The influence of 5-iron clubhead mass distribution on clubhead presentation and initial ball launch conditions – Part II: Player tests

ES Wallace[a], TW Corke[a,b], KM Jones[a,b*], NF Betzler[c], SR Otto[b]

[a]Sport and Exercise Sciences Research Institute, Ulster University, Northern Ireland

[b]R&A Rules Ltd, St Andrews, Scotland

[c]Qualisys AB, Gothenburg, Sweden

[*]Corresponding author

Abstract

Iron clubheads can be classified as blades or perimeter-weighted, depending on the distribution of their mass. Despite the widely held views that perimeter-weighting can offer performance benefits for lesser skilled players, a direct comparison with players using these two clubhead types has not been thoroughly investigated. The aims of the study were to determine differences in clubhead presentation and ball launch between a blade 5-iron and a cavity-back 5-iron in a mixed cohort of golfers and examine trends in central tendency and variability in relation to skill for males using the blade club. Nine clubhead presentation variables and six ball launch variables were measured for 96 participants hitting shots from natural turf with each of the clubs. Group means for club effect were analysed statistically using an independent samples approach, whilst a rank-based nonparametric test was used to determine significant trends between handicap categories and ball launch conditions for the male cohort. The cavity-back displayed higher effective loft, lower effective lie and a tendency to have ball strikes closer to the centre. Higher values were also noted for the cavity-back for vertical launch angle and total spin. As expected, higher handicap male golfers showed lesser consistency and displayed slower ball speeds and lower efficiency than the more skilled players. Together these results concur with the findings in Part I in support of the theory of 'forgiveness' associated with cavity-back clubs, whilst also highlighting the over-riding importance of skill level on performance.

Keywords

Golf, iron clubheads, perimeter-weighted, performance, player variability

1. Introduction

Different iron clubhead designs are aimed at optimising ball launch conditions for a wide range of player abilities. A central difference between iron clubhead designs is the distribution of the mass within a clubhead, known as ‘perimeter-weighting’. The aim of perimeter-weighting is to increase the clubhead’s moment of inertia (MOI), providing greater resistance to twisting when ball contact occurs away from the projection of the clubhead’s centre of gravity (CG) onto the club face. Iron clubheads with mass re-distributed to the outer borders are referred to as ‘cavity-backs’, due to the cavity created by the redistributed mass, whereas clubs without a prominent cavity are known as ‘blades’. The introduction in Part I of this paper provides a review of previous research aimed at demonstrating the extent to which the inertia properties of iron clubheads were affected by relocating discretionary mass; starting with early computer modelling, followed by idealised blade and cavity-back modelling and robot and mechanical testing. In general, findings showed some potential gains in shot outcomes associated with perimeter-weighting, however the studies tended to use highly idealised models or were lacking in methodological detail.

The research undertaken in Part I of this paper investigated the effect of clubhead mass distribution on clubhead presentation and initial ball launch conditions. Two commercially available 5-iron clubs, a cavity-back and a blade, were systematically examined across a range of impact locations using a golf robot which provided consistent and highly repeatable swings. The cavity-back clubhead showed higher effective clubhead loft with greater total ball spin than the blade, whilst also providing more consistent launch results across a given range of impact locations. Evidence of the ‘gear effect' was found for the cavity-back, but not the blade, suggesting that the threshold at which the clubhead's centre of gravity (CG) is deep enough to noticeably elicit the gear effect lies between the CGs of the two 5-iron types. A further study involving player testing was suggested as a natural progression from the robot testing in Part I, as it was not known whether the performance differences observed in the highly controlled robot tests would remain tangible once human variation is introduced. Trial-to-trial differences in movement are characteristic of all human movement and occur both within and between individuals and at all levels of task familiarity and skill [1], with previous work demonstrating the link between the variability in clubhead presentation and shot outcome [2].

There are relatively few published studies on the effect of clubhead mass distribution on clubhead presentation and initial ball launch conditions involving human players. Some driver studies report findings from both modelling and/or machine tests combined with player test results. The potential advantages of increasing clubhead MOI on the outcome of a golf shot with drivers were investigated by Olsavsky [3], who used a mechanical golfer and a group of amateur golfers (handicaps: 3-18) to evaluate the performance of three drivers with different clubhead head volumes. The mechanical golfer results showed a reduction in shot dispersion variation, as measured by the resultant position of the ball, associated with an increase in clubhead volume (and consequently increased MOI) for a comparable array of impact locations on the face of each driver. The same relationship between variation in shot dispersion and driver clubhead volume was observed in the player testing. The player testing also revealed increased average efficiency (ratio of ball speed to clubhead speed) for clubheads with greater volume. This finding, although theoretically sound, is difficult to evaluate given that efficiency was not reported for the mechanical golfer tests and that neither clubhead presentation nor impact location were quantified for the player testing.

Given the lack of published scientific research on player-based performance differences between blade and cavity-back iron clubheads, the purpose of this study in Part II was to determine key differences between these two clubhead designs in a controlled field-based investigation. The present study builds on Part I of this paper, which utilised a golf robot to produce consistent and highly repeatable swings, by using human golfers across a wide handicap range with inherent levels of swing variability. The specific aims of the present study were to (i) determine the differences between a blade and a cavity-back 5-iron with respect to clubhead presentation and ball launch variables for golfers, and (ii) show trends in central tendency and variability in clubhead presentation and ball launch associated with skill level in males for the blade club.

2. Methods

Part I of the paper contains test club details and generic methods (summarised below where necessary), with methods specific to player testing presented below.

2.1. Participants

A convenience sample of 96 right-handed golfers volunteered to participate in the study (Table 1). Whilst the sample was predominantly male (*n=79*), the gender representation (M:82.3%; F:17.7%) was similar to that of the Scottish Golf Union [4] Central Database of Handicaps (M:88.2%; F:11.8%). The study was approved by the University Research Ethics board and all testing procedures were fully explained to each participant prior to giving their written informed consent.

Table 1. Number of male and female golfers per handicap category.

Category	Handicap	Male	Female	Total
1	<6	46	10	56
2	6-12	24	3	27
3 - 5	13-36	9	4	13
Total		79	17	96

** Table 1 near here **

2.2. Procedures

Tests were carried out at three outdoor locations, each with natural and maintained parkland fairway grass turf approximately 1 cm in height with a wide fairway extending at least 220 m with a target flag located 180 m from the hitting area. Shots were hit from clean flat lies on the turf. Prior to testing, the participants performed a self-directed warm-up, either hitting shots with their own clubs or either of the two test clubs - a blade 5-iron and a cavity-back 5-iron (properties presented in Paper 1, Table 1). Participants were informed that the two clubs were matched, except for the clubheads, but were given no further information.

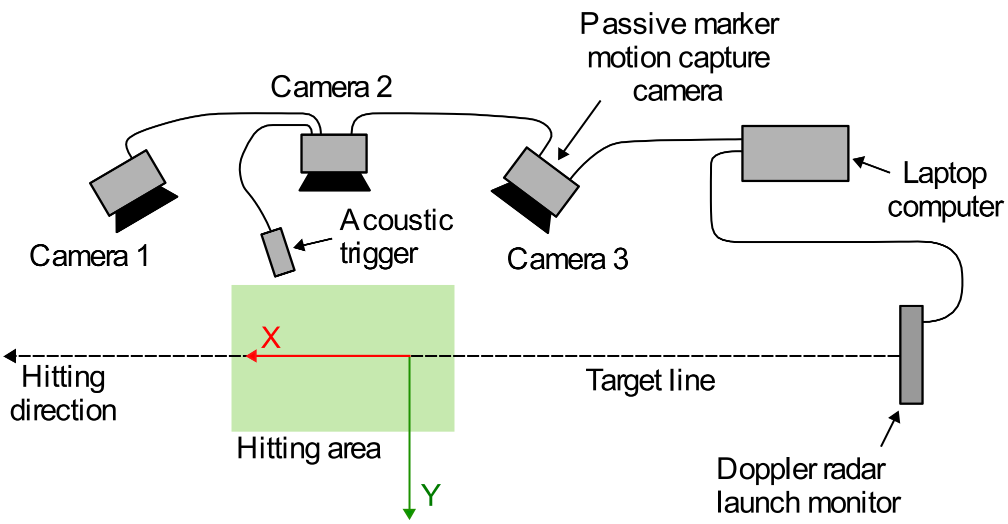
Following the warm-up, instructions were given to hit 'full' shots at their own pace from good lies on the turf, aiming at the target flag, without intending to necessarily reach the target. Each participant hit four sets of at least six shots per set, alternating between the two clubs (i.e. blade, cavity-back, blade, cavity-back, etc.). The order was alternated so that the next participant would hit the cavity-back first and so on. All shots were recorded, except for extreme mishits, which were shots not measured by the systems, such as impacts off the hosel rather than the face of the club that only occurred for some Category 3+ players. Statistical outliers were later detected and removed from the dataset using the leverage and Cook's distance values from a regression analysis

(Betzler et al., under review). The total number of shots analysed was 1127 for the blade club and 1122 for the cavity-back club.

The club face of the test clubs were thoroughly cleaned and dried after each shot. The same premium commercially available urethane-covered golf balls used in Part I were used in this study. Up to 48 clean and undamaged balls were available for each participant with new balls provided when required.

2.3. Data collection and processing

The clubhead motion tracking cameras were set up as in Part I except, being outdoors, they were mounted on tripods approximately 1-2 m above the ground (Fig. 1). Clubhead presentation was calculated as reported in Part I and Corke et al. [5]. The clubhead presentation, ball launch and shot outcome variables studied have been defined in previous literature [2,5].



** Figure 1 near here **

Figure 1. Schematic diagram of experimental setup and camera placement for outdoor player testing. Cameras mounted on tripods at a height of 1-2 m above ground. The global Z-axis (not pictured) pointed vertically upwards.

The volume of the clubhead motion capture system enabled a teeing area of approximately 0.5 m^2. As each shot damaged the turf to a varying degree, the ‘teeing area' was regularly relocated, requiring recalibration of the measurement systems. The stereoscopic launch monitor used in Part I was poorly suited to this repeated recalibration. Thus, a more portable Doppler-radar launch monitor (Trackman 3e, Trackman, Vedbæk, Denmark) was used instead. Measurements obtained from this Doppler device have been compared to those of the stereoscopic launch monitor used for the previous robot testing [6], with root mean square (RMS) error values reported as 0.31 m.s^{-1} (0.69 mph), 0.53° and 92 rpm for ball speed, launch angle and total spin, respectively.

2.4. Statistical analysis

All statistical analysis was performed in MATLAB 2019b (Mathworks, Natick, MA). Clubhead comparisons examined differences in clubhead presentation between the clubhead types, whilst handicap comparisons examined differences in clubhead presentation and ball launch variables between handicap groups. Handicap comparisons also considered differences in variability between golfers of different handicap groups, as these provide context relating to the benefits of different club designs.

2.4.1. Relationships between clubhead type and performance

The variables used to understand differences between clubhead types in Part I were also used in the present study. These variables include the following: mean value for the blade club over all shots ($\bar{x}_{blade}$), difference in means between the two clubs ($\bar{x}_{blade-cavity}$), pooled standard deviation ($s = \sqrt{\frac{(n_B-1)s_B^2+(n_C-1)s_C^2}{n_B+n_C-2}}$), and Cohen's *d* effect size of the difference [7]. Effect sizes of 0.2 were considered small, effect sizes of 0.5 were considered medium and effect sizes greater than 0.8 were considered large [7]. Since the number of shots compared was large, two sample t-tests were used to assess the statistical significance of differences with a Bonferroni correction applied to the significance level to give a threshold for statistical significance of $p < 0.003$.

2.4.2. Relationships between handicap and performance

Mann-Whitney U-tests indicated that male and female golfers differed significantly in the majority of clubhead presentation variables, so both results could not be included in a single analysis. Differences also occurred in clubhead presentation and ball launch variables between the two clubs, thus only the blade club data were used to examine relationships between handicap and performance. Either club could have been chosen as this section of analysis aimed primarily to provide the context within which club-type effects could be interpreted. The blade club was chosen as the main basis for comparison, but results for the cavity-back club are included as a supplement (there were no meaningful differences in average or variability between the clubs). Furthermore, since the number of female golfers was relatively small, only male golfers were included in the statistical analysis of handicap effects. The Jonckheere-Terpstra test for ordered differences was used to determine whether within-player median or median absolute deviations were ordered across the handicap categories for each variable. For the statistical tests for handicap and performance, a Bonferroni correction was applied to the significance level to give a threshold for statistical significance of $p < 0.0016$.

3. Results

3.1 Relationships between clubhead type and performance

Significant differences in clubhead presentation (Table 2) averaged over all shots between the two club types were observed for effective loft (cavity-back 1.0° greater than blade, small effect), effective lie (blade 0.7° more toe-up, small effect), and horizontal impact location (cavity-back tendency to have ball strikes closer to the face centre, medium effect). In terms of ball launch, significant differences (negligible/small effects) were observed for both launch angle and total spin, with the cavity-back showing higher values for both by 0.5° and 313 rpm, respectively.

Table 2. Clubhead presentation for the two clubs, averaged over all shots. Statistically significant p-values are highlighted in bold.

	$\bar{x}_{blade}$	$\bar{x}_{blade - cavity}$	Cohen's *d*	Pooled standard deviation	*p*
Clubhead speed ($m \cdot s^{-1}$)	38.2	-0.2	-0.04	4.17	0.382
Face angle (°)	-1.0	0.0	0.00	3.73	0.991
Face angle rate of change ($° \cdot s^{-1}$)	2530	26	0.06	454	0.168
Path angle (°)	-0.6	0.1	0.01	4.42	0.803
Attack angle (°)	-4.0	0.0	0.00	2.60	0.940
Effective loft (°)	20.0	-1.0	-0.25	3.8	**<0.001**
Effective lie (°)	-2.2	0.7	0.20	3.63	**<0.001**
Horizontal impact location (mm)	-5.9	-5.0	-0.50	10.15	**<0.001**
Vertical impact location (mm)	-10.3	0.7	0.10	6.63	0.017
Ball speed ($m.s^{-1}$)	51.1	-0.5	-0.07	6.60	0.097
Efficiency (no units)	1.38	-0.01	-0.07	0.09	0.080
Launch angle (°)	12.4	-0.5	-0.15	3.54	**<0.001**
Side angle (°)	-1.1	0.0	0.01	3.35	0.827
Total spin (rpm)	5155	-313	-0.31	1019	**<0.001**
Spin axis angle (°)	2.6	-0.1	-0.01	7.01	0.772
Total distance (m)	152.8	-0.1	0.00	26.43	0.938
Total side (m)	0.9	-0.1	-0.01	12.42	0.853

** Table 2 near here **

3.2 Relationships between handicap and performance

Table 3 and Table 4 show the relationship between handicap and clubhead presentation and ball launch, respectively. The only variables to display a statistically significant trend in within-player median values across the handicap groups were ball speed (higher handicap golfers displayed a slower ball speed), efficiency (higher handicap golfers displayed lower efficiency) and total distance (higher handicap golfers had shorter shots). In contrast, most within-player median absolute deviation values indicated the presence of statistically significant trends – toward the higher handicap golfers being less consistent. The exceptions to this were clubhead speed, path angle, attack angle, launch angle, total distance and total side, in which the higher handicap golfers were no more variable than lower handicap golfers.

Table 3. Mean within-player median and median absolute deviations (MAD) by handicap category for clubhead presentation variables and the results of Jonckheere-Terpstra tests for ordered differences. Statistically significant p-values are highlighted in bold.

	Category	Clubhead speed ($m \cdot s^{-1}$)	Face angle (°)	Face angle rate of change ($° \cdot s^{-1}$)	Path angle (°)	Attack angle (°)	Effective loft (°)	Effective lie (°)	Horizontal impact location (mm)	Vertical impact location (mm)
Median	1 (<6)	40.0	-0.2	2485	0.6	-4.7	19.1	-2.2	-4.5	-9.6
	2 (6-12)	38.4	-1.4	2583	-0.6	-3.9	20.0	-1.4	-6.6	-11.0
	3+ (>12)	38.4	-2.8	2822	-2.1	-4.3	20.3	-5.4	-10.5	-11.3
	Mean	39.3	-0.9	2565	-0.1	-4.4	19.5	-2.5	-6.0	-10.2
	z	2.25	2.97	2.18	2.03	1.44	1.45	1.69	2.70	2.10
	P	0.012	0.002	0.015	0.021	0.075	0.074	0.046	0.003	0.018
MAD	1 (<6)	0.2	1.1	55	0.8	0.5	0.8	0.4	4.2	2.9
	2 (6-12)	0.3	1.4	68	1.0	0.5	1.0	0.6	4.9	4.3
	3+ (>12)	0.4	1.9	104	1.6	0.7	1.6	0.7	6.6	5.9
	Mean	0.3	1.3	66	1.0	0.5	1.0	0.5	4.8	3.8
	z	2.94	3.16	4.04	2.77	1.55	3.32	4.17	3.83	5.09
	P	0.002	**0.001**	**<0.001**	0.003	0.060	**<0.001**	**<0.001**	**<0.001**	**<0.001**

** Table 3 near here **

Table 4. Mean within-player median and median absolute deviations (MAD) by handicap category for ball launch variables and the results of Jonckheere-Terpstra tests for ordered differences. Statistically significant p-values are highlighted in bold.

	Category	Ball speed ($m·s^{-1}$)	Efficiency	Launch angle (°)	Side angle (°)	Total spin (rpm)	Spin axis angle (°)	Total distance (m)	Total side (m)
Median	1 (<6)	54.4	1.40	12.1	-0.2	5351	1.5	166.3	1.8
	2 (6-12)	51.8	1.39	12.3	-1.6	5166	2.8	154.8	0.7
	3+ (>12)	50.4	1.36	11.5	-1.7	5176	4.8	142.8	2.9
	Mean	53.1	1.39	12.0	-0.8	5276	2.4	159.5	1.7
	z	3.05	3.62	0.55	2.46	1.04	1.66	4.58	0.36
	P	**0.001**	**<0.001**	0.292	0.007	0.150	0.048	<0.001	0.358
MAD	1 (<6)	1.1	0.03	0.8	1.1	279	2.6	5.5	6.6
	2 (6-12)	1.2	0.03	1.0	1.2	356	2.9	5.7	6.1
	3+ (>12)	1.7	0.05	1.2	1.7	610	4.2	8.2	7.7
	Mean	1.2	0.03	0.9	1.2	353	3.0	6.0	6.6
	z	3.75	3.43	2.59	3.08	3.54	3.18	2.63	0.43
	P	**<0.001**	**<0.001**	0.005	**0.001**	**<0.001**	**0.001**	0.004	0.333

** Table 4 near here **

4. Discussion

The first aim of the study was to determine differences between a blade 5-iron and a cavity-back 5-iron in clubhead presentation and ball launch in a large sample of male and female golfers across a range of skill levels represented by handicap. The higher effective loft (cavity-back 1.0° higher than blade) and resultant higher launch angle (cavity-back 0.5° higher than blade) and spin rate (cavity-back 313 rpm higher than blade) noted for the cavity-back club agree with the findings of Part I. However, these differences were small and, whilst the agreement with Part I suggests that they could be due to the different clubhead characteristics of the two clubs, there was no meaningful difference in shot outcome (total distance 0.1 m longer with cavity-back). Alternatively, it is possible that players slightly modified their swings between clubs, or that ground effects (where the clubs struck the ground before the ball) differed. In combination, the results of Part I and Part II suggest that, whilst perimeter-weighted irons are more forgiving in theory (see Part I results), their effect on players' shot outcomes are most likely negligible.

The second aim was to examine trends in central tendency and variability in relation to the handicap category. Due to insufficient data for females, this analysis only examined males. The variability of golfers provides important context with which to interpret differences due to the properties of the clubs. The differences between the clubs (club effect) across all shots, noted above, were small when compared to within-player variability. For example, the largest difference between the clubs was in horizontal impact location (5.0 mm), but the median absolute deviation in horizontal impact location was of similar magnitude (4.8 mm). Even in the case of the largest standardised effect size, a golfer's average difference from their average shot is similar in magnitude to the effect of changing club. Therefore, whilst there is a difference between the clubs, the difference is small enough that it is difficult to observe on a shot-by-shot basis.

Previous research has indicated how both clubhead presentation and ball launch variables can differentiate between skill-levels with a driver club [2]. A more central strike and greater impact efficiency (which are clearly not mutually exclusive) were reported to be characteristic of more skilled players. In the present study, the ball speed and efficiency differed between the handicap categories. Lower handicap golfers displayed a higher ball speed and greater efficiency (Table 3 and Table 4). These results are as expected and the differences in ball speed and efficiency should result in longer shot distances for the lower handicap golfers (as observed).

The variability of clubhead presentation and ball launch proved to be an even better differentiator, with more skilled players (defined by handicap) performing more consistently [2]. Other research has also noted the consistency in clubhead presentation and ball launch for more skilled players with both driver [8] and iron [9] clubs. This study agrees with previous work, with a trend toward higher handicap golfers displaying less consistency for all clubhead presentation and ball launch variables except for attack angle and launch angle.

A limitation of this study is that the differences in performance and variability were only examined in the male golfers, since there were only a small number of high handicap female golfers recruited for the study. No effort was made to recruit golfers with certain characteristics, and the population was somewhat biased as a result. This was not an issue for the comparison between clubs, since the golfers delivered enough scatter to examine the effect, but it did limit the analysis which can be performed on the golfers themselves. This bias has been observed in previous literature [8] and future research could consider actively recruiting larger samples of high handicap and female golfers to address this bias.

5. Conclusions

This player-based study (Part II) sought to corroborate the findings from the robot study (Part I). The predominant differences between blade and cavity-back irons noted in Part I were that the cavity-back generated a higher ball launch angle and offered more consistent ball launch characteristics when impact location was varied. This increased consistency was noted for vertical impact efficiency (the ratio of ball speed to clubhead speed moving vertically on the face) and spin axis angle. The effect of CG location on effective loft was also observed to generate a higher launch angle and greater spin relative to the blade. The agreement in the differences in launch conditions between the clubs when tested with a large, diverse sample of golfers adds considerable confidence to these findings in Part I. However, results in Part I relating to the forgiveness of the cavity-back club did not manifest more consistent shot outcomes when used by golfers. From a coaching perspective, the effect of skill level on performance and consistency of performance should not be underestimated: differences between clubs were relatively small compared to differences between golfers of different skill levels and similar to within-player consistency.

Both parts of this paper add new scientific knowledge on the effect of perimeter-weighting in irons and lend some support to the widely held view that 'cavity-back' clubs are more forgiving than 'blade' clubs, whilst finding that skill was the most important factor in performance. However, whilst there were clear differences in clubhead properties between the two test clubs, it should be noted that clubheads with no perimeter-weighting do exist (unlike the blade clubhead used in this study which had a small cavity, albeit much smaller than the cavity-back club). Therefore, there may be clubhead models where the differences in performance are greater than those observed here. Consideration of more 'blade' style clubs, along with a higher representation of female and high handicap golfers, could form the basis of future studies investigating further the effects of perimeter-weighted irons and skill level on shot outcomes.

6. References

[1] Bartlett R, Wheat J, Robins M (2007) Is movement variability important for sports biomechanists? Sports Biomech 6:224–243. https://doi.org/10.1080/14763140701322994

[2] Betzler N. F., Monk, S. A., Wallace, E. S., Otto, S. R. (2012). Variability in clubhead presentation characteristics and ball impact location for golfers' drives. *Journal of Sports Sciences*, 30:439–448

[3] Olsavsky, T. (1994). The effect of driver head size on performance. In: Farrally MR, Cochran, A. J. (eds). *Science and Golf II*. E & FN Spon, pp 321–326

[4] Scottish Golf (2015). Central database of handicaps. Available from: https://www.scottishgolf.org/club-services/handicapping/central-database-of-handicaps/ Accessed: January 2015

[5] Corke, T. W., Betzler, N. F., Wallace, E. S., Otto, S. R. (2019). A novel system for tracking iron golf clubheads. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 233.

[6] Betzler, N. F. (2010). *The Effect of Differing Shaft Dynamics on the Biomechanics of the Golf Swing*. PhD, Edinburgh Napier University

[7] Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*, 2nd Edition. Hillsdale, Lawrence Erlbaum

[8] Hocknell, A. (2002). High performance driver design: benefits for all golfers. In: Thain, E. (ed) *Proceedings of the World Scientific Congress of Golf*. St Andrews, Scotland, pp 438–448

[9] Healy, A., Moran, K. A., Dickson, J., et al (2011). Analysis of the 5 iron golf swing when hitting for maximum distance. *Journal of Sports Sciences*, 29:1079–1088