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Relationship Between Variability in Clubhead Movement Using a Doppler Radar Launch Monitor and Golf Strokes Across 15 Driver Shots

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ABSTRACT

Background: Due to individual patterns of body and clubhead movement in golf, a uniform assessment method has been considered difficult. **Objective:** This study aimed to establish a statistical model that can assess a player's shot performance in a short time by analyzing the relationship between the golf strokes and their clubhead movement data. **Methods:** In this cross-sectional, observational study, we analyzed the clubhead movement data of 15 driver shots (three sets of five shots) by 14 amateur golfers (AGs) and 14 skilled golfers (SGs). After performing warm-up, participants used their own drivers to hit at a crosshair-shaped target positioned in an indoor driving range. Data were captured for each parameter relating to clubhead movement at the moment of impact using the Doppler radar launch monitor (FlightScope X3). **Results:** Face-to-target angles showed significant interactions between three conditions (Set 1, Set 2, and Set 3) and two groups (AGs and SGs); SGs consistently displayed smaller angles in every set than their amateur counterparts ($p<0.5$). A post-hoc test further increased the discrepancy between Sets 2 and 3 for AGs and SGs. In addition, a strong correlation was found between each participant's average number of strokes and the mean clubhead speed (CHS) across 15 driver shots. A stepwise multiple regression analysis indicated that CHS was a significant predictor of a player's average number of strokes. **Conclusion:** SGs achieved extremely accurate clubface control during multiple hits with a high CHS. We found no trade-off relationship between a higher CHS and smaller face-to-target opening/closing in SGs.

Key words: Golf, Sports Equipment, Athletic Performance, Motor Activity, Radar

INTRODUCTION

In explaining technical factors related to golf shots, many top golf coaches have advocated a variety of swing plane theories and swing techniques in golf magazines worldwide (Jenkins, 2007; Nesbit et al., 2019). Meanwhile, academic research in sports science has shown advancements in analyses based on kinematic data obtained from the displacement and angles of the body segments of participants in detailed high-speed camera images (Cheetham et al., 2001; MacKenzie, 2012). Attempts have been made to assess golfers' swings using inverse dynamics with ground reaction force information to compute kinetic data represented by power and joint torque (McGuigan, 2017), and easily installable ground reaction force measurement systems such as the Balance Plate have been popularized and introduced in indoor studios (Shepherd et al., 2020). In addition, a variety of Doppler radar-based launch monitors have been developed in recent years to visualize and quantify the ball path and clubhead movement resulting from the ball being struck (Penner, 2002; Toms, 2017). The measurements of high-speed cameras and launch monitors are highly reliable, and the discrepancy in precision between them has been shown to be negligible (Leach et al., 2017). To date, it has been necessary to manually digitize the images obtained from high-speed cameras, resulting in a long-time lag before players can receive feedback on their club movement and ball path. However, using launch monitors now makes it possible to receive instant data feedback.

In contrast to the ever-evolving measurement devices, it is difficult to determine what rapid improvements or progress have been made in the golfer techniques. This is partly because various devices are used only transiently in the field, yet provide so much data that players cannot determine the ideal values for themselves (McLean & Kolloff, 2021). It is

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also unclear which readings should be focused on and the over-provision of trend data can sometimes lead to technical confusion for players (Jorgensen, 1999; Nesbit et al., 2019). Coaches have their own ways of using such data as well. No clear and simple method of assessment that can serve as a gold standard has been found, and notably, few findings have been published in the related literature. Therefore, it is important to establish a methodology that aggregates multiple-shot results from both amateur golfers (AGs) and skilled golfers (SGs), including professional players, to derive certain rules and evidence related to golf ability (Suzuki et al., 2019). To assess a player's shot abilities in terms of different levels, TrackMan devised the TrackMan Combine Test (McLean & Kolloff, 2021), which is the one and only test. However, while it assesses a player's number of total strokes over a total of 60 shots consisting of shots randomly designated at 60–180-yard distances and two sets of three driver shots, the test requires multiple clubs, and even if only 30 seconds were spent on each shot, the test would take more than 40 min. Therefore, these tests are only available outdoors and are time-consuming, thus impractical for indoor golf lessons, which are becoming increasingly common worldwide.

However, a study that measured performance across multiple driver shots advocated using the second-farthest shot out of five or the third-farthest out of nine (the third quartile for assessment) (Broadie, 2008). This study also pointed out that rarely-occurring "awful shots" are a major factor that worsens AGs' strokes, and even if the third-quartile method is used to set benchmarks for performance, shot consistency cannot necessarily be assessed accurately. Similarly, Suzuki et al. (2021) compared uphill and downhill drive trajectories using the average of three shots for each player. To date, analyses of golf shots have used different numbers of shots and different parameters depending on what was being analyzed.

Eighteen holes for a round of golf are laid out so that, as a rule, the front nine and back nine each have two par-three holes. Therefore, a player will have 14 holes in the fairway, with considerably important shots (Suzuki et al., 2020). In terms of flight distance, AGs have a greater disadvantage than SGs and often use drivers for tee shots. However, despite the fact that tee shots achieved with a driver by AGs exhibit an approximate 50-yard difference in flight distance compared to those of Professional Golfers' Association (PGA) pro-tour players, they have more than twice the variance in landing position, which indicates poor accuracy (Broadie, 2008). As such, trouble with tee shots is likely to be a factor that ultimately worsens players' strokes. Conversely, Fradkin et al. (2004) showed that a 5-week intervention of warm-up exercises, 5 times a week, just before a round of golf in 20 AGs improved clubhead speed (CHS) by 3-6 (m/s). Hence, CHS is an important factor in improving golf performance.

Regarding full-body movement variability, Kudo et al. (2000) asked participants to throw a ball at a static target with their nondominant hand and found that consistency in bodily movement is not necessary to achieve consistent results, indicating that there are individual differences in movement, even for simple actions. Bartlett et al. (2007) showed that this variability even exists in full-power throwing actions such as javelin throwing, warning that coaching methods instructing athletes to copy the techniques of world champions precisely are meaningless and instead advocating the promotion of training methods that value and reproduce each individual's movements. For this reason, it is necessary to consider that there is no single correct way to move and assess human movement because of the individual patterns that exist. However, it should be possible to assess players in a uniform way if their golf swings are assessed according to factors related to the swing at the moment of impact, that is, the face angle required for a straight shot. If this perspective is to be introduced in actual coaching, establishing a method of analysis that requires less time and burden on the players and that can be used with various measurement devices is important.

Golf performance is evaluated in terms of strokes. In previous studies irrelevant factors for AGs and SGs, such as prize money and ranking, have been the independent variables of focus in multiple regression analyses of golf strokes, and the results present information they cannot utilize (Broadie, 2014; Pfitzner & Rishel, 2005). Therefore, the objective of this study was to establish a statistical model that can assess a player's shot performance in a short amount of time by analyzing the relationship between the golf strokes of AGs and SGs and their clubhead movement data during 15 driver shots.

METHODS

Participants and Study design

We compared two groups of golfers in a cross-sectional, observational study. Shot performance data was collected and compared over a specified time period in subjects with large differences in golfing skill. This study used statistical analysis to determine the relationship between a player's average number of strokes (the dependent variable) and five clubhead movement parameters (the independent variables). A priori power analysis was performed using G*Power version 3.1 (Faul et al., 2007) for sample size estimation, based on data from a preliminary experiment results, which compared between AGs and SGs. The effect size in the study was 2.21, which was considered to be large based on Cohen's (1988) criteria. With a significance level of $\alpha = 0.05$ and power = 0.95, the minimum sample size needed with this effect size was N = 14 for a statistical model that could assess a player's shot performance in a short time by analyzing the relationship between golf strokes and their clubhead movement data. For better understanding we have doubled the sample size. Thus, the selected sample size of N = 28 was more than adequate to test the study hypothesis.

The golfers in the AG group had values (mean ± standard deviation [SD]) of height (165.6 ± 28.9 cm), weight (72.6 ± 10.6 kg), and golf stroke (94.2 ± 6.3). In addition, those in the SG group had values (mean ± SD) of height (175.4 ± 7.6 cm), weight (73.9 ± 8.3 kg), and golf stroke (74.5 ± 2.6). The average strokes were obtained from the participants' self-attested average number of strokes at their most-frequented golf courses over the past year. A-grade members of the PGA of Japan and tour members were included in the SG group in this study; those who did not meet these qualifications were excluded from the study.

We distributed written explanations to each participant detailing the content of the study, which was approved by the Academic Research Ethical Review Committee at Tokyo International University (2018–15), and recorded measurements of those who agreed to provide written consent after giving them a verbal explanation of what would be measured. To prioritize respect for human rights and safety during all phases of research involving human participants, we abided by the principles of the Declaration of Helsinki in terms of the protection of human rights. We also explained that participation in the study was not mandatory and that participants could withdraw from the study even after initially providing consent (Harriss et al., 2019).

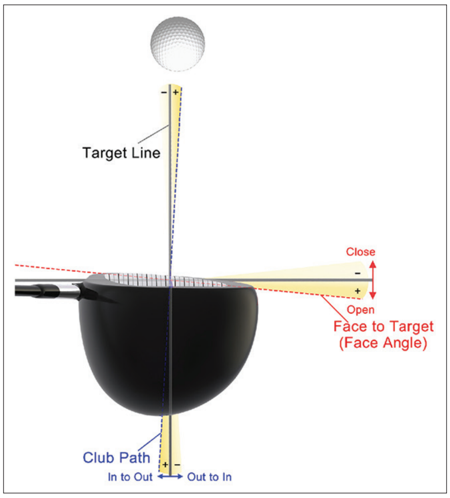

Figure 1. Definitions related to the face-to-face target and club-path angle (example: the face-to-target is 5° [open] and the club path is 3° [in-to-out])

Procedure and Data Acquisition

This study was conducted entirely at an indoor golf facility to eliminate the effect of air temperature and wind. After performing warm-up exercises and hitting practice shots, participants used their own drivers to hit five shots at a cross-hair-shaped target positioned in front of them. Each set consisted of five shots with a 1-minute break between sets, and we used a total of three sets to reflect the number of driver shots a player could expect to shoot in a single round of golf. We instructed the participants to imagine that they were hitting tee shots on an actual outdoor course and to carefully address the ball and swing accurately for each shot. In conducting the experiment, we did not show the participants the readings taken by the device until the measurements were complete, so they would not know their results. We used the Doppler radar launch monitor, called FlightScope X3 (Flight Scope Orlando, FL, USA), to obtain the ball trajectory and clubhead movement readings. The validity of the Doppler radar launch monitoring data has been confirmed in studies comparing the output data from high-speed cameras and launch monitors in three-dimensional movement analyses (Leach et al., 2017; Sweeney et al., 2009).

In this study, we assessed the movement of the club at the moment of impact based on the following parameters: CHS (m/s), face-to-target angle (º), club path angle (º), face-to-path angle (º), and attack angle (º). The angle data are defined such that a clockwise rotation around the central axis (clockwise from 0º) is expressed as a positive number and a counterclockwise rotation is expressed as a negative number (Figure 1). A face-to-target angle of 0º denotes a square face on impact, while a positive value denotes an open face (rotation to the right, for a right-handed golfer) and a negative value denotes a closed face (rotation to the left). The club path angle is a value that indicates the lateral path of the swing from just before impact through impact, with a positive value denoting inside-out and a negative value denoting outside-in. The face-to-path angle is an indicator calculated by subtracting the club path angle from the face-to-target angle and determines how open the club face is in relation to the club path at the moment of impact; a negative value means that the club face faces to the left of the club path, and a positive value means that the club face faces to the right of the club path. The attack angle was the incidence vertical angle of the club, with a negative value denoting a downward angle and a positive value denoting an upward angle. Regarding the face-to-target and club path angles at the moment of impact, we took into account the fact that some golfers may have a tendency to hit draw shots or fade shots, and since positive and negative data will cancel each other out if they co-occur, we took the absolute value of the raw values obtained before performing statistical processing on the data (Johansson et al., 2015).

Data Analyses and Statistics

To assess the stability of the measurements obtained using the CHS across 15 shots by AGs and SGs, we performed an analysis using the intraclass correlation coefficient (ICC). An ICC of 0.75 or greater is considered to denote satisfactory reliability (Fleiss, 2011). We tested the significance of the five clubhead movement readings for the AGs and SGs using unpaired t-tests for each group's combined results from the mean data of 15 shots.

Next, we performed a two-factor repeated measures analysis of variance (ANOVA) on three sets of five shots for AGs and SGs, i.e. three conditions (Set 1, Set 2, and Set 3) × two groups (AGs and SGs). When the two-way interaction between a condition and group was significant, the Bonferroni post-hoc test was used for multiple comparisons among Sets 1–3 or AGs and SGs. In addition, we used the coefficient of variation ([CV]: individual SD/individual mean) to perform significance testing for AGs and SGs in shot variability. To confirm whether the data satisfied the assumption of homoscedasticity in the t-tests, we performed Levene's test, and if the significance level was greater than 5%, we used the result that assumed homoscedasticity.

To quantitatively assess the magnitude of inter-variable effects, we used Cohen's d as the effect size, with sample variance (0.20, small; 0.50, medium; 0.80, large) (Cohen, 1988). Furthermore, we performed a simple regression analysis using Pearson's correlation coefficient to investigate the correlations between CHS, absolute mean value of clubhead movement, and average stroke. Then, to predict the average stroke from these five parameters, we performed a forward-backward stepwise selection method with the average stroke as the dependent variable and the other readings as independent variables. The variance inflation factor (VIF) was used to check for the presence of multicollinearity, which was considered to be present if the VIF was 5 or greater, and multicollinearity did not occur (Daoud, 2017). The statistical significance level was set at 5%. IBM SPSS Statistics version 27 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses.

RESULTS

An inter-trial CHS reliability analysis revealed a variance ratio (F-value) of 0.376 (P = 0.980, > 0.05) among AGs, which indicated no difference between trials, and a very high ICC of 0.974. The F-value among SGs was 0.870 (P = 0.593, > 0.05), which indicated no difference between trials, and the 0.871 ICC was very high.

We performed unpaired t-tests on all parameters between the AGs and SGs, and the results are shown in Table 1. CHS tended to be significantly higher among SGs, the face-to-target and face-to-path angles tended to be significantly smaller among SGs, the club path angle tended to be significantly smaller among AGs, and the attack angle tended to be significantly larger among SGs.

The two-factor repeated ANOVA test results between the condition and group in terms of the mean data for each participant were determined There was no significant difference in the main effects of condition; however, the main effects of group for face-to-target and face-to-path of SGs were all significantly smaller than the AG values (Table 2). This indicates that SGs tended to hit with smaller variability, despite the fact their CHS was significantly higher. The results of the two-way interaction for face-to-target between the condition and

Table 1. Unpaired t-test for mean values of clubhead movement across 15 shots and average stroke between AGs and SGs

	AG		SG		*t (418)*	*P*	AG vs SG	95% CI		ES
	M	*SD*	*M*	*SD*				*LL*	*UL*	Cohen's d
CHS (m/s)	41.6	4.3	48.8	2.2	-21.72	0.00	AG<SG	-7.88	-6.57	-2.12
Face to target (º)	3.5	2.4	2.3	1.8	5.71	0.00	AG>SG	0.78	1.59	0.56
Club path (º)	3.1	2.4	3.8	2.4	-3.12	0.00	AG<SG	-1.20	-0.27	-0.30
Face to path (º)	4.1	3.4	2.5	1.9	6.05	0.00	AG>SG	1.11	2.18	0.59
Attack angle (º)	3.3	2.1	4.8	2.6	-6.33	0.00	AG<SG	-1.89	-0.99	-0.62
Average stroke (strokes)	94.2	6.3	74.5	2.6	42.09	0.00	AG>SG	18.79	20.64	4.11

AG, amateur golfer (n = 14); CHS, clubhead speed; CI, confidence interval; ES, effect size; LL, lower limit; M, mean; SD, standard deviation; SG, skilled golfer (n = 14); UL, upper limit

Table 2. Results of two-way analysis of variance for three sets of five shots between AGs and SGs

	Condition	Group				Main effect		Interaction
	Set	AG		SG		Condition	Group	Condition×Group
		M	*SD*	*M*	*SD*			
CHS (m/s)	1	41.5	4.2	48.7	2.3	F (2, 414) = 0.07	F (1, 414) = 467.23	F (2, 414) = 0.01
	2	41.6	4.3	48.9	2.0	*P* = 0.93	*P* = 0.00	*P* = 0.99
	3	41.6	4.4	48.9	2.3	—	AG<SG	—
Face to target (º)	1	3.3	2.1	2.6	2.0	F (2, 414) = 0.36	F (1, 414) = 33.10	F (2, 414) = 4.47
	2	3.2	2.6	2.4	1.8	*P* = 0.70	*P* = 0.00	*P* = 0.01
	3	4.1	2.3	2.0	1.6	—	AG>SG	**
Club path (º)	1	2.9	2.3	3.8	2.6	F (2, 414) = 0.42	F (1, 414) = 9.64	F (2, 414) = 0.09
	2	3.2	2.2	4.0	2.4	*P* = 0.66	*P* = 0.00	*P* = 0.91
	3	3.2	2.7	3.8	2.4	—	AG<SG	—
Face to path (º)	1	4.1	3.9	2.5	1.9	F (2, 414) = 0.12	F (1, 414) = 36.34	F (2, 414) = 0.16
	2	3.9	3.1	2.4	1.8	*P* = 0.89	*P* = 0.00	*P* = 0.86
	3	4.3	3.2	2.4	2.1	—	AG>SG	—
Attack angle (º)	1	3.2	2.1	4.7	2.6	F (2, 414) = 0.15	F (1, 414) = 39.70	F (2, 414) = 0.03
	2	3.4	2.0	4.8	2.6	*P* = 0.86	*P* = 0.00	*P* = 0.97
	3	3.3	2.1	4.8	2.6	—	AG<SG	—

**P < 0.01; Abbreviations: AG, amateur golfer (n = 14); CHS, clubhead speed; M, mean; SD, standard deviation; SG, skilled golfer (n = 14) group were significantly different ($F [2, 414] = 4.47$, $P = 0.01$, $\eta_p^2 = 0.00$). Therefore, the Bonferroni post-hoc test was applied, and the significance for Set 2 and Set 3 was smaller for SGs than for AGs ($P = 0.024$ and $P = 0.000$, respectively) (Figure 2). The unpaired t-test for the CV of clubhead movement across 15 shots between AGs and SGs showed no significant differences among all parameters (Table 3).

In the correlation analysis among CHS, the absolute value of clubhead movement and average stroke demonstrated that CHS, face-to-target, club path, face-to-path, and attack angle were all correlated with the average stroke at a 1% significance level, indicating that a higher CHS and greater precision in three-dimensional clubhead movement resulted in lower average strokes (Table 4). In particular, the correlation coefficient between average stroke and CHS was $r = -.746$, a strong correlation ($p < .01$).

The multiple regression analysis determined a significant regression line with five independent factors, modeled as [$Y = 153.17 + (-1.51_{x1}) + (0.67_{x2}) + (-0.45_{x3}) + (-0.47_{x4}) + (0.33_{x5})$, ($_{x1}$: CHS, $_{x2}$: face-to-target, $_{x3}$: attack angle, $_{x4}$: club path, $_{x5}$: face-to-path), $F = 126.75$, $P = 0.000$]. These five independent variables were significant predictors of the dependent variable (average stroke) and explained 60% of the dependent variable ($R = 0.778$). The standard error of the estimate was 6.94 strokes (Table 5). CHS alone explained 56% of the dependent variable ($R = 0.746$) in model 1 (Table 5).

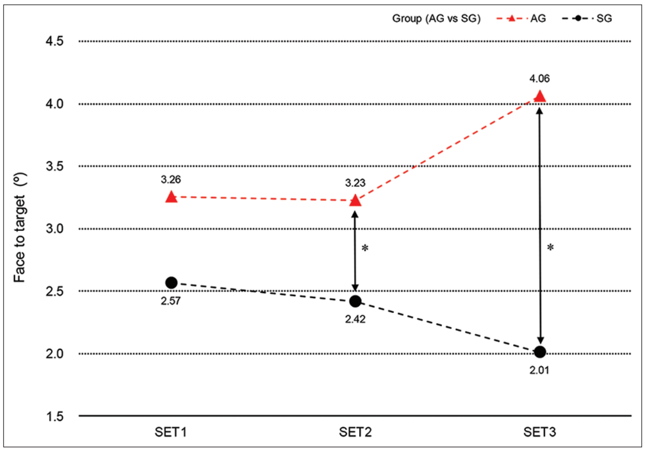

Figure 2. Comparison of face-to-target angle between AGs and SGs with 3 sets of 5 shots AG, amateur golfer; SG, skilled golfer; $^*P < .05$

DISCUSSION

In this study, the ICC of CHS across 15 shots was high for both AGs and SGs, which indicated the validity of the data and that fatigue and learning effects would not influence the data even if the number of shots was increased. Furthermore, CHS was significantly higher among SGs. The absolute values of the SGs' mean face-to-target and face-to-path angles across the 15 shots were significantly smaller than those of the AGs. That is, SGs exhibited a CHS that was approximately 7 m/s faster than AGs, while also displaying less openness/closedness in relation to the line of the target and extremely low variance in performance. However, although the absolute values of the SGs' club path and attack angle tended to be fairly large, their SD variability was low. The CV of CHS was extremely small: 0.03 for AGs and 0.01 for SGs. Although the CHS of the two groups differed greatly, it was observed that both groups maintained stable swing speeds. In particular, the cause of the large CV of AGs in the other parameters may have been the lack of control of clubface movement in an attempt to make the ball fly farther. In addition, Sell et al. (2007) also reported that high-handicap golfers' value were worse than low-handicap golfers on a single-leg standing balance test. Hence, we speculated that AGs will be required to train for lower legs balance control against high swing speeds. The average stroke was found to correlate strongly with CHS and was chosen in the stepwise multiple regression analysis. Model 5 was chosen to explain approximately 60% of the average stroke. Therefore, if players increased one point in CHS, they decreased by approximately -1.5 strokes. In the next analysis, face-to-target was selected. In contrast, if there was a one-point increase in the face-to-target, 0.67 strokes was revealed (Table 5). It should be noted that a difference of more than 20 strokes was observed between the average strokes of the AGs and SGs. In other words, 56% of the average stroke can be explained by the CHS in Model 1, confirming that this was a very important factor at the moment of ball impact (Table 5). In addition, the results for face-to-target suggest that consistent face control when using a driver for tee shots is extremely important for controlling an average stroke. From the above results, we found no trade-off relationship between a higher CHS and smaller face-to-target opening/closing in SGs.

Johansson et al. (2015) analyzed four handicap groups in terms of the one driver shot out of five that resulted in their median ball carry distance and found that both the ab-

Table 3. Unpaired t-test for the coefficient of variation of clubhead movement across 15 shots between AGs and SGs

	AG		SG		*t (26)*	*P*	AG vs SG	95% CI		ES
	M	*SD*	*M*	*SD*				*LL*	*UL*	Cohen's d
CHS (m/s)	0.03	0.04	0.01	0.01	1.39	0.18	—	-0.01	0.04	0.53
Face to target (°)	0.71	0.26	0.59	0.23	1.30	0.21	—	-0.07	0.31	0.25
Club path (°)	0.54	0.33	0.34	0.22	1.90	0.07	—	-0.02	0.42	0.28
Face to path (°)	0.80	0.20	0.67	0.18	1.80	0.08	—	-0.02	0.28	0.19
Attack angle (°)	0.49	0.27	0.31	0.25	1.81	0.08	—	-0.02	0.38	0.26

AG, amateur golfer (n = 14); CHS, clubhead speed; CI, confidence interval; ES, effect size; LL, lower limit; M, mean; SD, standard deviation; SG, skilled golfer (n = 14); UL, upper limit

Table 4. Correlation analysis among CHS, the absolute value of clubhead movement, and average stroke

Measure	1	2	3	4	5	6
1. CHS (m/s)	—	-0.112*	0.051	-0.229**	0.204**	-0.746**
2. Face to target (º)	-0.112*	—	0.196**	0.349**	-0.155**	0.238**
3. Club path (º)	0.051	0.196**	—	0.312**	0.133**	-0.099*
4. Face to path (º)	-0.229**	0.349**	0.312**	—	-0.055	0.265**
5. Attack angle (º)	0.204**	-0.155**	0.133**	-0.055	—	-0.279**
6. Average stroke (strokes)	-0.746**	0.238**	-0.099*	0.265**	-0.279**	—
Mean	45.2	2.9	3.5	3.3	4.0	84.4
Standard deviation	5.0	2.2	2.4	2.9	2.4	11.0

Intercorrelations for amateur golfer and skilled golfer (total: n = 28) are presented. **p < 0.01, *p < 0.05. Means and standard deviations in the horizontal rows. CHS, clubhead speed

Table 5. Regression analysis results predicting average stroke from each clubhead movement data

	B	SE B	β	T	P	R^2 (Adjusted R^2)	VIF
Model 1						0.56 (.56)	
CHS	-1.65	0.07	-0.75	-22.92	0.00		1.00
Model 2						0.58 (.58)	
CHS	-1.61	0.07	-0.73	-22.84	0.00		1.01
Face to target	0.78	0.16	0.16	4.89	0.00		1.01
Model 3						0.59 (.59)	
CHS	-1.56	0.07	-0.71	-22.06	0.00		1.05
Face to target	0.70	0.16	0.14	4.43	0.00		1.03
Attack angle	-0.51	0.15	-0.11	-3.48	0.00		1.06
Model 4						0.60 (.59)	
CHS	-1.56	0.07	-0.70	-22.07	0.00		1.05
Face to target	0.79	0.16	0.16	4.91	0.00		1.09
Attack angle	-0.45	0.15	-0.10	-3.07	0.00		1.09
Club path	-0.36	0.14	-0.08	-2.51	0.01		1.07
Model 5						0.60 (.60)	
CHS	-1.51	0.07	-0.69	-21.05	0.00		1.11
Face to target	0.67	0.17	0.14	4.02	0.00		1.18
Attack angle	-0.45	0.15	-0.10	-3.07	0.00		1.09
Club path	-0.47	0.15	-0.10	-3.14	0.00		1.17
Face to path	0.33	0.13	0.09	2.51	0.01		1.30

B, partial regression coefficient; β, standard partial regression coefficient; CHS, clubhead speed R^2, coefficient of determination; SE B, standard error; VIF=variance inflation factor

solute value and spread of the face angle (face-to-target) were smaller in the lower handicap group. In our study, we statistically analyzed multiple shots that were closer to a formal round, but the tendency was similar. Broadie (2014), used "accuracy in degrees offline" to express, as an angle, the precision of a driver shot hit in the field with regard to how far the landing position of the ball was from the target; the simulation analysis calculated that a 1° improvement in accuracy reduced players' strokes per round by 0.8 for PGA tour players, 0.9 for players scoring in the 90s, and 1.0 for players scoring in the 100s (Broadie & Ko, 2009). This indicates that if the face-to-target angle of each participant in our experiment was reduced by 1°, there was a fairly strong probability their mean strokes would have decreased.

To date, it has been difficult to keep players motivated even when using measuring devices that can capture the clubface data of their golf shots, because they do not provide a way to set numerical goals for practice or force players to engage in routine practice (Renshaw et al., 2020). However, the assessment indices in this study would make it possible to set specific numerical goals, thereby possibly increasing players' motivation to practice, and also be used to assess consistency and accuracy in actual coaching situations without having to rely on the subjective perspective of the coach or the player.

Regarding the way the ball will curve once it is hit, the D-plane theory advocated by Jorgensen (1999) states that if the face-to-path angle is calculated from the difference between the face angle and club path at the moment of impact, then a larger face-to-path angle means that the ball will curve more dramatically in mid-air. In our study, SGs swung the club toward the target at a somewhat wider angle than AGs but had a significantly smaller face-to-path angle, which suggests AGs used motor control to regulate the variability of the width of the curve of the ball in mid-air and make it narrower. It should be noted that some of the SGs in this study simply squared their club face and directed their club path toward the target to hit as straight a shot as possible, while others excelled at hitting draw and fade shots to control the ball curve width. Accordingly, one way for an AG to reach a high skill level may be to increase the accuracy of their face control in a typical shot.

A previous study revealed that flight distance and lateral accuracy at the target position were significantly negatively correlated and that the better a player is at long drives, the greater is the lateral accuracy (Broadie, 2014). SGs have also been reported to exhibit less variability in CHS than AGs, even when applying a putting movement that involves a much slower CHS than a driver shot (Hasegawa et al., 2017). While different clubs are used for every shot in golf, SGs are considered to apply affordance, the ability to perceive the environment even in situations that require different CHSs, and the ability to hit the ball at an appropriate speed and angle and with a square club face regardless of the type of club (Suzuki et al., 2021). SGs simultaneously achieve two results that contradict one another from the perspective of kinematics (Fitts' law) (Fitts, 1954). Although it is expected that a player would be able to reproduce a square impact more easily when swinging at a lower CHS, as noted in AGs, this is actually not the case. The evidence of this study revealed the possible cause of the technical plateau in AGs.

From recent advancements in launch monitors, we can understand how difficult it is for golfers to contact the ball with a perpendicular clubface blade, regardless of the speed of the swing. This is universally important evidence for golf. Therefore, what causes a player not to be able to contact the ball squarely upon impact? Naturally, this is an effect of individual physical characteristics such as musculature, range of motion, and training methods, not something that can be easily described. However, it may be possible to trace cause-and-effect relationships to determine the cause. Impact can be considered a result of the preceding swing phase. If there is an issue with the club face at the moment of impact, then there is an issue with the downswing, which is a preceding step. If there is an issue with the downswing, then there is an issue with the top of the swing, which is one further step back. Golfers should make an effort to find the cause by going further back through to the backswing, takeaway, and address the static position, including the grip (Renshaw et al., 2020; Renshaw et al., 2010).

In golf, often a player who cannot squarely impact the ball has more fundamental issues with their address and grip. Studies on grip include one in which the same driver was fitted with grips in 15º increments from –30º (weak) to +30°(strong), and a Doppler radar launch monitor was used to measure the data (D'Arcy et al., 2021). That study showed that changing the way the left hand grips the club changes the clubface angle, even for the same swing, and that the left-right sideways deviation of where the ball lands changed in a similar way to the grip angle. AGs often struggle to improve their shot trajectories because they overlook their address and grip and try to find the cause in their downswing or the top of their swing. AGs must first reexamine the basics of their address and grip, which are close to the source of the cause, and SGs must develop their physical abilities in a comprehensive way so that they can exercise face control even at a high CHS.

Study Limitations

This study has some limitations. First, this study only analyzed players' performance with the driver. This was to avoid inconsistencies that can surround iron clubs, such as the likelihood that AGs miss their shots because they hit the top of the ball or the ground behind the ball. Second, although we speculated that SGs have less ball impact location variance on the clubface, this was not investigated. It would be important to examine in detail where the ball is impacting at the clubface area in the future. Last, this study only looked at SGs at the national level; we believe that expanding the study to include international SGs would further enhance our research.

Strength and Practical Implication of Study

We speculate that AGs are likely to have poorer control of their center of gravity and balance of the lower legs due to a lack of training. In addition to strengthening the torso, in recent years, golfers have introduced training using towing cables (velocity-based training) for improving their swing. We believe that developing a physical training methods combining these activities with a practical application of our models would contribute to improving the clubface control of AGs.

CONCLUSION

This study investigated the clubface angle at the moment of impact and established a statistical model that could assess a player's shot performance between AGs and SGs. We found significant differences between the clubhead movement data of AGs and SGs. SGs achieved extremely accurate face control during multiple hits with a high CHS. We conclude that this finding will help create a future model for coaches and players to understand the results of Doppler radar launch monitoring from a common view.

DISCLOSURE STATEMENT

The authors report there are no competing interests to declare.

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