BIOMECHANICAL ANALYSIS OF THE MOMENT ABOUT THE CENTER OF MASS DURING THE DOWNSWING PHASE IN WOMEN'S DRIVER SHOT

Atsushi Okamoto[1]

School of Sport and Health Science, Tokai Gakuen University, Miyoshi, Japan[1]

The purpose of this study was to investigate the moment about the center of mass (CM) acting on the golfer-club system during the downswing phase in women's driver shots. Fourteen female golfers volunteered as subjects. The maximum clubhead speed, angular momentum ot the thorax and moment about the CM were calculated. There was a strong significant correlation between the frontal-plane moment about the CM and the maximum clubhead speed ($p<0.01$). At the same time, there was a significant correlation between the frontal-plane moment about the CM and angular momentum of the thorax about the Z-axis ($p<0.05$). In conclusion, in order to get higher clubhead speed it is important to generate the larger frontal-plane moment about the CM and to transfer the momentum generated from the body to the clubhead.

KEYWORDS: women's driver shot, clubhead speed, moment about the CM.

INTRODUCTION: The golf swing is a dynamic and complex total body motion that requires the golf players to hit a ball accurately over a variety of distances. Some previous studies determined that the whole-body rotation was associated with the ground reaction force (GRF) during the golf swing (Williams, 2004; McNitty-Gray et al. 2013; Peterson et al. 2016). The centre of pressure motion (weight shift) during the golf swing has strong correlations with the production of clubhead speed (Ball et al., 2001; Wallace, Graham & Bleakley, 1990). The clubhead speed at impact is the principal factor that determines the distance that a golf ball will travel. The importance of shot distance increases as the level of competitiveness increases (Hellstrom, 2009). Therefore, it is important to understand how to accelerate the golf club. The GRF and the ground reaction moment acting on the body during the swing are the sole sources of angular momentum for the golfer-club system. Thus the quality of the foot-ground interaction (i.e. magnitude, direction, and point of action of the GRF) is a key factor for a biomechanically good golf swing. However, there is no knowledge about the relationship between moment about the CM and clubhead speed in the golf swing. The purpose of this study was to investigate the relationship between the moment about the CM and maximum speed of the clubhead during the downswing phase in women's driver shots.

METHODS: Six female professional and eight female amateur golfers volunteered as subjects (age = 27.8 ± 15.1 yrs, height = 1.62 ± 0.05 m, mass = 59.6 ± 7.6 kg). In this study, four of the professional golfers were golf instructors and the amateur golfers, aged from 12 to 24 years old were aiming to become professional golfers. Written informed consent was obtained from the golfers. A 10-camera (250 Hz) VICON system was used in an indoor motion analysis facility to capture 3D trajectories of 57 reflective markers attached to each golfer's body and the driver (Fig. 1). The 3D coordinates were expressed in an orthogonal reference frame in which the X-axis pointed to the right, the Y-axis forward, and the Z-axis upward (Fig. 2). For testing sessions, each golfer instructed to hit optimally (for distance and accuracy) as they normally would on the golf course and then performed 5 shots into a target net 5 m away. The fastest of the 5 shots of each participant was analyzed. The speed of the clubhead was calculated from displacement of the marker on the clubhead. The sagittal- and frontal-plane moment about the CM was calculated by the cross-product of the CM's position vector (from center of pressure to the CM) and the GRF vector. The transverse-plane moment about the CM also was calculated with the sum of GRF moment about the CM and free moment of each foot (Holden & Cavanagh, 1991). The Cardan angles of thorax was calculated. The angle of the segment was filtered using a Butterworth filter with a cut off frequency of 10 Hz (Winter, 1990). Then angular velocity and angular momentum of thorax about the Y- and Z-axis were calculated. The CM and moment of inertia of body segments were estimated from the data of Ae (Ae, Tang, & Yokoi, 1992). The normality of the data was performed by Shapiro-Wilk test. Then the correlation of the data was investigated.

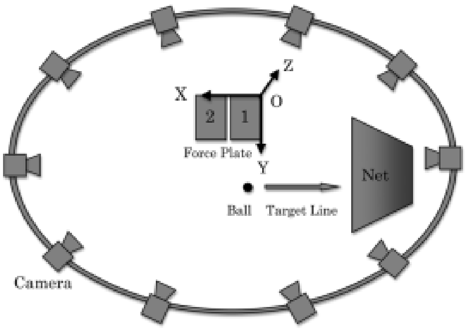

Figure 1: Experimental set-up.

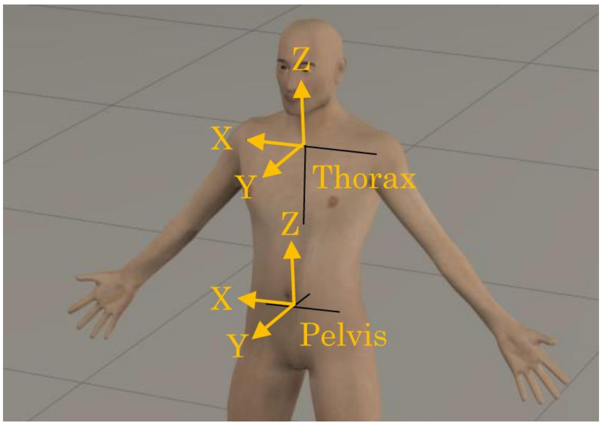

Figure 2: Coordinate system of the pelvis and thorax segments.

RESULTS: The normality of the maximum clubhead speed, angular momentum of the thorax about the X-, Y- and Z-axes, the sagittal-, frontal-, and transverse-plane moment about the CM were confirmed. The mean and standard deviation of all subject's maximum clubhead speed was 38.4 ± 1.9 m/s just before impact. An example of the stacking GRF vector of frontal-plane and transverse-plane during the downswing phase in women's driver shot is shown in figure 3.

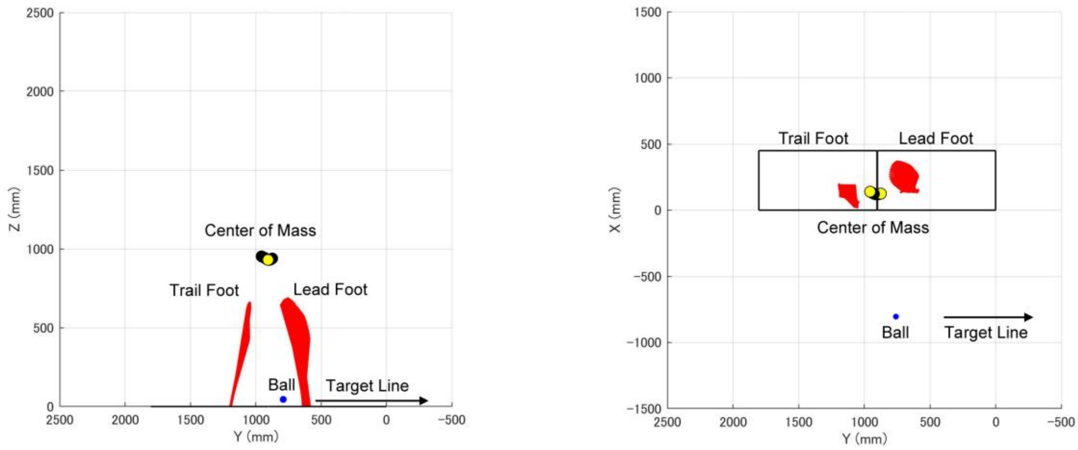

Figure 3: Example of the stacking GRF vector of frontal-plane (left) and transverse-plane (right) during the downswing phase (——— : force vector, ○ : center of mass).

The maximum sagittal-, frontal- and transverse-plane moment about the CM were 51.7 ± 18.8 N•m, 78.3 ± 17.9 N•m and 82.7 ± 20.1 N•m, respectively. The relationship between the maximum sagittal-, frontal- and transverse-plane moment about the CM and the maximum speed of the clubhead during the downswing phase is shown in figure 4.

There was a strong positive linear relationship between the frontal-plane moment about the CM and the maximum clubhead speed ($p<0.01$). However, there was no significant correlation between maximum sagittal- and transverse-plane moment about the CM and the maximum speed of the clubhead during the downswing phase.

The relationship between the maximum frontal-plane moment about the CM and the maximum angular momentum of the thorax about the Y- and Z-axis is shown in figure 5. There was a moderate positive linear relationship between maximum frontal-plane moment about the CM and the maximum angular momentum of the thorax about the Z-axis ($p<0.05$). A 3D scatter diagram and 95% confidence ellipsoid for clubhead speed is shown in figure 6.

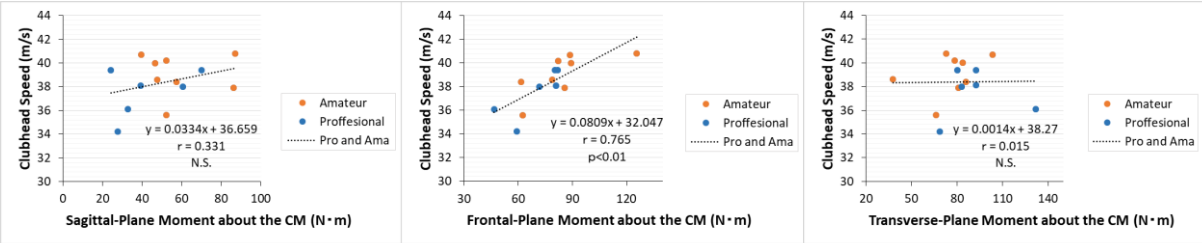

Figure 4: Relationship between the maximum sagittal- (left), frontal- (center) and transverse-plane (right) moment about the CM and the maximum speed of the clubhead.

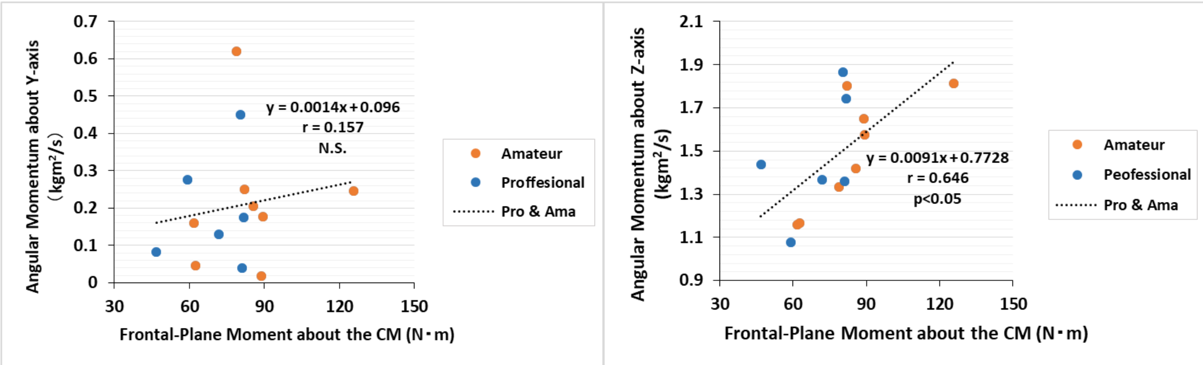

Figure 5: Relationship between the maximum frontal-plane moment about the CM and the maximum angular momentum of the thorax about the Y- (left) and Z-axis (right).

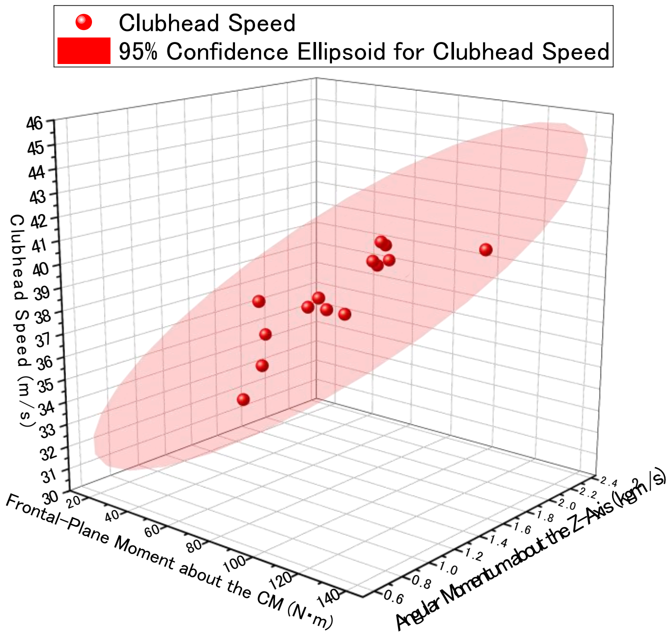

Figure 6: 3D scatter diagram of the maximum frontal-plane moment about the CM, the maximum angular momentum about the Z-axis and the maximum clubhead speed. : 95% confidence ellipsoid for clubhead speed.

DISCUSSION: One main goal in a golf swing is to develop a large clubhead speed through angular motions of the body while maintaining control. The GRF and the ground reaction moment acting on the body during the swing are the sole sources of angular momentum for the golfer-club system. The quality of the foot-ground interaction is a key factor for a biomechanically good golf swing. There was a strong positive linear relationship between the frontal-plane moment about the CM and the maximum clubhead speed ($p<0.01$). However, there was no significant correlation between the maximum sagittal-plane moment and transverse-plane moment about the CM and the maximum clubhead speed during the downswing phase. These results are different from a previous study (Han et al., 2014). Han et al. (2014) described the peak frontal-plane GRF moment and peak transverse-plane coupling moment showing significant correlations with peak clubhead speed. This difference was considered to be affected by the difference between sexes. Okamoto (2018) reported significant relation of angular momentum of the thorax about the Z-axis and the maximum clubhead speed. Therefore, the relationship between the moment about the CM and angular momentum of the thorax about the Z-axis was investigated. Then a moderate positive linear relationship was observed between the maximum frontal-plane moment about the CM and angular momentum of the thorax about the Z-axis ($p<0.05$). In this study, the frontal-plane moment about the CM was calculated regarding the global coordinate system. On the other hand, angular momentum of the thorax about the Z-axis was calculated regarding the local coordinate system on the thorax segment. Therefore, because of the forward tilting of the body from the hip joint, the frontal-plane moment about the CM contributed to increasing the angular momentum of the thorax about the Z-axis. From the 3D scatter diagram (figure 6), it was suggested that the frontal-plane moment about the CM contributed to the angular momentum of the thorax about the Z-axis, and then large amount of the momentum was transfer to the clubhead. Therefore, it is important to generate the large frontal-plane moment about the CM to get a longer distance of driver shot in a golf swing.

CONCLUSION: This study analyzed the relationship between the moment about the CM and the maximum speed of the clubhead during the downswing phase in women's driver shots. The maximum frontal-plane moment about the CM was 78.3 ± 17.9 N•m. This maximum frontal-plane moment about the CM contributed to increasing the angular momentum of the thorax about the Z-axis, then this momentum transfers to the clubhead to get higher clubhead speed. These results suggest that generating the large frontal-plane moment about the CM was important to get a longer distance of the driver shot in a golf swing.

REFERENCES

Ae, M., Tang, H., & Yokoi, T. (1992). Estimation of inertia properties of the body segments in Japanese athletes. *Biomechanisms* (in Japanese), 11, 23-33.

Ball, K. A., Best, R. J., Wrigley, T., Brown, D., & Dowlan, S. (2001). Centre of pressure correlations with clubhead speed in the golf swing. In J. R. Blackwell & R. H. Sanders (Eds.), XIX International Symposium on Biomechanics in sport, 48-53.

Han, K. H., Lee, S., & Kwon, Y.-H. (2014). Associations between maximum clubhead speed and select GRF and moment parameters in skilled golfers. In E. J. Bradshaw, A. Burnett &P.A.Hume(Eds.), *2014 Incheon Asian Games International Sport Seience Congress - In commemoration of The 1988 Seoul Olympic Games*, 379.

Hellströma, J. (2009). Competitive Elite Golf : A review of the relationships between playing results, technique and physique. *Sports Medicine*. 39(9), 723-741.

Holden, J. P., & Cavanagh, P. R. (1991). The free moment of ground reaction in distance running and its change with pronation. *Journal of Biomechanics*, 24, 887-897.

McNitt-Gray, J. L., Munaretto, J., Zaferiou, A., Requejo, P. S., Flashner, H. (2013). Regulation of reaction forces during golf swing. *Sports Biomechanics*, 12(2), 121-131.

Okamoto, A. (2018). The relationship between angular momentum of body segment and velocity of the clubhead in women's driver shot. *Proceeding of the 36th Conference of the International Society of Biomechanics in Sports*, 1062-1065.

Peterson, T. J., Wilcox, R. R., McNitt-Gray, J. L. (2016). Angular Impulse and Balance Regulation During the Golf Swing. *Journal of Applied Biomechanics*, 32(4), 342-349.

Wallace, E. S., Graham, D., & Bleakley, E. W. (1990). Foot to ground pressure patterns during the golf drive: A case study involving a low handicap player and a high handicap player. In A. J. Cochran (Ed.), Science and golf: *Proceedings of the first world scientific congress of golf*, 25-29. London: E & FN Spon.

Williams, K. R. (2004). Relationships between ground reaction forces during the golf swing and ability level. *The Engineering of Sport*, 5, 189-195.

Winter, D. A. (1990). Biomechanics and motor control of human movement (2nd ed.). New York, NY: John Wiley & Sons.