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Effect of slope change on kinematics of amateur golfers' full swing

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Abstract.
BACKGROUND: Golf courses are designed with uneven terrain. These factors are especially important when facing (slope), players need to straighten the posture of each part of the body in order to complete the swing on an inclined surface such as flat ground. Amateur players may be more likely to change the movement patterns of their shots due to uneven terrain. Therefore, it may be necessary to clarify the shot characteristics of amateur players and provide reference materials for technical improvement.
OBJECTIVE: The purpose of this study was to examine the effect of slope on amateur golfers' swing kinematics by analyzing the variation of time variables, body center of gravity (COG), and shot parameters of amateur golfers' swing at different ground slopes.
METHODS: Six male amateur golfers participated in the experiment. The 7-iron was used for 5 swings each at three slopes: flat ground (FG, 0°), ball below foot (BBF, $+10^\circ$), and foot below ball (FBB, -10°). The OptiTrack-Motion capture system was used to collect kinematic data, and the three-dimensional motion data will be transmitted to Visual3D software for subsequent data analysis such as golf swing division and body COG changes. Shot parameters (carry, swing speed, ball speed, and smash factor) were recorded for each swing using the Caddie SC300 radar monitoring device.
RESULTS: The results showed that there was no difference in the overall swing time and the time required for each interval at different slopes ($p > 0.05$) there is no significant difference in the change of the COG of the body in the forward and backward directions ($p > 0.05$). The three slopes of swing speed, ball speed, carry and smash factor were not significantly different ($p > 0.05$).
CONCLUSION: The rhythm of the amateur golfer's swing was not affected by the slope, but the slope restricts the movement of the body's COG, which may affect the weight movement, and ultimately cause the performance parameters to not reach the level of the FG.

Keywords: Golf swing, center of gravity, slopes

1. Introduction

Golf as a popular outdoor recreational sport, in the world about 55 million people were involved in this sport [1]. The reason why golf was enjoyed by more and more people was not only because of the fun of the game [2], but also because of its health benefits [3,4], and it had no restrictions on the gender, skill level and age of the sports crowd [5,6].

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As participation in the sport of golf increases, so does the need for high-level athletic performance. In order to improve motor skills, more and more scholars have carried out related research on golf biomechanics [7–12], most of which were carried out in closed laboratory environment and choose flat ground. However, real golf courses were generally designed around topography, incorporating natural features such as trees, sand, ponds and ground slopes [13]. These factors make the sport more challenging, especially when faced with uneven terrain (slopes), found It seriously affects the player's stability and sports performance [14–16].

According to coaching literature [17], when facing a slope, players need to adjust the width of the stance and the flexion of the torso. The change of the golfer's stance width directly affects the area of the support base, which may affect the stability of the body. In addition, the center line of the human body (line of gravity) moves to a lower area due to the change of the support surface formed by the soles of the feet [18]. This change in the center position will change the functional factors of the muscles, and finally manifest as deformation of the movement [19]. Therefore, it is necessary to adjust the posture of each part of the human body in order to complete the swing on the slope like on the flat.

Several previous studies have investigated the effects of ball position changes and slope on golf swing kinematics and kinetics [12,14,20,21]. However, no studies related to the FG, BBF and FBB slopes were found. Sung Eun Kim et al. [10] studied the impact of small changes in ball position at impact on the golf swing and found that the weight distribution of the left foot in the left ball position was greater throughout the golf swing compared to the reference ball position, The whole-body center of mass was more toward the target, and the right-side ball position had the opposite trend, and they believe that the initial hitting position causes a series of knock-on effects throughout the swing. A previous study [22] selected 8 college golfers with a handicap of 5 or less as subjects, and examined the motion characteristics of golf swings on the flat, uphill, and downhill slopes. It was found that changes in body center of gravity displacement, in the anterior and posterior axis, increased by 30–40% on the downhill slope than on the flat slope, and increased by 20–24% on the uphill slope than on the flat slope. On the left and right axis, on the downhill slope moves the center of gravity to the left by 22% more than on the flat slope. Both Blenkinsop et al. [23] and Hiley et al. [24] studied changes in center of pressure (COP) motion and shot outcomes when golfers play golf from flat, uphill, and downhill slopes. The results all found that the slope had an effect on the change in the center of pressure during the full swing, but the speed of the ball was not affected. Similarly, a study [25] examined the swings of 3 KPGA players and 3 KLPGA players according to the difference in the slope of the ground (flat, uphill, and downhill), and concluded that the swing action on the inclined plane may be a factor that hinders the lower body cooling during the backswing, and also negatively affects the lower body blocking and subsequent release during the downswing with minimal weight distribution.

So far, the prior research on golf swings has found that most of the research on golf has analyzed professional golfers as the research object [10,14,26]. According to previous research results [27,28], low handicap golfers have better balance than high handicap golfers, which may suggest that high-handicap golfers may be more likely to alter the movement patterns of their shots due to uneven terrain [23]. Amateur golfers account for a large proportion of the golf population [1]. Therefore, there is more attention may be needed to reveal the characteristics of amateur players' shots, provide reference for their technical improvement, and avoid related injuries.

Therefore, this study selects amateur golfers as the research object, with the purpose of revealing three different ground slopes for golf swings: FG (0°), FBB (+10°) and BBF (−10°). kinematic changes over time. To help amateur golfers complete the correct swing on the slope to provide useful scientific basis data.

Table 1
Subject characteristics

Characteristics	Mean ± SD
Age (yr)	51.33 ± 9.75
Height (cm)	171.00 ± 4.73
Body mass (kg)	68.83 ± 5.08
Handicap	18.50 ± 1.64
Experience(yr)	7.2 ± 6.85

Fig. 1. Experimental environment.

2. Method

2.1. Research subjects

The subjects of this study were 6 right-handed recreational golfers (Table 1). The skill level of the participants was self-reported based on the USGA Handicap. Participants received an explanation of the experimental protocol and provided informed consent before testing.

2.2. Experimental tools and procedures

Participants were asked to hit the ball to the net (specification: length 5 meters * width 2 meters * height 5 meters) at a distance of 3 meters (see Fig. 1). Five hits are performed under the FG (0°), FBB (+10°) and BBF (−10°) three slopes (see Fig. 2). Participants used their own 7 irons, gloves and shoes, and the golf balls used Titleist.

This study used an OptiTrack-Motion (Oxford Indicators Ltd, UK) capture system for kinematic data acquisition, which included 13 high-speed cameras with a sampling frequency of 360 hz. 57 reflective markers were placed on the participants (see Fig. 3), and static models were created for the subjects prior to the experiment. After the static model was built, 3 reflective markers were placed on the subject's club in order to determine the swing phase later. After that, a club model was established, and the club model was established and handed to the subjects. The subjects would swing at three slopes, and the equipment operator would observe the screen to ensure the effectiveness of each swing. After the experiment, the 3D motion data will be transferred to Visual3D software (C-Motion, USA) for subsequent data analysis such as body center of gravity changes. The body center of gravity trajectory in the global coordinate system was transformed by the local coordinate system based on the address position to eliminate the influence of the initial setting attitude [16].

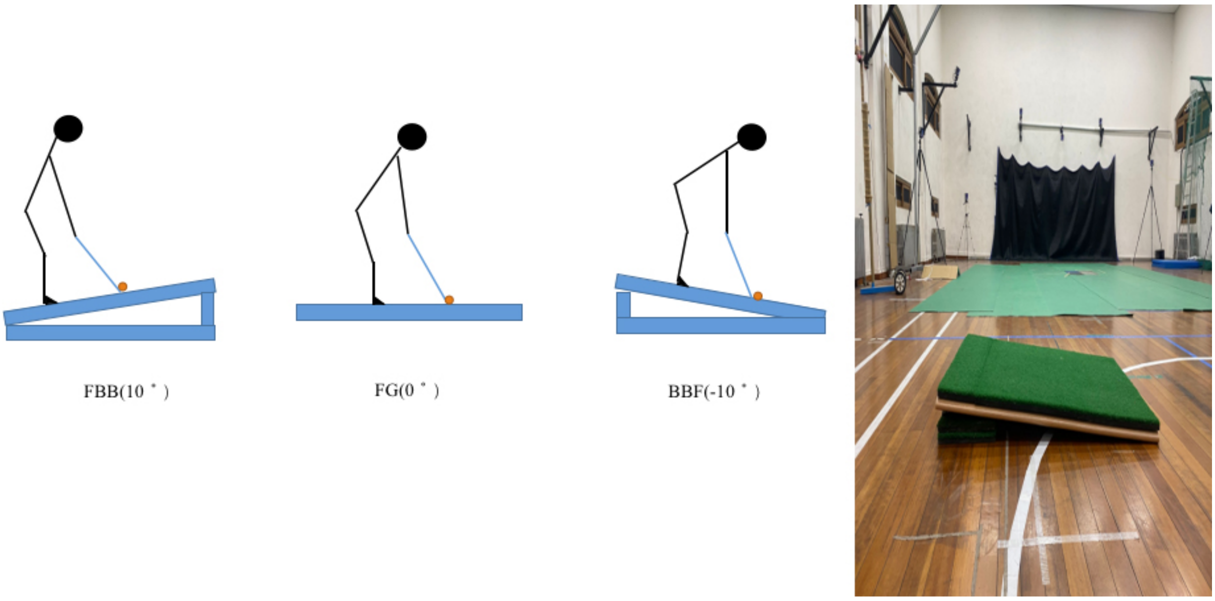

Fig. 2. The left side is the Side view of three slopes, and the right is the set slope (the bottom side is 118 cm long, the hypotenuse is 120 cm, the height is 20.8 cm, and the width is 80 cm).

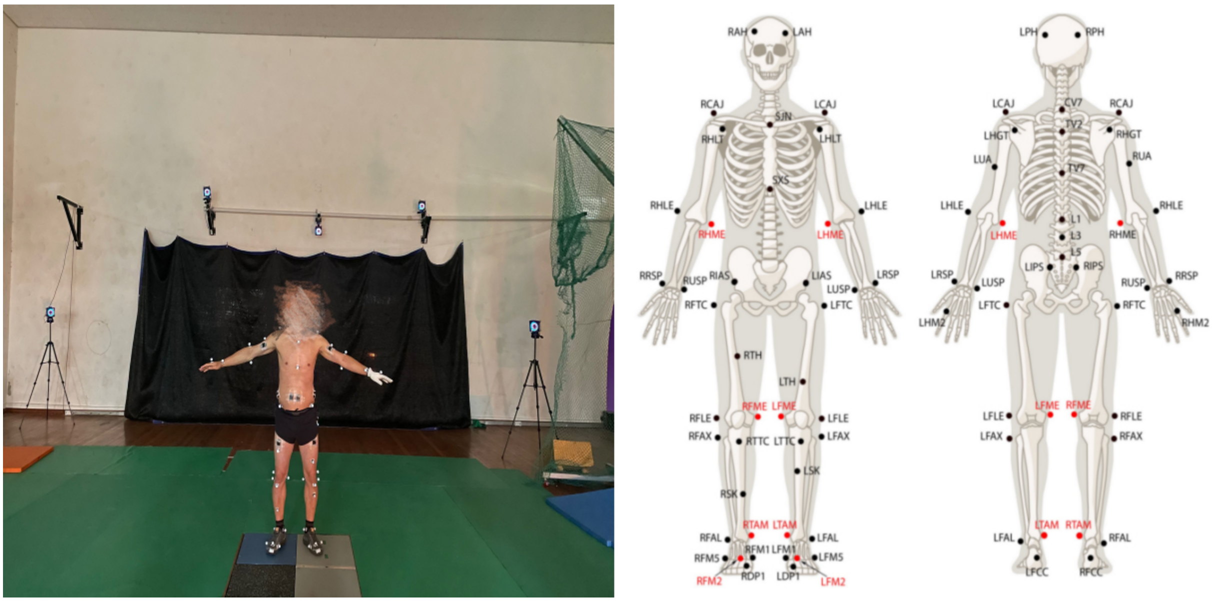

Fig. 3. Reflective marker attachment location. Motive (NaturalPoint Inc., OR, USA) placed 57 markers on landmarks to build predefined models.

During the experiment, a Caddie SC300 radar monitoring device (VC, South Korea) was used to record the carry, swing speed, ball speed, and smash factor of each swing. The launch monitor needs to be placed 1.2 meter behind the golf ball and towards the golfer's target line. After hitting the golf ball each time, take a photo with a mobile phone and mark the file name in the corresponding Motive. After the

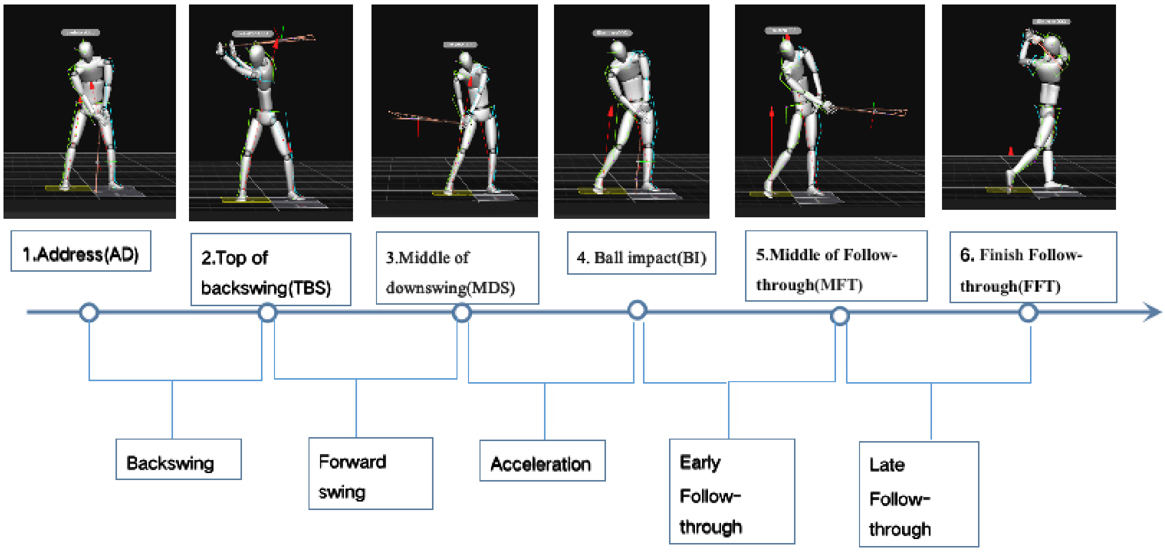

Fig. 4. Phase division.

experiment was over, record the swing performance parameters in an Excel sheet and perform subsequent calculations.

2.3. Swing phase division

A golf swing was divided into the following five phases [29,30]: (1) Back Swing (BS) – from the address of the ball to the top of the backswing; (2) Forward Swing (FS) – from the top of the backswing to the middle of the downswing; (3) Acceleration (ACC) – from the middle of the downswing to ball impact; (4) Early Follow-Through (EFT) – from ball impact to the middle of follow-through; (5) Late Follow-Through (LFT), from the middle of follow-through to the finish of follow-through. For each swing, there were six time lines: address (AD)-the moment the club head starts to move, top of backswing (TBS)-the moment the club shaft stops at the top of the backswing, middle of downswing (MDS)-the moment when the club shaft was parallel to the ground in the downswing, ball impact (BI)-The moment the clubhead impacts on the ball, middle of follow-through (MFT)-the moment when the club shaft was parallel to the ground during the follow through, finish follow-through (FFT)-the moment when the swing was completed (Fig. 4).

2.4. Statistical analysis

Data were processed in Prism Statistical Software 9.0 (GraphPad Corporation, CA, USA) software. Swing time was analyzed using descriptive statistics, and all performance variables were analyzed by one-way repeated measures ANOVA for statistical significance. Bonferroni post hoc contrast was applied to conduct pairwise comparisons between slopes. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Comparison of the time requires under different slopes

The total swing times for FG, BBF and FBB slopes were 1.93 $\pm$ 0.22 s, 1.98 $\pm$ 0.23 s and 1.97 $\pm$

Table 2
Swing time parameters for different slopes (mean ± SD, seconds)

	Backswing time	Downswing time	Follow-through time	Total time
Flat ground (FG)	1.09 ± 0.13	0.36 ± 0.06	0.48 ± 0.1	1.93 ± 0.22
Ball below feet (BBF)	1.08 ± 0.21	0.36 ± 0.03	0.53 ± 0.12	1.98 ± 0.23
Feet below ball (FBB)	1.12 ± 0.16	0.35 ± 0.05	0.49 ± 0.09	1.97 ± 0.17
ANOVA:				
F value	0.09	0.05	0.34	0.07
p-value	0.913	0.951	0.716	0.933
Post-hoc	–	–	–	–

Note: Differences in comparison are indicated by $^{*}p < 0.05$.

Table 3
Center of gravity displacement changes in the forward/backward direction (unit, m)

	AD-TBS	TBS-BI	AD-BI	MAX-MIN
Flat ground (FG)	0.03 ± 0.03	0.02 ± 0.01	0.03 ± 0.01	0.04 ± 0.02
Ball below feet (BBF)	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.04 ± 0.02
Feet below ball (FBB)	0.02 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.03 ± 0.01
ANOVA				
F value	0.51	2.49	1.44	0.35
p-value	0.63	0.16	0.31	0.72
Post-hoc	–	–	–	–

Note: Differences in comparison are indicated by $^{*}p < 0.05$.

0.17 s, respectively. There was no significant difference in the total swing time among the three slopes ($F = 0.07$, $p = 0.933$). In addition, there was no significant difference in the proportion of swing at each phase between flat ground, high ball low and ball high and low slope (Backswing time: $F = 0.09$, $p = 0.913$; Downswing time: $F = 0.05$, $p = 0.951$; Follow-through time: $F = 0.34$, $p = 0.716$). The time ratio of backswing and downswing is about 3:1 (Table 2).

3.2. *Comparison of changes in body center of gravity (COG)*

The overall displacement of the body's center of gravity in the forward-backward directions was within 0.04 m on average (FG: 0.04 m, BBF: 0.04 m, FBB: 0.03 m), and the body's center of gravity changes very little with the gradient, but if we observe the change of the displacement trajectory, we can find that, compared with the FG slope, both the BBF and FBB slopes show a backward movement of the body's center of gravity at the beginning of the backswing phase (Table 3) (Fig. 5).

The center of gravity change pattern in the lead-trail direction (for a forehand, the lead side is the target side) shows the most typical "V" form. The difference between the maximum and minimum peak displacement changes, the FG slope was 0.15 m, the BBF slope was 0.11 m, and the FBB slope was 0.12 m. It was shown that the center of gravity shift on FG slopes was larger than that on slopes. From the top of the backswing to the moment of hitting the ball, the center of gravity of the body moved 0.08 m on the FG slope, BBF 0.07 m, and FBB 0.06 m (Table 4). In addition, we found from the results that the position of the center of gravity of the body at the moment of hitting the ball was closer to the lead side, that was, the target side (Fig. 5), relative to the initial position of the ball.

In the upward-downward direction, the FG, BBF and FBB slopes moved 0.03 m, 0.01 m and 0.03 m respectively from the initial position to the moment of impact (Table 5). The results showed that on the flat ground, the body's center of gravity shifted up and down more (Fig. 5).

Table 4
Center of gravity displacement changes in the lead/trail direction (unit, m)

	AD-TBS	TBS-BI	AD-BI	MAX-MIN
Flat ground (FG)	0.07 ± 0.04	0.08 ± 0.07	0.03 ± 0.01	0.15 ± 0.07
Ball below feet (BBF)	0.05 ± 0.02	0.07 ± 0.04	0.02 ± 0.02	0.11 ± 0.04
Feet below ball (FBB)	0.05 ± 0.04	0.06 ± 0.04	0.01 ± 0.01	0.12 ± 0.03
ANOVA				
F value	0.22	0.1	1.38	0.37
p-value	0.81	0.9	0.32	0.7
Post-hoc	–	–	–	–

Note: Differences in comparison are indicated by $^{*}p < 0.05$.

Table 5
Center of gravity displacement changes in the upward/downward direction (unit, m)

	AD-TBS	TBS-BI	AD-BI	MAX-MIN
Flat ground (FG)	0.04 ± 0.03	0.03 ± 0.03	0.03 ± 0.01	0.1 ± 0.01
Ball below feet (BBF)	0.05 ± 0.02	0.03 ± 0.02	0.02 ± 0.01	0.08 ± 0.01
Feet below ball (FBB)	0.05 ± 0.02	0.02 ± 0.02	0.03 ± 0.02	0.09 ± 0
ANOVA				
F value	0.05	0.07	0.51	4.87
p-value	0.95	0.93	0.63	0.06
Post-hoc	–	–	–	–

Note: Differences in comparison are indicated by $^{*}p < 0.05$.

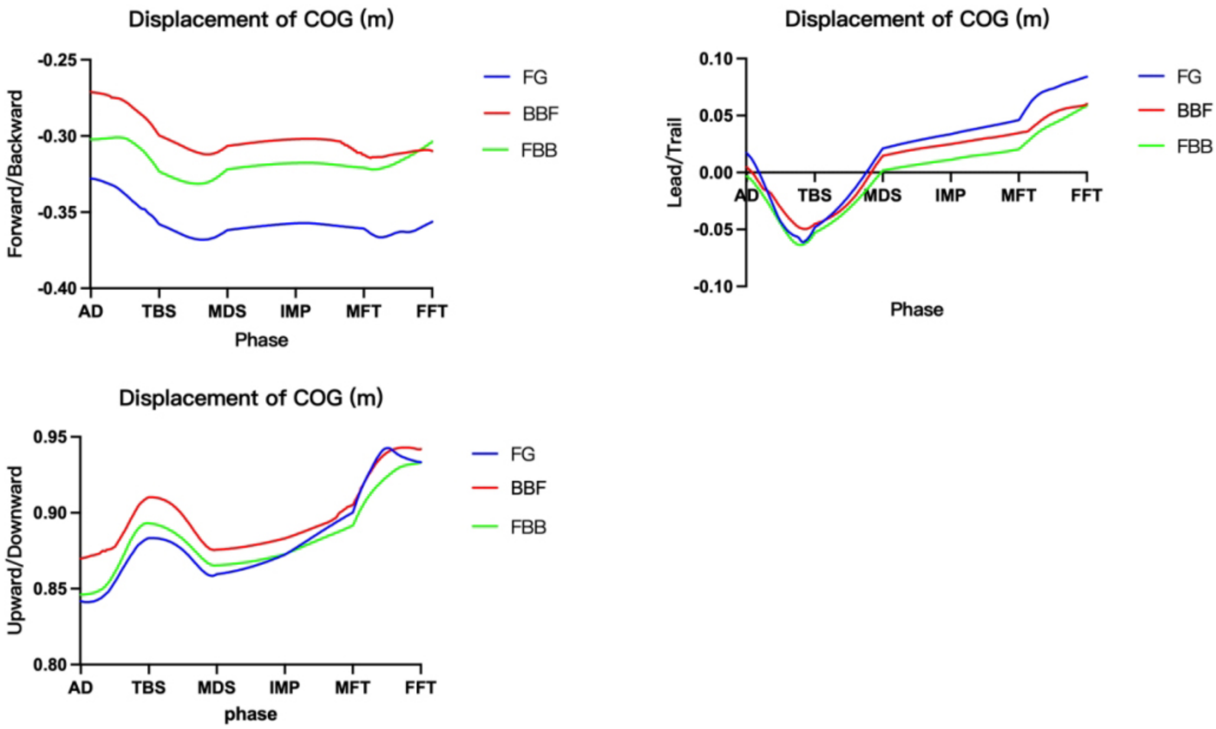

Fig. 5. Represents the change of the displacement trajectory of the center of gravity of the body in the forward/backward, lead/trail (for a forehand, the lead side is the target side) and upward and downward directions during the swings.

Table 6
Hit parameter results for FG, BBF, and FBB measured by launch monitor (mean ± SD)

	Ball speed (mph)	Swing speed (mph)	Carry (yards)	Smash factor
Flat ground (FG)	102.2 ± 4.8	75.2 ± 4.3	139.9 ± 8.7	1.36 ± 0.07
Ball below feet (BBF)	97.0 ± 8.9	71.5 ± 4.6	130.5 ± 17.7	1.36 ± 0.07
Feet below ball (FBB)	92.6 ± 7.9	69.8 ± 4.9	123.0 ± 16.3	1.33 ± 0.09
ANOVA:				
F value	2.5	2.1	2.0	0.3
p-value	0.115	0.156	0.173	0.692
Post-hoc	–	–	–	–

Note: Differences in comparison are indicated by $^{*}p < 0.05$.

3.3. Comparison of batting parameters

There were no significant differences in the hit parameters among the three slopes (Ball speed: $F = 2.5$, $p = 0.115$; Swing speed: $F = 2.1$, $p = 0.156$; Carry: $F = 2.0$, $p = 0.173$; Smash factor: $F = 0.3$, $p = 0.692$). The ball speed on the FG was 5.2 mph faster than on the BBF and 9.6 mph faster than on the FBB, and the ball speed on the BBF was 4.4 mph faster than on the FBB. The swing speed on the FG was 3.7 mph faster than on the BBF and 5.4 mph faster than on the FBB. On the BBF was 1.7 mph faster than on the FBB's swing speed. The carry on the FG was 9.4 yards farther than on the BBF, 16.9 yards farther than on the FBB, and on the BBF was 7.5 yards farther than on the FBB. The smash factor on the FG was 0.01 higher than on the BBF, 0.04 higher than on the FBB, and the smash factor on the BBF was 0.03 higher than on the FBB (Table 6). The smash factor on the FG and BBF was the same as 1.36, which was 0.03 larger than that of FBB (Table 6).

4. Discussion

The aim of this study was to examine the influence of slope on swing kinematics in amateur golfers, and to explain the impact of uneven stance and corresponding stroke strategy.

Examining the time variable found that, depending on the inclination, the overall required time ranged from 1.71 to 2.21 seconds, and the overall required time did not differ according to the inclination. This result was similar to 1.80 $\sim$ 1.90 seconds [21] and 1.7 $\sim$ 2.24 seconds [20]. Judging from the time required for each phase, there was no significant difference between the swing time of the FG slope and the swing time under other slope conditions. The time ratio of the backswing to the downswing was about 3:1, which was similar to research that the average rhythm ratio of the backswing and the downswing was 57.5:20.5% [14]. In the follow-through phase, on the FG takes less time than on the other two slopes. The FG and the FBB used relatively less time than the BBF slope in the follow-through phase. The reason may be that the BBF slope limited the movement of the lower extremity joints and thus affected the rotation of the body. According to the coaching literature [31], the knee will tend to bend more when facing the BBF, although This was good for maintaining the position to make the shot more solid, but it may affect the release of the upper body due to the limitation of the lower body [32]; in addition, when facing the FBB slope, because this slope will bring the ball closer to body, which was It makes body position more upright, and starting the swing in this position results in a flatter or more rounded swing plane, like a baseball swing. This can cause more spin in the hands and arms during impact, causing the club face to close faster on the downswing, so it doesn't have much impact on club release.

Overall, there was no significant difference in the proportions of swings between FG, BBF and FBB slopes ($p > 0.05$). According to the above results, there was no difference in the overall swing time of different slopes and the time required for each interval, which proves that the swing rhythm of amateur golfers was not affected by the slope.

Regarding the body's center of gravity, the average displacement of the body's center of gravity in the forward-backward direction was in the range of 0.04 m. The results of the present study were basically similar to the forward-backward body's center of gravity change found in a previous study [14], which was about 0.03 m. Therefore, the center of gravity of the body changes very little with the displacement before and after the slope. However, if observe the change of the displacement trajectory, we can find that, compared with the FG slope, the center of gravity of the body moves backwards at the initial phase of the backswing for both the BBF and FBB slopes. The difference in directionality may reflect a tendency for amateur golfers to lean back due to movements such as upper body lifts or excessively bent knees.

The COG of the body change pattern in the lead-trail direction (for a forehand, the lead side is the target side) shows the most typical "V" pattern. The difference between the maximum and minimum peak displacement changes, On the FG slope was the largest (FG 0.15 m > FBB 0.12 m > BBF 0.11 m), indicating that the COG on the FG slope moves more than it does on the other two slope. From the top of the backswing to the moment of hitting the ball, the COG of the body moves the most on the FG slope (FG 0.08 m > BBF 0.07 m > FBB 0.06 m). Plagenhoef believes that the COG should move in the direction of impact during the downswing, from the beginning of the hem to the end of the impact, in order to achieve a sufficient transfer of the COG [33]. Although the COG shift on the FG slope relative to the other two slopes changes more in the lead-trail direction, according to a previous study by Choi et al. [27], the optimal weight change may be a factor that increases the displacement of the body's COG in the lead-trail direction, so this does not necessarily lead to loss of balance during the swing. In addition, we found from the results that the position of the COG of the body at the moment of hitting the ball was closer to the lead side, that is, the target side, at the moment of hitting the ball, indicating that the transfer of the COG has been completed at the moment of hitting the ball.

In the upward-downward direction, from the address position to the moment of hitting the ball, the result was displayed on the FG, and the COG of the body shifts more (FG 0.03 m > FBB 0.03 m > BBF 0.01 m). The reason why the COG of the body changes in the upward-downward direction may be because the arm drives the club to swing upward during the backswing, and then the weight moves from the downswing to the moment of hitting the ball. When there was a slope, may have an impact on the golfer's backswing range, so that the golfer cannot achieve a larger backswing like on the FG, so the result of a large change in the displacement of the upper body's COG.

Observing the hitting performance parameters, it was found that there were significant differences in ball speed and carry between on the FG and FBB (on the FG was 9.58 mph faster than FBB's ball speed; on the FG was 16.89 yards farther than FBB's carry). This was basically similar to the results of a previous study [14], which showed that compare to on the flat ground, club head speed was reduced by an average of 5% and 7% on the slope of downhill and uphill, respectively. And the ball speed decreased by an average of 1.3% and 4%, respectively [34] did a similar study and found that as the ground inclination increases, the carry distance, the vertical launch angle of the ball, and the flying height of the ball decrease. Unlike our study, the results of Hiley et al. showed no statistical difference in ball speed and hitting distance between the three slopes [24]. The reason may be that they studied a slope of 5°, Smaller slopes may have less effect on hitting parameters. There was no significant difference between the three slopes of swing speed and smash factor.

5. Conclusion

This study examined the changes in the kinematics of amateur golfers as they swing at three slopes and draws the following conclusions:

First, there was no difference between the overall swing time of different slopes and the time required for each interval, which proves that the swing rhythm of amateur golfers was not affected by the slope.

Second, although the forward-backward displacement of the body's COG varies slightly with different slopes, it shows a difference in directionality; the lead-trail displacement is larger than the displacement of the COG of the other two slopes, which indirectly shows that Optimum weight transfer. In addition, the position of the COG with the three slopes at the moment of impact was closer to the lead side, that is, the target side, relative to the initial position of the impact; upward-downward displacement, the COG displacement changes more on the FG than the other two slopes, it may be because the slope limits the golfer's backswing range, which affects the COG change.

Third, in terms of batting parameters, there was no significant difference between the three slopes of Swing speed, ball speed, carry and Smash factor.

To sum up, although the rhythm of the amateur golfer's swing was not affected by the slope, the slope restricts the movement of the body's COG, which may affect the weight movement, and ultimately cause the hitting parameters to not reach the level of the flat ground, so it is recommended that when hitting the ball in the face of uneven conditions, you can choose a bigger club (7 to 6) to reduce the loss in distance.

Acknowledgments

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Conflict of interest

None to report.

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