM at  $t_{Add}$  on the COM downswing curve: (Figure 3B, square point). Then, the maximum difference between the curve of the COM during downswing phase and the straight line joining the top of the backswing and the projected point was calculated. The estimated maximum distance was assumed as the maximum non-linearity of the downswing curve. We normalized this value by the range of motion of COM in



**Figure 3.** (A) Typical pattern of the COM and the position of the principal phases. (B) Estimation of non-linearity of COM trajectory at early swing phase.

A-P direction to estimate the percentage of non-linearity.

### Statistical analysis

A one-way analysis of variance (ANOVA) test was used to determine if there was confounding within groups with respect to age, gender, and body mass index (BMI). If a significant difference was observed, we used multiple-way analysis of variance (MANOVA) to consider potential covariates, otherwise ANOVA test (one-way) was applied for inter-group comparisons. If significance inter-group differences were observed, a Wilcoxon rank sum test was used to determine which group was significantly different. Significance was set at a  $p < 0.05$ . To test the reliability of the measurements, the intra class correlation (ICC(1,1))(Alexander and Young, 2005) among the three swings for each subject was calculated. Reliability was defined as excellent if the ICC was higher than 0.75, fair-to-good between 0.40-0.75 and poor if smaller than 0.40 (Najafi et al., 2009). All calculations were made using MATLAB® version 7.4 (R2007z) (The MathWorks, Inc., Natick, MA).

### Results

The descriptive characteristics of the subjects are described in Table 1. There were no significant differences among groups based on gender ( $p = 0.315$ ), age ( $p = 0.971$ ) or BMI ( $p = 0.085$ ).

Fifty four swings were measured including 12, 21, and 21 swings respectively for advance, intermediate, and novice group. Test-retest reliability between three measured swings was excellent for the estimated values in A-P direction (ICC(1,1) = 0.87, raters = 3,  $p < 0.001$ ) and fair-to-good for the estimated values in M-L direction (ICC(1,1) = 0.7, raters = 3,  $p < 0.001$ ).

Table 2 summarized the COM measures between groups. By examining the COM area at  $t_{MAS}$ , we found that by increasing skill level, the maximum arm speed happens at the COM position closer to the COM position at the  $t_{Add}$  (ANOVA,  $p = 0.001$ ). In advanced players, the COM area between  $t_{MAS}$  and  $t_{Add}$  was reduced by 57% and 73% compared to intermediate ( $p = 0.014$ ) and novice players ( $p = 0.023$ ), respectively, Figure 4A. On the other hand, we found that by increasing skill level, the displacement of COM from  $t_{TBS}$  till the  $t_{MAS}$  is significantly increased (ANOVA,  $p < 0.05$ ), Figure 4B. In advanced players, the COM area between  $t_{TBS}$  and  $t_{MAS}$  was increased in average by 32% ( $p = 0.013$ ) and 105% ( $p = 0.005$ ) compared to intermediate and novice players, respectively. Interestingly, by increasing skill level, COM

acceleration reached its maximum value quickly after  $t_{TBS}$  and far from  $t_{Impact}$  (ANOVA,  $p = 0.04$ ). We observed a significantly decreased COM area between the  $t_{AccMax}$  and  $t_{Impact}$  for novice golfers in comparison with intermediate (39%,  $p = 0.037$ ) and advanced players (59%,  $p = 0.008$ ), Figure 4C.

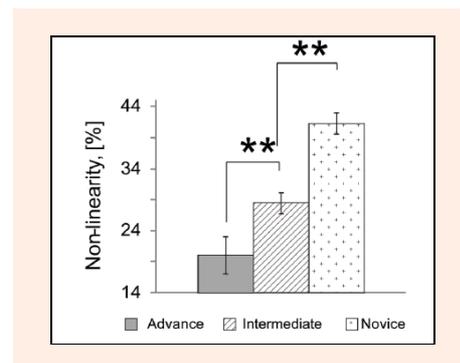
After normalizing COM values by maximum of arm speed (Figure 4D), two additional significant parameters were discovered. Results suggest that both advance and intermediate players have a significantly better postural stability normalized by the maximum arm speed compared to novice players at the  $t_{Impact}$  (ANOVA,  $p = 0.0004$ ). On the same note, novice players have significantly less postural control at  $t_{MAS}$  compared to other groups (ANOVA,  $p < 0.001$ ). More specifically, normalized  $COM_{A-P}$  distance between  $t_{Impact}$  and  $t_{UP}$  was significantly lower for the intermediate (19%,  $p = 0.0021$ ) and advanced golfers (22%,  $p = 0.0003$ ) compared to the novice, Figure 4E. Furthermore, the COM area between  $t_{MAS}$  and  $t_{UP}$  was significantly smaller for advanced (43%,  $p = 0.0026$ ) and intermediate players (50%,  $p < 0.001$ ) than for the novice golfer, Figure 4F.

We also found advanced golfers had an improved linearity of COM trajectory during downswing phase (ANOVA,  $p < 0.001$ ) compared to less-skilled players (intermediate: 30%,  $p = 0.029$ ; novice: 51%,  $p < 0.001$ ). This difference was also significantly greater for the intermediate group (45%,  $p < 0.001$ ) than for novice golfers (Figure 5).

### Discussion

#### Interpretation of postural control parameters

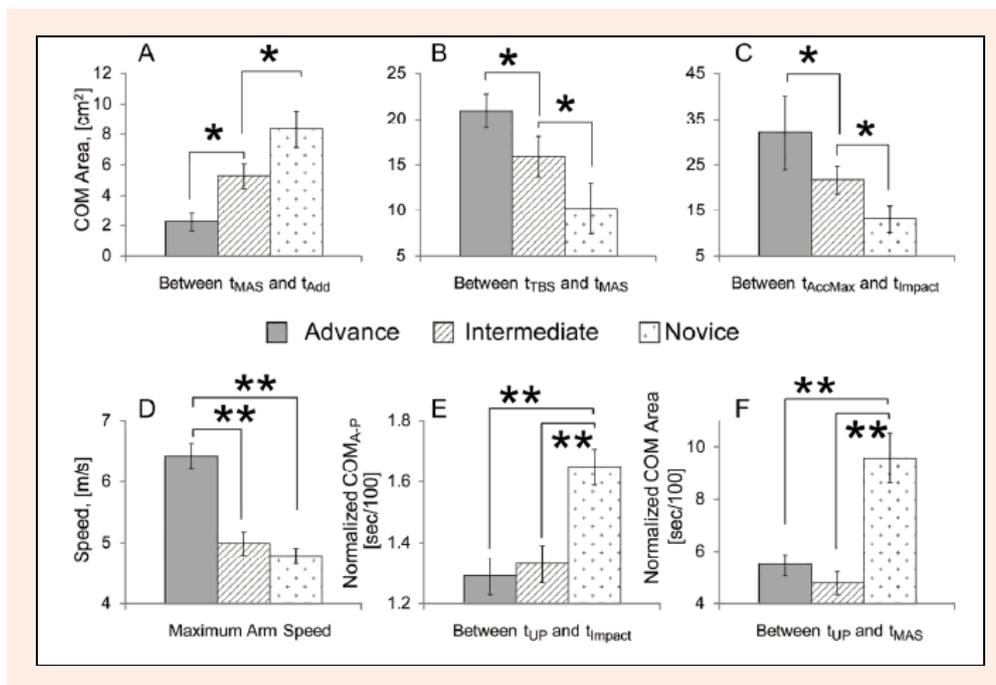
This study proposed new objective outcomes for assessing the golfer's skill level using the COM analysis at



**Figure 5.** Non-linearity of COM during early downswing phase for three groups.

**Table 2.** The most significant measured COM values at different key instances during swing. Data are means ( $\pm$ SD).

Golfer level	p-value	Advanced	Intermediate	Novice
Number of Swings	-	12	21	21
Maximum arm speed ( $m \cdot s^{-1}$ )	0.001	6.43 (.77)	4.99 (0.89)	4.78 (.61)
COM Area Between $t_{MAS}$ and $t_{Add}$ ( $cm^2$ )	0.001	2.25 (1.96)	5.27 (3.81)	8.34 (5.77)
COM Area Between $t_{TBS}$ and $t_{MAS}$ ( $cm^2$ )	0.05	20.95 (6.56)	15.93 (10.34)	10.21 (12.91)
COM Area Between $t_{AccMax}$ and $t_{Impact}$ ( $cm^2$ )	0.05	32.12 (29.27)	21.82 (16.67)	13.21 (16.66)
Normalized $COM_{A-P}$ by arm velocity	0.001	1.29 (.22)	1.33 (.31)	1.65 (.28)
Between $t_{UP}$ and $t_{Impact}$ (sec/100)				
Normalized COM Area by arm velocity	0.001	5.48 (1.43)	4.80 (1.96)	9.58 (4.47)
Between $t_{UP}$ and $t_{MAS}$ ( $cm \cdot sec/100$ )				



**Figure 4.** (A) COM area estimated between  $t_{MAS}$  and  $t_{Add}$ , (B) COM area estimated between  $t_{TBS}$  and  $t_{MAS}$ , (C) COM area estimated between  $t_{AccMax}$  and  $t_{Impact}$ , (D) the arm maximum speed during down swing phase, (E)  $COM_{A-P}$  normalized by the maximum arm speed, (F) COM area between  $t_{UP}$  and  $t_{MAS}$  normalized by the maximum arm speed.

different phases during the swing. Our findings suggest advanced players demonstrated improved postural control at the point of maximum arm speed when compared to less skilled players. Furthermore, COM acceleration for advanced players after reaching maximum arm speed is closer to impact than less-skilled players which occur prior to impact. This finding is in agreement with Zheng and colleagues (2008). This strategy may help advanced players to improve both their shot accuracy and distance.

In the other words, when these players reached maximum arm speed, there was minimal challenge to their postural control at impact. This strategy could also help players mentally focus on the shot (e.g., shot shape and trajectory) with minimal disturbance to postural control (Hrysomallis 2011).

We also observed novice players reached COM acceleration maximum closer to the top of the backswing than impact as observed in advanced players. This could explain the common teaching observation of the “over the top” move (e.g., trailing shoulder moves toward the target very early in the downswing earlier and to a higher degree) seen in novice players. This is also suggested by our data where the upper spine angle remained tilted more towards the back foot and there was less shoulder rotation

through impact in advanced players (Table 3). This is also suggested by the delayed COM acceleration, increased arm speed max, and increased distance to maximal arm speed in advanced players. Taken together, all of these findings may also explain why advanced players demonstrated a more linear path into impact and less  $COM_{A-P}$  motion. Lastly, we also observed an increased COM area for advanced players when moving from the top of the backswing to maximum arm speed suggesting that maximal arm speed was delayed, COM acceleration was later for more efficient energy transfer, (e.g., “the delayed hit”) and an increased maximal arm speed. These findings were also supported by Zheng and colleagues (2008) that observed a higher velocity closer to impact attributed to maintaining separation of the upper torso and pelvis, extended lead arm, and wrist position later in the downswing.

Considering that the challenge to postural control could be greater when the arm speed is higher, we normalized postural control parameters by the maximum arm speed. This scheme could help us to better evaluate golfer’s skill level, since the combination of the distance of the shot and postural control together could suggest good skill performance. Results confirmed this hypothesis.

**Table 3.** The most significant measured hip and shoulder angles at different key instances during swing. Data are means ( $\pm$ SD).

Golfer level	<i>p</i> -value	Advanced	Intermediate	Novice
<b>At <math>t_{TBS}</math></b>				
Upper spinal angle A-P ( $^{\circ}$ )	.01	15.01 (8.00)	24.09 (5.48)	20.72 (7.35)
Upper spinal angle M-L ( $^{\circ}$ )	.05	-18.33 (2.89)	-13.40 (6.31)	-12.61 (6.42)
<b>At <math>t_{Impact}</math></b>				
Upper spinal angle A-P ( $^{\circ}$ )	0.05	28.54 (6.57)	31.81 (5.72)	35.01 (6.74)
Upper spinal angle M-L ( $^{\circ}$ )	0.05	-17.15 (4.89)	-10.45 (5.51)	-10.30 (10.45)
Hip angle ( $^{\circ}$ )	0.01	-17.88 (5.45)	-28.69 (7.70)	-26.80 (11.90)
Shoulder angle ( $^{\circ}$ )	0.01	2.76 (6.10)	-8.89 (10.28)	-9.48 (13.25)

In the other words, we found out that for advanced players, the normalized position of COM at the time of impact in A-P direction is closer to the upright position than low skilled players. This suggests that advanced players have a better stability at that moment of impact than other players. Similarly, the normalized value of COM area at the time of maximum arm speed with respect to the upright position was smaller for advanced players. This may suggest that advanced players also have a better postural control at the maximum of the arm speed than other players.

### Interpretation of linearity of COM trajectory during downswing

We observed an increased COM linearity of trajectory during the early downswing for advanced players over novice players. We theorized this strategy may help advanced golfers to improve the economy of COM motion during golf swing (i.e., turning around the spine) and improve the performance of the shot. From biomechanical standpoint, to improve the performance of locomotion, it is better that COM moves in a linear direction rather than moving on a curve. Our findings can also be interpreted from postural configuration and motor control experiments performed outside of golf. According to Bingham et al. (2011), the nervous system likely selects a specific postural configuration to reduce the neural demand of the task. Our finding of advanced players taking a more linear COM path into impact and matching their maximum COM acceleration closer to impact could be supported by this strategy. Furthermore, changes in postural configuration affect body dynamics resulting in changes in neural control to perform the movement (Bingham et al., 2011). We found novice players' maximal COM acceleration occurring just after the top of the backswing. Zheng and colleagues (2008) observed that the average downswing time was 0.34 s for novice and 0.30 s for professional players. According to Horak and Macpherson (1996), there is a 0.15 s delay in response to COM perturbation for active muscle response and force generation. Taken together, these findings suggest significant sensorimotor feedback gains during the time of the golf downswing are very limited (Bingham et al., 2011).

One of the key advantages of the proposed method for assessing golfer's skill level is that the proposed COM values were estimated using a simplified model of human body including only two body segments rotating around spine and ankle. In a recent study, we demonstrated that the estimated COM value using this simplified model during golf swing trials has high correlation ( $r > 0.9$ ) compared to full body model (Marclay et al., 2012). Additionally, the estimated COM values using the proposed simplified model have also an excellent correlation with the COP values measured using a pressure platform (Najafi et al., 2010a; Marclay et al., 2012). In our previous study, we demonstrated that ankle and spine angles as well as COM could accurately be estimated using low cost and miniaturized body worn sensors (Aminian and Najafi, 2004; Favre et al., 2006; Najafi et al., 2010a; 2010b; Marclay et al., 2012). This strategy facilitates direct measurement on the course under shot-making

conditions when balance demands are varied (Hrysomallis, 2011). There are other potential advantages for using this approach. Measuring COM over COP may increase responsiveness. Najafi et al. (2010a) have described a high correlation ( $r = 0.92$ ) with the COP and COM with the COM having up to 10-12 fold higher movement during balance tasks (Najafi et al., 2010a). The COP trajectory is limited to the base of support (e.g. area between two feet), whereas the COM boundary is only constrained by the subject's range of motion while maintaining stability. Measuring the COP often requires a gait laboratory with dedicated platform making it difficult for infield measurement. The measurable area surface of force platform could also be a serious limitation for natural swing assessment. In our study, we noticed that the neutral base of support of our players exceed the measurable area of a standard pressure platform. Additionally, standing on an instrumented platform makes it difficult to examine balance on different types of surfaces which better replicate a golfer's natural competitive environment. On the other hand, camera motion analysis systems permit accurate assessment of balance via measuring COM sway independent of the type of surface. However, the spatial and time constraints of using a dedicated gait lab often preclude motion analysis system usage in the athletic environment and for usual practice.

There are several potential limitations to this pilot study. This was a pilot study of golfers with a small sample size. Further study design improvements would consist of expert golfers and be powered adequately to detect gender differences as to better elucidate these possible relationships. The golf swings were made in a simulated environment without knowledge of the launch conditions of the golf ball. Further studies are needed to address if these improved COM conditions result in optimized ball launch conditions.

### Conclusion

In this pilot study, we found advanced players had decreased COM displacement at the point of maximum arm speed indicating a better stability. Additionally, the amount of stability taking in to account the value of maximum arm speed is better in advanced players compare to novices. They also demonstrated a more linear path of COM motion during the downswing possibly indicating a better economy of COM motion during golf swing. Further study should focus on changes in the parameters with respect to ball launch conditions.

### Acknowledgments

Mr. Samuel Marclay was a master student visiting fellow from Ecole Polytechnique Federale de Lausanne (Lausanne, Switzerland), who contributed to this study as a part of his master project. After termination of this study, a patent pending application was filed based on the observed results.

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## Key points

- Studies suggest that static and dynamic balance is important in golf. However, none have investigated dynamic postural control during the golf swing in golfers of varying proficiency.
- Our findings suggest advanced players demonstrated improved postural control at the point of maximum arm speed when compared to less skilled players. Furthermore, center of mass acceleration in advanced players is closer to impact than less-skilled players.
- We observed an increased center of mass linearity of trajectory during the early downswing for advanced players over novice players. We theorized this strategy may help advanced golfers to improve the economy of COM motion during golf swing and improve the performance of the shot.

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