Clustering Golfers through Force Plate Analysis †

Jonathan Shepherd [1,2,*], Erik Henrikson [2], Scott Lynn [3] and Paul Wood [2]

[1] School of Engineering and the Built Environment, Griffith University, Nathan, QLD 4111, Australia

[2] PING Inc., Phoenix, AZ 85029, USA; erikh@ping.com (E.H.); paulw@ping.com (P.W.)

[3] Department of Kinesiology, California State University, Fullerton, CA 92831, USA; slynn@fullerton.edu

* Correspondence: jonathans@ping.com; Tel.: +1-602-687-5640

† Presented at the 13th Conference of the International Sports Engineering Association, Online, 22–26 June 2020.

Abstract: Golf is a sport which requires players to use ground interaction to generate clubhead speed in order to propel the ball towards the target. Force platforms are a technology which can be used to measure these ground reaction forces. Golfers generate force through a combination of jumping, sliding or twisting actions during the swing. Understanding how golfers generate these forces and if there are any groups which golfers could be clustered into could be used to enhance golf instruction as well as clubhead design or fitting practices for golf equipment. A total of 105 right-handed experienced golfers (handicap mean = 8.32 ± 8.31) consented to participate in the study of different swing speeds (31 below 95 mph, 41 over 105 mph and 33 between 95 and 105 mph). A calibrated single force plate was used for the test which sampled at 1000 Hz and recorded force and moment data in three axes. After a self-guided warm up, the players were instructed to hit five 7-iron shots and five drives to the best of their ability in an indoor hitting bay which used a launch monitor to record the club delivery and ball flight information. It was found that handicap or swing speed did not dictate the primary force production mechanism (sliding, jumping or twisting/spinning). This knowledge could aid engineers to design equipment better suited to the individual and help coaches build individualized programs to create power and clubhead speed in all players.

Keywords: golf; force plate; swing classification; sport measurement; balance; power

1. Introduction

Golf is a popular sport both in terms of participation and investment, with approximately 29 million Americans playing golf (77.5% male, 22.5% female) and the average golfer investing 2800 USD annually playing the sport. As a factor in the strong golf market, new technological innovations in this sector are continually being offered. New technologies come in the form of new equipment (hard goods and soft goods) and tools aimed at quantifying and analyzing performance. One cluster of technologies that are becoming increasingly used in the sport is force or balance platforms. Balance is defined as the ability to keep the body's center of mass within the base of support [1]. Golf is a complex motor task which requires dynamic balance with motor coordination in order to correctly execute the swing [2]. In biomechanical studies, a typical metrology technique to quantify dynamic balance is using force plates during the performance of the task. Force platforms are made of a dimensionally stable board instrumented with strain gauges and hall effect or piezoelectric sensors, which quantify forces in the measurement axes and the moments around these axes [1]. Ground reaction forces (which force plates measure) are imperative in a golf swing in order to propel the ball.

Ball and Best [3] explained the possible limitations of previous force plate literature:

(1) The studies did not account for different swing styles in the golfers examined. (2) Handicap does not always correlate to swing quality. (3) The small number of examined events (top of swing/impact) limits knowledge. Ball and Best [3] used eight point of reference during each swing (take-away, mid-backswing, top of backswing, early downswing, mid downswing, ball contact,

follow through). (4) The use of 1–3 trials seen in other publications might not be enough to establish an average or typical swing.

The classification of players based on swing styles has been limited. Ball and Best [4] found two primary trends (Table 1), including a front foot group where the center of pressure (CoP) moved forward at impact, and reverse CoP style where the pressure turns around and moves towards the trail foot in the late downswing. However, for all groups the maximum CoPy velocity occurred 0.14 s prior to ball contact.

Table 1. Categorization rules for classifying someone as a front foot vs. reverse style COP (Ball and Best, 2007).

Category	CoP at Backswing	CoP at Contact
Front foot CoP style	Back foot	Front foot
Reverse CoP style	Mid stance of front foot	Mid stance

In the current literature, there has been some research performed on classifying how golfers use ground reaction forces to produce force. For example, researchers have used a principle component analysis of a golf swing to compare a small group of elite and beginner golfers to assess differences in loading patterns [5]. In the golf coaching community, coaches have also classified players into groups who generate their primary golf swing force by jumping, sliding or twisting/spinning. Some coaches advocate that a specific force production mechanism is superior over another; however, it is not known in the literature if better players fall primarily into one of these categories or what the standardized process is for clustering golfers into these categories. This study utilizes the Ball and Best [3] guidelines with a large group of players to see if players can be clustered by their primary power mechanism and if this is useful for coaching or equipment design applications.

2. Materials and Methods

2.1. Materials

A single force plate was used for the test (Bertec, Columbus, OH, USA) which sampled at 1000 Hz and recorded force and moment data in three axes using Swing Catalyst software (West Chester, PA, USA). Prior to testing, the inbuilt calibration was performed as per the manufacture's guidelines. A launch monitor (GCQuad, Foresight Sports, San Diego, CA, USA) used to collect the club and ball information was synchronized to the force plate software. This launch monitor was set up and calibrated to the manufacturer's instructions. Two synchronized high-speed cameras filming at 200 Hz were also inputted into the force plate software.

To provide knowledge of results to the players, a computer simulation software (TestFlight v2.3, PING, Phoenix, AZ, United States of America) of ball flight was used. The software takes in launch monitor data and projects a three-dimensional representation of ball flight in a simulated driving bay. This software has two modes: a driver mode, which has a small centered flag at the end of the driving range which forms the target; and a pin mode, which gives a centered island green for the players to aim for. It also has a pop-up dialog box mechanism to capture quantitative feedback after each stroke.

2.2. Pilot Study

The force plate was positioned on a rubberized hitting mat with a custom-made aluminum base plate to ensure the plate had a solid supporting base and did not move during the swing. To ensure that the data from this housing gave correct data, after a suitable warm up three elite golfers (handicap 0) were asked to hit five driver shots and five 7-iron strokes that they were subjectively "happy" with from the force plate positioned on the raw ground (concrete with carpet surface), using the rubberized mat and the custom-made housing. The results showed that the rubberized mat altered the results; however, the aluminum housing base gave the same results as the raw ground and therefore was deemed an appropriate setup for the full test.2.3. Participant Methods

The test proper used 106 right-handed golfers (handicap mean = 9.36 ± 9.21) who consented to participate in the trial. These golfers were employees of PING Inc and were made aware of the purpose of the study; they were informed that their participation was completely voluntary and had full access to their own data. The testing was conducted in an indoor hitting bay instrumented as shown below (Figure 1) with one operator observing the testing.
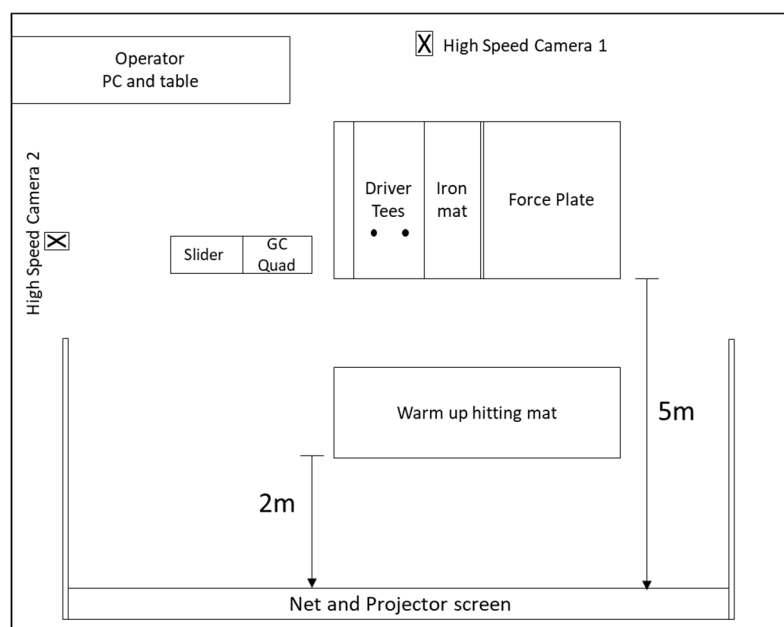

Figure 1. Experimental setup of the room.

Each player was instructed to perform a self-paced and self-conducted warm up on the front hitting zone and given a 7-iron for this period (Figure 1). There was a minimum warm up time requirement of 5 min, although this was not explicitly communicated to the players. If they wanted to stop short of this time, they were asked to continue the warm-up protocol and told the computer was not ready for data capture. This was to ensure players were "warm" to improve swing consistency. After the player reported that they were at a subjective level of being "warmed up", the golfer was then instructed to stand on the force plate and the hitting tee was adjusted to ensure it was in the correct place (both reach and tee height). The launch monitor was also adjusted to ensure the ball was centered in the monitor. The participants were instructed to hit three practice drives. During this time, the swing speed was observed and compared to the lookup table (Table 2). If the player was using the "wrong" club, the operator replaced it and they were then instructed to hit three more practice drives. This process was performed in a manner that the participants were not aware that swing speed was a decisive factor in the decision process.

Table 2. Golfers were clustered into which clubs they would be "fit" into. All the clubs were at the PING standard length and built to a blue lie color code to match the fitting specifications of most of the tested players. R—regular flex shaft; S—stiff flex shaft; X—extra stiff flex shaft.

Category	Slow	Medium	Fast
Speed	<42 m/s (95 mph)	42 m/s (95 mph)–47 m/s (105 mph)	>47 m/s (105 mph)
Driver Specifications	10.5° G400 Alta 55 R	10.5° G400 Alta CB 55 S	8.98° G400 LST Tour 65 X
Iron Specifications	30.04° G400 AWT 2.0 R	30.05° G400 AWT 2.0 S	33.00° I210 Dynamic gold ×100
Golfers	31	33	41
Handicap	17.55 ± 10.65	10.16 ± 5.64	3.13 ± 4.04

After the three drives, if the participant was not comfortable they could hit more practice drives. When they were at a subjective level of being "ready and comfortable", the five recorded data points started. After each shot, the participant was instructed to rate the shot based on their own perceptual feeling of the shot (1) completely unsatisfied, (2) unsatisfied, (3) satisfied, (4) completely satisfied.

The player was then handed the matching 7-iron and the simulator software was set to show a green and pin target on the projector, with the pin adjusted to match the player's usual 7-iron distance. The test followed the same three shot warm up protocol with the option to hit more shots if the player was not "ready and comfortable". As in the driver test, after each shot qualitative feedback was requested.

2.4. Anaylsis

A program was written in the R language using Rstudio (Boston, MA, United States) as the integrated development environment. This code combined the raw outputted files from the swing catalyst with the TestFlight captured data. It separated the swing phases and then found the COP type using the Ball and Best (2007) calculations. Following this, players were clustered by their primary force production measure. To achieve this, the players were given a percentage for each category of force production based on the tour player means derived from the Swing Catalyst software (Table 3).

Table 3. Force production cluster measure, where BW is body weight.

Measure	Jumper	Spinner	Slider
Primary Force Plane	Vertical	Twisting	Forward/backward
Tour threshold	179% bw	127.7 Nm	19.0% bw
% Player pool	32%	10%	58%

The largest ratio for each swing was then tagged as the primary force production mechanism and that was calculated per shot.

$$Primary\ Force\ Mechanism\ =\ Max \begin{cases} Jumping\ Ratio \\ Sliding\ Ratio \\ Sliding\ Ratio \end{cases} \tag{1}$$

The primary force mechanism was clustered by person, club type, club head speed, ball speed and handicap to assess whether there were any general trends.

3. Results

Players naturally create force in all planes. Figure 2 highlights these forces and the cluster of the 105 golfers' average production for both drivers and 7-irons.
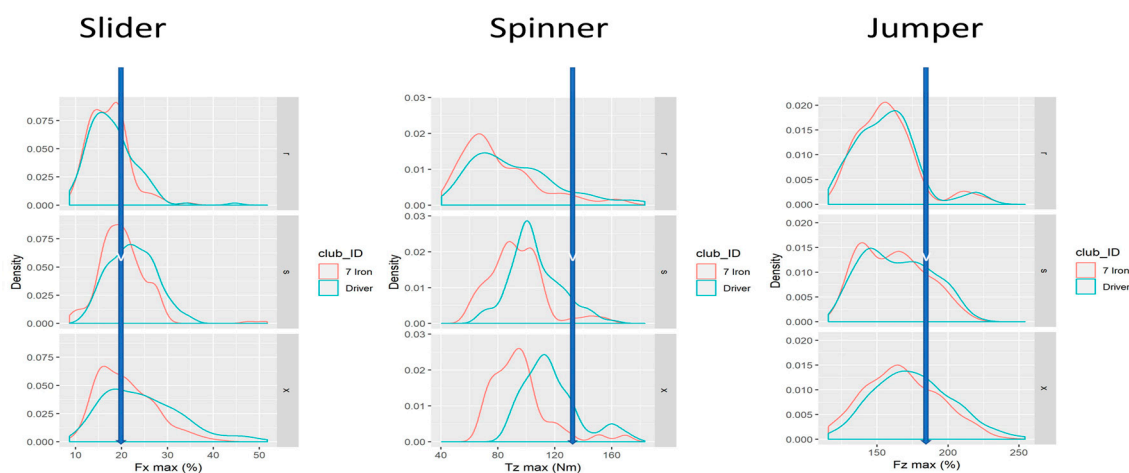

Figure 2. Density plot all the golfers' force productions differentiated by club (color) and faceted by the shaft flex. The PGA tour average threshold (blue line) is overlaid.

Some players may have a different primary force mechanism between shots, for example if they adopt different swing strategies or have similar ratios between two or three of the categories. Thus, it was investigated whether the golfers changed categories at all during the five 7-iron or five driver swings (Table 4).

Table 4. Highlighting whether people stay in the same category of primary force production between shots.

Club	Same Category	Two Categories	Three Categories
Driver	67%	32%	1%
Iron	85%	14%	1%
Combined	53%	38%	9%

Players were also clustered into each power type, grouped by the club they were using, and all binned together to see if there were any general trends (Figure 3).
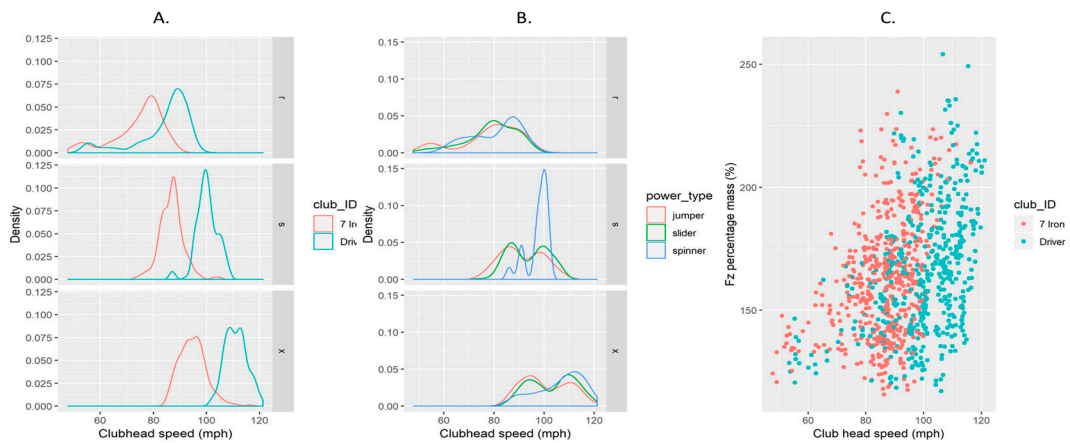

Figure 3. (**A**) Density plot all the golfers by clubhead speed against the club flex for both driver and 7-iron. (**B**) Separating each shaft group into different force productions differentiated by club (color) and faceted by the shaft flex. (**C**) Adding every shot clubhead speed as a scatter plot with percentage mass. S.

Players were also clustered by their power type (Figure 4) to see if cluster trends were evident established (Table 5).
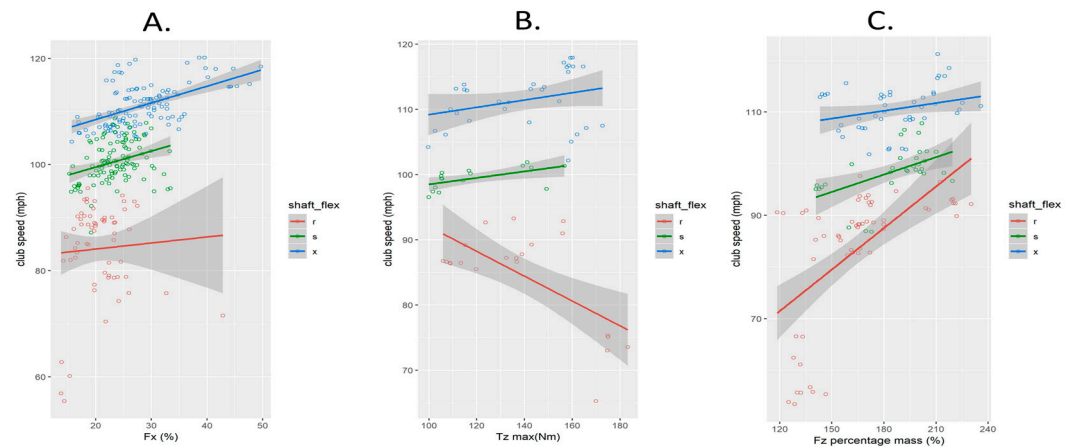

Figure 4. Above, driver-only shots are plotted. Subcategorizing each player into their primary force mechanism showing (**A**) sliders, (**B**) twisters (**C**) jumpers and plotting this factor against clubhead speed.

Table 5. Key impact factors measured through the launch monitored were paired with the power production clusters.

Factor (Units)	Group Mean	Slider	Jumper	Spinner
Face Angle (°)	0.48 ± 5.9	0.53 ± 5.4	0.96 ± 6.6	−1.44 ± 6.4
Attack Angle (°)	−0.86 ± 4.1	−0.94 ± 4.0	−1.02 ± 3.8	0.16 ± 4.4
Dispersion Area (y²)	315.41 ± 415.6	338.5 ± 448.3	227.30 ± 329.4	461.77 ± 410.2
Offline Distance (y)	−2.01 ± 22.2	−2.61 ± 23.0	0.20 ± 18.3	−5.56 ± 28.1
Club path (°)	0.32 ± 4.7	1.18 ± 4.7	−0.65 ± 4.2	−1.57 ± 5.3
Closure rate (°/s)	2643 ± 1107	2561 ± 983.4	2729 ± 1379	2857 ± 682

4. Discussion

Different handicap golfers can be found in all categories (Figure 3), with no trend to suggest that low handicappers primarily fall into one category. Furthermore, swing speeds also did not have a trend to which would be the primary force production mechanism. Most players stay in the same category for each shot; however, some players can move into two or all three of the categories. Therefore, it can be hypothesized that no one force production measure is "better" than another in terms of coaching a large group of players. This is evident in Figure 3c, where all the players are clustered together and there is no direct relationship between increasing force production in the up/down (z) jumping plane and the influence on clubhead speed. However, when an intra-cluster investigation occurs, it is shown for this cohort that increasing the force in the primary force mechanism can increase the athlete's swing speed. This could be because it is the least disruptive to timing for the player and feels more natural; however, to optimize the player's clubhead speed, it is hypothesized that this will be individualized and would not be as simple as just boosting the primary force production factor. Rather, it is a composite of all three based on the individual. Non-statistically significant trends were observed for the different groups in terms of launch monitor characteristics—for example, spinning classified golfers had a small tendency to have a higher closure rate and subsequent right/left shot bend.

5. Conclusions

It is evident that golfers can be categorized into a primary force production mechanism (jumping, spinning or twisting/sliding) by using a ratio approach based on tour average comparison. This technique could be useful in designing equipment for a specific force production group or aiding coaches to improve performance for golfers who are in one of these categories.

Conflicts of Interest: The authors declare no conflict of interest.

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