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ORIGINAL

Biomechanical Analysis of Golf Driver Swing Motion According to Gender

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Objective: The purpose of this study is to investigate the differences in biomechanical variables of golf driving motion according to gender.

Method: A total of 21 healthy golfers (11 men and 10 women) who have more than 5 years of professional experience and have been registered in the Korea Golf Association was recruited. A 250-Hz 8-camera motion capture system (MX-T20, Vicon, LA, USA) was used to capture the motion trajectories of a total of 42 reflective markers attached to the golfer's body and club. Moreover, two 1,000-Hz AMTI force plates (AMTI OR6-7-400, AMTI, MA, USA) were used to measure the ground reaction force. The mean and standard deviation for each parameter were then calculated for both groups of 21 subjects. SPSS Windows version 23.0 was used for statistical analysis. The independent *t*-test was used to determine the differences between groups. An alpha level of .05 was utilized in all tests.

Results: There were differences in joint angles according to gender during golf driver swing. Men showed a statistically significantly higher peak joint angle and maximum range of angle in sagittal and frontal axis of the pelvis, hip, and knee. Moreover, women's swing of the pelvis and hips was found to have a pattern using the peak joint angle and range of angle in the vertical axis of the pelvis and hip. There were the differences in peak joint moment according to gender during golf driver swing. Men used higher joint moment in the downswing phase than women in the extensor, abductor, and external rotator muscles of the right hip; flexor and adductor muscles of left hip joint; and flexor and extensor muscles of the right knee.

Conclusion: This result reveals that male golfers conducted driver swing using stronger force of the lower body and ground reaction force based on strength of hip and thigh than female golfers.

Keywords: Driver swing, Joint angle, Joint moment, Gender difference, Golf, Muscles

INTRODUCTION

The golf swing is one of the most complex sports movements that involve both muscles and joints. Accuracy, consistency, and power are the most important factors in the golf swing, and driving distance and direction are the two key targets (Chu, Sell, & Lephart, 2010). In a golf game, driving distance is one of the most important factors of game performance that affects the choice of club and course strategy in the second shot. With the length of golf courses on the rise, it becomes highly challenging to hit the green with approach shots without making a long driver shot. Further, even if the ball hits the green, the chance of shooting a birdie is reduced without a long driver distance because a golfer would have to make a long putt (Shin, 2007). Therefore, acquiring the skills to make drivers shots with strong impact is a desire shared by all golfers (Kang, Kim, & Kim, 2014).

Among the various biomechanical variables of the complex golf swing, the only external force and moment that could be voluntarily controlled by the golfer is ground reaction force (GRF). Moment, which is the maximum force generated from the interaction between the foot and ground, generated in the early downswing phase is significantly correlated with club head speed, and the lower body plays an important role in facilitating the interaction between the feet and ground (Han, Lee, & Kwon, 2014). Angular momentum produced by the interaction between the feet and ground is delivered to the upper body through the lower body, and the golfer can control the interaction between the feet and ground by controlling the lower extremity muscles (Ball & Best, 2007; Kawashima, Meshizuka, & Takeshita, 1998). Therefore, appropriate control of the lower body is an essential requirement for high club head speed at impact. The lower body not only leads the downswing but also affects the upper body, and sound lower extremity movement is critical for the upper body to play its role (Park, Youm, & Seo, 2005). However, despite the importance of the mechanical role of the lower body, the direct biomechanical relation between lower extremity training and club head speed has not been established in the literature (Han, 2016). Thus, more detailed studies on the lower extremity motions during the golf swing, as well as studies investigating the motion in relation to the characteristics of the lower body, are needed.

Furthermore, there are clear gender differences in terms of lower extremity features. In a comparison of the range of motion between men and women, Park, Son, and Kim (2007) found a significant difference in left and right hip joints and suggested that such physical differences may pose advantages and disadvantages in the golf swing. In the past, the training programs devised based on research data on men have been equally applied to female golfers, but different approaches are needed for women due to clear physiological and skeletal differences as well as differences in explosive power and strength. In terms of the physique, women's appendicular skeleton is only about 65~75% as heavy as men's, and women also have smaller transverse lumbar and proximal femoral area and mass with weaker connective tissues in the joints. However, women are superior to men in terms of flexibility (Riggs et al., 2004). Despite such physical differences between men and women, most studies have simply compared swing motions of skilled and non-skilled golfers (Kim, Choi, & Park, 2015; Kim & Kim, 2017; Lee, 2000; Ryu & Kim, 2011; Sim et al., 2017), with comparisons within and not between gender (Lee & Park, 2006; Oh, Shin, Hong, & Kim, 2016; Cuniberti & Poser, 2017; Hirano et al., 2017; Sohn, Ryue, Lee, & Lim, 2010).

Sex-specific golfing must be preceded by an understanding of differences between sexes in order to devise sex-appropriate swing postures, training programs, and game strategies. Thus, studies that analyze and understand the differences of the golf swing between male and female golfers are essential. With such research data, it would be possible to develop appropriate swing patterns based on quantified sex-specific differences, select appropriate equipment, accumulate scientific data for effective coaching, and scientifically refine training programs. Hence, this study aims to provide foundational scientific data by quantitatively and objectively analyzing the kinematic variables of the golf swing by male and female golfers.

METHOD

1. Participants

This study was a comparative group one-shot case study, and the participants of this study were skilled golfers registered in the Korea Golf Association (KGA) as of 2017 with a golf career of greater than five years. A total of 21 golfers (11 male, 10 female) was finally selected based on the inclusion criteria of not having a history of injury or surgery that may impact sports performance in the past year and voluntarily declaring willingness to participate and signing an informed consent form.

To compute the kinetic and kinematic variables, the participants' heights and weights were first measured with a body composition analyzer. The participants' physical characteristics are shown in Table 1. The male golfers had a mean age of 33.4±5.0 years, height of 177.5±4.0 cm, weight of 79.1±7.8 kg, BMI (body max index) of 25.1±2.0 kg/m^2, and career of 11.9±4.2 years. The female golfers had a mean age of 32.2±4.8 years, height of 164.0±4.5 cm, weight of 53.1±3.1 kg, BMI of 21.98±1.0 kg/m^2, and career of 11.3±5.1 years.

Table 1. Characteristics of subjects

Section	Male (*N*=11)	Female (*N*=10)
	M ± SD	M ± SD
Age (years)	33.4±5.0	32.2±4.8
Height (cm)	177.5±4.0	164.0±4.5
Weight (kg)	79.1±7.8	53.1±3.1
BMI (kg/m^2)	25.1±2.0	21.98±1.0
Golf career (years)	11.9±4.2	11.3±5.1

2. Measurements

1) Measuring instrument and research process

The following instruments were used for this study. A body composition analyzer (X-Scan Plus 950, AccuNic, Co., Daejeon, Korea) was used to measure the height and weight, and eight infrared motion-capture cameras (MX-T20, Vicon, LA, USA) were used to photograph swing motions. Two GRF sensor systems (AMTI OR6-7-400, AMTI Inc., MA, USA) were used to measure GRF. The collected data were analyzed with Kwon3D version 3.1 (XP version, Visol, Seoul, Korea).

The participants' physical characteristics (height and weight) were measured prior to the experiment. The participants wore spandex pants and t-shirts and black swim caps prepared for the study. They wore their own gloves and shoes. The participants warmed up and practiced swing sufficiently prior to beginning the experiment. During the experiment, the participants were told to perform their driver swing freely, and three swing motions with no data error were selected for analysis. The participants chose their own drivers that they feel comfortable with and their preferred tee height (40 mm, 45 mm, and 50 mm). A soft ball made of sponge was used for the study.

The placement of the instruments for motion imaging and analysis is shown in Figure 1.

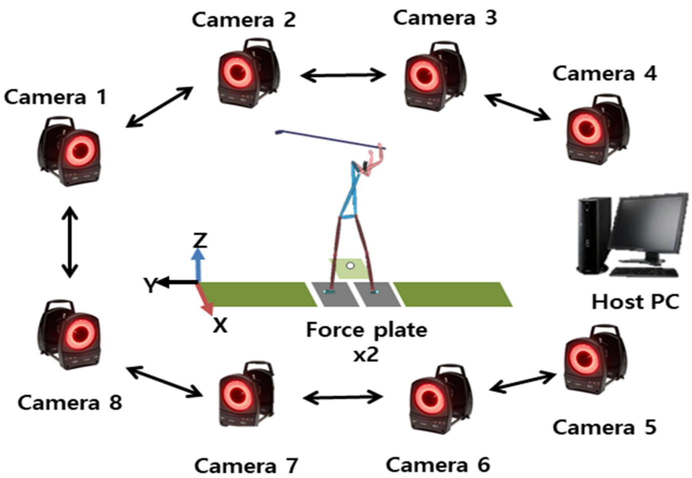

Figure 1. Experimental equipment

2) Frame of reference and body segment

Direct linear transformation (DLT) technique was used for spatial coordination. For the laboratory frame of reference, the front of the subject during address was set as the X axis, direction of ball as the Y axis, and vertical direction as the Z axis. For the local frame of reference, the sagittal axis was set as the X axis, the frontal axis as the Y axis, and the vertical axis as the Z axis.

Each segment was classified into linear segment that connects two points and plane segment that connects three or more points. Surface reflective markers (diameter, 10 mm) were attached to 46 places using the TWU (Texas Woman's University) Golfer model (Kwon, Como, Singhal, Lee, & Han, 2012). Further 11 markers were attached to the driver club and five markers were attached to the ball mat to set the reference frames for analysis. The positions of the markers are shown in Figure 2.

3) Definition of backswing and downswing phase

For the analysis, the golf driver swing was divided into the backswing and downswing as shown in Figure 3 (Han, 2016).

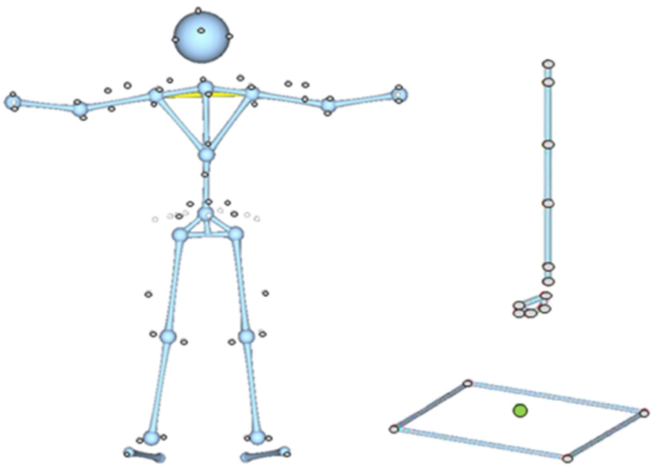

Figure 2. Reflective marker setting

3. Data processing

The variables for analysis were joint angles (pelvic, hip, knee, and ankle), which are kinetic variables, and joint moment (hip, knee, and ankle), which are kinematic variables. Because the pelvic and hip joints are ball-and-socket joints that move along three axes, we collected data from the X, Y, and Z axes. In addition, knee and ankle joints are hinge joints that move around one axis with only one type of rotational movement, so we collected data from the X axis.

4. Statistical analysis

The three-dimensional coordinates and kinetic and kinematic data for the biomechanical variables of the driver swing were analyzed using Kwon3D XP version 3.1 (Visol Inc., Korea). To analyze the differences of variables for each event and phase, means and standard deviations were computed, and intergroup differences were verified with independent *t*-test using SPSS Windows version 23.0. Statistical significance was set at .05.

RESULTS AND DISCUSSION

1. Comparison of maximal joint angle according to gender

Tables 2 and 3 show the gender comparisons of the peak joint angle in the backswing and downswing. The X axis was defined as the sagittal axis, Y axis as the frontal axis, and Z axis as the vertical axis. For the pelvis, posterior and anterior tilt are defined as + and -, respectively; right and left tilt as + and -, respectively; and left and right rotation as + and -, respectively.

There were no significant differences in the peak joint moment in the backswing between men and women. In the downswing, there was a significant difference between men and women in peak joint angle in the sagittal axis as the pelvis neared the impact point and tilted

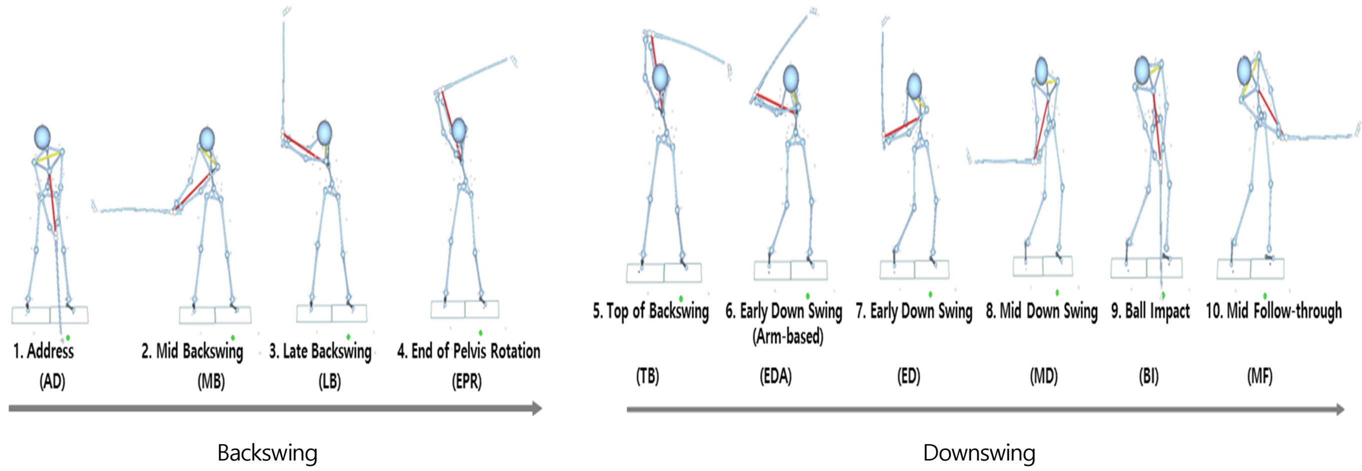

Figure 3. Backswing and downswing

posteriorly, with 19.11±12.47° for men and 7.90±12.05° for women (t=2.090, p=.050). There were no significant differences in frontal and vertical axes.

During the downswing, pelvic movement changed from anterior tilt and left tilt to posterior tilt and right tilt, respectively, and a continuous left rotation was shown. For the sagittal axis, male golfers showed a significantly greater peak posterior tilt angle as the impact point went near. In light of Mclean's (2009) report that the larger the pelvic and knee rotational angles, the better the swing at the top of the backswing and downswing, male golfers seem to move their body weight more aggressively; further, the fact that the pelvic angle from the early anterior tilt to posterior tilt was large suggests that the golfers pushed their torso to the posterior using larger GRF. As stated in a previous study, women use the quadriceps femoris to maintain balance (Kang, 2004), so they may be more disadvantaged than men in controlling the lower body when performing explosive movement in the downswing.

The peak joint angle for the right hip in the backswing significantly differed in the sagittal axis between men (52.84±13.79°) and women (36.40±14.58°) (t=2.654, p=.016). In the downswing, the peak joint angle for the right hip in the flexion-extension axis significantly differed between men (54.47±14.00°) and women (39.07±14.58°) (t=2.469, p=.023). Further, the peak extension and abduction angles also significantly differed between men (3.35±14.29° and -28.42±4.72°, respectively) and women (-16.82±17.38° and -22.28±4.98°, respectively) (t=2.917, p=.009, and t=-2.898, p=.009, respectively).

The peak left hip angle in the backswing significantly differed in the sagittal axis between men (31.66±11.89°) and women (6.00±17.29°) (t=3.995, p=.001). There was also a significant difference in the frontal axis between men (39.57±5.08°) and women (30.11±5.58°) (t=4.069, p=.001). Even in the peak left hip angle in the downswing, men showed a significantly higher flexion-extension angle in the sagittal axis (57.50±13.84° and 24.92±12.02°) than women (31.68±14.61° and 2.37±16.70°) (t=4.160, p=.001, t=3.676, p=.002). There was also a significant difference in the frontal axis between men (40.97±4.80°) and women (35.67±5.57°) (t=2.344, p=.030). These results are in line with previous reports that men and women show different femoral angles in the top of the backswing (Egret, Nicolle, Dujardin, Weber, & Choll, 2006). Further, our results are also in line with a previous finding that men tend to bend the hip and knee more than women in the address position and that such features may facilitate more movement of weight to the target direction during the downswing (Zheng et al., 2008).

In the backswing, the peak bending angle for the right knee significantly differed between men (-40.57±5.50°) and women (-32.76±9.41°) (t=-2.350, p=.030). There was also a significant difference in the left knee angle between men (-51.41±4.18°) and women (-33.14±14.65°) (t=-3.805, p=.003). The peak bending angle for the left knee in the downswing was significantly greater in men (-61.65±4.62°) than in women (-44.32±16.33°) (t=-3.381, p=.003).

This is in line with a previous finding that men bend their knees more than women do during the backswing (Egret et al., 2006). Furthermore, in light of the findings that club head speed increases with left knee bending angle (Chu et al., 2010), left knee moment is correlated with club head speed (Han, 2016), and left leg joint power is significantly correlated with club head speed (McNally, Yontz, & Chaudhari, 2014), it can be speculated that the higher knee bending angle in men have some impact on club head speed.

With regard to the left and right ankle angles in the backswing, golfers dorsally bent both feet very mildly, and there were no significant

Table 2. Comparison of maximal joint angle during backswing (unit, degrees)

Joint	Axis	Peak position	Male (N=11) M ± SD	Female (N=10) M ± SD	t	p-value
Pelvis	X	Anteriorly tilted	-15.08±11.69	-5.21±12.81	-1.847	.080
	Y	Left tilted	-15.17±4.52	-11.84±3.11	-1.948	.066
	Z	Right rotated	-48.59±11.10	-54.64±11.80	1.210	.241
Right hip	X	Flexed	52.84±13.79	36.40±14.58	2.654	.016*
	Y	Adducted	14.75±4.40	16.79±5.01	-.994	.333
	Z	Internal rotated	12.92±15.53	21.61±29.51	-.856	.402
Left hip	X	Flexed	31.66±11.89	6.00±17.29	3.995	.001**
	Y	Abducted	39.57±5.08	30.11±5.58	4.069	.001**
	Z	Internal rotated	-7.36±10.55	-13.06±31.93	.538	.601
Right knee	X	Flexed	-40.57±5.50	-32.76±9.41	-2.350	.030*
Left knee	X	Flexed	-51.41±4.18	-33.14±14.65	-3.805	.003*
Right ankle	X	Dorsiflexed	105.65±4.44	102.82±5.47	1.308	.207
Left ankle	X	Dorsiflexed	114.32±4.52	112.939±5.21	.649	.524

Table 3. Comparison of maximal joint angle during downswing (unit, degrees)

Joint	Axis	Peak position	Male (N=11)	Female (N=10)	t	p-value
			M ± SD	M ± SD		
Pelvis	X	Posteriorly tilted	19.11±12.47	7.90±12.05	2.090	.050*
	Y	Right tilted	13.75±4.31	10.61±3.94	1.736	.099
		Left tilted	-18.80±3.81	-15.59±3.76	-1.943	.067
	Z	Left rotated	55.70±13.09	59.51±7.76	-.800	.434
Right hip	X	Flexed	54.47±14.00	39.07±14.58	2.469	.023*
		Extended	3.35±14.29	-16.82±17.38	2.917	.009*
	Y	Adducted	14.85±4.29	17.74±5.15	-1.403	.177
		Abducted	-28.42±4.72	-22.28±4.98	-2.898	.009*
	Z	Internal rotated	23.35±15.07	35.97±31.30	-1.196	.246
Left hip	X	Flexed	57.50±13.84	31.68±14.61	4.160	.001**
		Extended	24.92±12.02	2.37±16.70	3.676	.002*
	Y	Abducted	40.97±4.80	35.67±5.57	2.344	.030*
		Adducted	-16.16±3.99	-14.38±4.69	-.941	.358
	Z	Internal rotated	-17.78±7.58	-31.38±28.40	1.467	.173
Right knee	X	Flexed	-46.78±8.15	-41.79±13.46	-1.040	.311
Left knee	X	Flexed	-61.65±4.62	-44.32±16.33	-3.381	.003*
Right ankle	X	Dorsiflexed	107.23±4.74	108.54±5.99	-.558	.538
Left ankle	X	Dorsiflexed	116.16±5.12	115.74±5.25	.186	.855

differences between peak joint angles between men and women.

There were no significant differences of peak left and right ankle angles in the downswing between men and women.

All in all, it is important to sufficiently flex and extend the knees in the downswing phase, promote adequate transfer of body weight by generating left and right hip angle in the frontal axis, and generating sufficient pelvic angle in the vertical axis are critical for increasing club head speed. These results are in line with previous findings that 84% of novice golfers fail at effectively transferring body weight during the driver swing (Koslow, 1994), novice golfers' lateral movement in the driver swing is only 50% of that of the skilled golfers (Sanders & Owens, 1992), and weight transfer in the downswing is a crucial component of club head speed for players with poorer physical conditions (Okuda, Armstrong, Tsunezumi, & Yoshiike, 2002). Further, during the backswing, golfers transfer weight to the right leg, and the lower body begins downswing while the upper body and the club continues to backswing (Pink, Jobe, & Perry, 1990). Studies have found that skilled golfers transfer more weight in a shorter period of time than do non-skilled golfers during the downswing (Wallace, Graham, & Bleakley, 1990).

In essence, men perform their driver swing by utilizing peak pelvic, hip, and knee angles in the sagittal and frontal axes, while women perform their driver swing by utilizing peak pelvic and hip angles in the vertical axis.

2. Comparison of joint moment according to gender

Joint moments during the golf driver swing by sex are shown in Tables 4 and 5.

There was a significant difference in the flexor moment in the right hip during the backswing between men (-1.10±0.18 Nm/kg) and women (-0.75±0.34 Nm/kg) (t=-3.020, p=.007). In the downswing phase, men showed a higher extensor moment (-2.51±0.37 Nm/kg) than that of women (-1.90±0.38 Nm/kg) (t=-3.761, p=.001) and higher abductor moment of the right hip (1.06±0.34 Nm/kg) than that of women (0.57±0.20 Nm/kg) (t=3.945, p=.001). Men also showed a significantly higher pronator moment of the right hip in the downswing (-0.93±0.24 Nm/kg) than that of women (-0.54±0.14 Nm/kg) (t=-4.472, p=.000).

These results are in line with previous findings that the right hip adductor moment in the backswing phase is correlated with club head speed (Haigh, Stewart, & Urwin, 2010), left rotation of the hip increases the momentum of the club head (Kim, 2008), and the hip performs most of the lower body's role in the sagittal and coronal planes (Ball & Best, 2012). These results suggest that male golfers use large right flexor moment in the backswing and aggressively uses the lower body to transfer the weight to the targeted direction during the downswing.

There was a significant difference of left hip pronator moment in the backswing phase between men (0.28±0.09 Nm/kg) and women

Table 4. Comparison of joint moment during backswing (unit, N/kg)

Joint	Axis	Peak position	Male (*N*=11) M ± SD	Female (*N*=10) M ± SD	*t*	*p*-value
Right hip	X	Flexor	-1.10±0.18	-0.75±0.34	-3.020	.007**
	Y	Abductor	-0.70±0.18	-0.63±0.27	-.628	.537
	Z	Internal rotator	0.23±0.13	0.15±0.11	1.601	.126
Left hip	X	Flexor	-1.01±0.14	-0.82±0.27	-2.036	.056
		Extensor	-0.27±0.21	0.15±0.23	1.274	.218
	Y	Abductor	-0.19±0.15	-0.07±0.13	-1.957	.065
	Z	Internal rotator	0.28±0.09	0.19±0.18	2.418	.026*
Right knee	X	Flexor	0.32±0.13	0.20±0.18	1.775	.092
Left knee	X	Extensor	0.53±0.10	0.35±0.30	1.890	.074
Right ankle	X	Plantar-flexor	-0.57±0.15	-0.47±0.19	-1.344	.195
Left ankle	X	Plantar-flexor	-0.43±0.06	-0.33±0.15	-1.927	.079

Table 5. Comparison of joint moment during downsiwng (unit, N/kg)

Joint	Axis	Peak position	Male (*N*=11) M ± SD	Female (*N*=10) M ± SD	*t*	*p*-value
Right hip	X	Extensor	-2.51±0.37	-1.90±0.38	-3.761	.001**
		Flexor	0.75±0.45	0.44±0.34	1.711	.103
	Y	Abductor	1.06±0.34	0.57±0.20	3.945	.001**
		Adductor	-0.86±0.27	-0.84±0.22	-.213	.834
	Z	Internal rotator	-0.93±0.24	-0.54±0.14	-4.472	.000***
		External rotator	0.48±0.13	0.39±0.18	1.351	.193
Left hip	X	Extensor	-1.29±0.33	-0.70±0.36	-3.927	.001**
		Flexor	1.15±0.29	1.23±0.22	-.699	.493
	Y	Adductor	-0.73±0.20	-0.40±0.20	-3.838	.001**
		Abductor	0.88±0.34	1.02±0.36	-.928	.365
	Z	Internal rotator	-0.59±0.14	-0.52±0.19	-1.060	.303
Right knee	X	Flexor	-0.98±0.13	-0.52±0.22	-5.964	.000***
Left knee	X	Extensor	2.00±0.34	1.23±0.57	3.826	.001**
Right ankle	X	Plantar-flexor	-0.83±0.21	-0.74±0.30	-.818	.423
Left ankle	X	Plantar-flexor	-1.00±0.29	-0.58±0.31	-3.172	.005**

(0.19±0.18 Nm/kg) (t=2.418, p=.026) and between left hip extensor moment in the downswing between men (-1.29±0.33 Nm/kg) and women (-0.70±0.36 Nm/kg) (t=-3.927, p=.001). In addition, men had a significantly higher peak left hip adductor moment (-0.73±0.20 Nm/kg) than that of women (-0.40±0.20 Nm/kg) (t=-3.838, p=.001).

Previous studies on the roles of the hip in the golf swing reported that hip adductor moment is correlated with club head speed and hip joint moment plays a crucial role in increasing club head speed (Kim, 2008; Ball & Best, 2012; Haigh et al., 2010; Han, 2016).

In the present study, men showed a significantly higher pronator moment in the backswing phase, but men and women showed a similar overall swing pattern. In the downswing phase, men showed a greater peak extensor moment than women, which suggests that men strive to generate greater GRF to easily transfer angular moment to the upper body. In the frontal axis, men showed a significantly greater adductor moment than women, demonstrating that golfers rotate the left hip to the left in the early downswing phase and male golfers generate high pelvic moment in this phase.

With regard to the knee joint, there were no significant differences in the backswing phase, but in the downswing, men showed significantly greater right and left knee extensor moments (-0.98±0.13 Nm/kg and 2.00±0.34 Nm/kg, respectively) than women (-0.52±0.22 Nm/kg and 1.23±0.57 Nm/kg, respectively) (t=-5.964, p=.000, and t=3.826, p=.001, respectively). The downswing phase in which the peak extensor moment in the left knee joint occurs first, after which the knee joint is bent, is a phase to prepare to transfer the weight to the target direction while extending the knees. Men showed significantly greater moment in this phase. The same was true for the right knee joint as well, which seems to suggest that male golfers try to generate GRF and transfer the center of mass easily using the extensor moment of the knee joint. Women show smaller angular momentum in the knee during the swing due to the differences of Q-angle between men and women (Mizuno et al., 2001), and this difference poses a disadvantage for women in terms of the peak knee moment.

With regard to the ankle joints, men and women did not show significant differences in peak joint moment in the backswing phase. In the downswing phase, however, men showed a significantly greater left ankle flexor moment (-1.00±0.29 Nm/kg) than women (-0.58±0.31 Nm/kg) (t=-3.172, p=.005).

In men, the greatest joint moment in the lower body during the driver swing occurred in the right hip extensor (-2.51±0.37 Nm/kg), followed by left knee extensor (2.00±0.34 Nm/kg), left hip flexor (-1.29 ±0.33 Nm/kg), and left hip extensor (-1.29±0.33 Nm/kg), and all of them occurred in the downswing phase. In women, the greatest joint moment occurred in the right hip extensor (-1.90±0.38 Nm/kg), followed by left knee extensor (1.23±0.57 Nm/kg), left hip extensor (1.23±0.22 Nm/kg), and left hip abductor (1.02±0.36 Nm/kg). These results are in line with the findings of a previous study on the physiques of golf players (Yoon, 1998), where leg and hip strengths were most strongly correlated with swing speed (r=0.60). In addition, a previous report by Kim and Joo (2008) that the right hip generates the greatest force in the sagittal and frontal axes during the downswing also supports our findings.

In essence, men used a greater joint moment than women in right hip flexion and left hip rotation during the backswing and greater joint moment for right hip extension, abduction, and pronation, left hip flexion and adduction, and right knee flexion and extension in the downswing phase. These findings suggest that men performed more efficient swings than women using the lower body and GRF based on their relatively greater gluteal, femoral, and lower leg strengths.

CONCLUSION

This study was a comparative group one-shot case study that analyzed the golf driver swing of 21 professional golfers using three-dimensional motion analysis and GRF systems in order to analyze the biomechanical variables of the driver swing. Joint angles and moments were analyzed in the backswing and downswing, and the following conclusions were drawn.

Men performed their driver swing using peak pelvic, hip, and knee joint angles in the sagittal and frontal axes, while women showed peak pelvic and hip joint angles in the vertical axis with their driver swing focused on pelvic and hip joint rotation around the vertical axis.

With regard to joint moments during the golf driver swing, men demonstrated greater joint moments than women in the right hip extensor, abductor, and pronator, left hip flexor and adductor, and right knee flexor and extensor during the downswing phase. This result indicates that male players performed swings utilizing lower body strength and GRF based on their greater gluteal and femoral strengths.

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