



Impact Location, Spin Loft, and Smash Factor: An Analysis Using Golfer-Club Systems and TrackMan 4 Data

Pasha Zabadneh



ABSTRACT

Smash factor is commonly used to describe energy-transfer efficiency between the golf club and ball, but it can be influenced by multiple aspects of club delivery and impact. This study examined how much unique variation in seven-iron smash factor was associated with spin loft and with two-dimensional impact location in eight individual golfer-club systems. Eight experienced right-handed male golfers were tested using a TrackMan 4 launch monitor. Each subject was tested indoors, using their personal seven-iron. 767 total shots were used in this study. Smash factor was treated as the dependent variable, while spin loft and impact location were the two predictors studied. Face angle was included as a control variable. Impact location was represented using a two-dimensional model of the second order, containing the terms x , y , x^2 , xy , and y^2 . Separate models were created for each golfer-club system. The unique contributions of spin loft and 2D impact location were measured as the decrease in R^2 when each predictor was removed from the full model. Across the eight golfer-club systems, impact location contributed greater explanatory information than spin loft, with a median unique ΔR^2 of 0.586. Spin loft's median ΔR^2 was 0.025. Five-fold cross-validation was used to evaluate predictive performance; cross-validated R^2 remained positive in every system, with a median of 0.529. These results suggest that preserving the direction of impact location retains important explanatory information when studying smash factor and that the relative importance of strike location and spin loft can vary across golfer-club systems.

1. INTRODUCTION

1.1 Background: Smash Factor and Energy Transfer

Smash factor is calculated as ball speed divided by clubhead speed and is commonly used as a central measure of strike quality and energy-transfer efficiency in golf (TrackMan, 2025c). The problem is that smash factor is an outcome metric, not a direct explanation of why a strike produced a given ball speed. Different combinations of delivery and contact can produce similar smash factors, while changes in impact location or delivered loft can alter smash factor even when clubhead speed is similar. Treating smash factor as a stand-alone measure of shot quality can therefore hide important mechanical differences between strikes.

To our knowledge, prior work has not directly stress-tested smash factor by separating the unique statistical information associated with spin loft from that associated with direction-preserving two-dimensional impact location within individual golfer-club systems. This study addresses that gap using real TrackMan 4 data. Rather than treating smash factor as self-explanatory, the analysis models spin loft and impact location simultaneously while controlling for face angle, then compares how much unique variation each predictor contributes. Detailed variable definitions and statistical procedures are presented in the Methodology section.

1.2 Research Question

Within individual golfer–club systems, how much unique variation in seven-iron smash factor is associated with spin loft, and how much is associated with direction-preserving two-dimensional impact location, after accounting for face angle and the competing predictor? The hypothesis is “Spin loft and 2D impact location will each explain unique variation in seven-iron smash factor. Impact location is expected to contribute greater explanatory power overall.”

2. METHODOLOGY

2.1 Setup

Eight experienced right-handed male golfers participated in this study. Subjects represented a range of skill levels, 15 handicap to +4 handicap (intermediate players to competitive collegiate athletes). Participants consented to participation and being referenced in this report prior to data collection. Participants are summarized in Table 1.

Golfer–club system	Club	Handicap	Shots analyzed
Brendan O'Brien	Mizuno MP-15 7 iron	15	91
DJ Nelson	Titleist T200 7 iron	0	89
Pasha Zabadneh	Titleist T150 7 iron	0	86
Trenton Kurtz	Titleist T150 7 iron	+3	90
Henry Way	Titleist T150 7 iron	+2	90
Jantzen Mizerak	Callaway Apex 7 iron	5	98
Henry Schmidt	Mizuno Pro 7 iron	+4	78
Jamal Edwards	Srixon ZXi7 7 iron	2	145

Table 1. Golfer–club systems, equipment, handicap, and shots analyzed ($n = 767$). A plus sign denotes a handicap below scratch.

Data collection was completed indoors using a TrackMan 4 launch monitor (Bishop et al., 2023). The recorded variables were ball speed, club speed, smash factor, spin loft, face angle, launch angle, and spin rate, and impact location. Positive impact offset (the distance away from the geometric center of the face) is positive toward the toe and top of the club, and negative toward the heel and bottom. Seven-irons were used with static lofts ranging from 29 degrees to 34 degrees. Titleist Pro V1 RCT balls were used by all subjects. All subjects hit off of the same type of generic astroturf mat. Google Sheets were used to store data. All data was environmentally normalized, meaning that simulated temperature was set to 77°F.

2.2 Data Collection Procedure

Subjects were given 8 warm shots, to be hit in under 5 minutes. This was after they had already gone through their individual mobility-stretching warm-up, to ensure that they were loose and limber for the volume of shots they were hitting. Subjects hit balls in 30 shot sessions, all less than 15 minutes. Files were exported in between each session as a CSV. Observations were not restricted to just one variable, as the aim of this study was to investigate the separate and

combined associations of spin loft and impact location. All valid shots (non misreads) were recorded by the TrackMan launch monitor.

Shots were excluded from the dataset if they were identified as launch-monitor misreads or data recording errors.

2.3 Statistical Analysis

Smash factor was the dependent variable and was used as a measure of energy-transfer efficiency between club and ball. It was calculated as follows (TrackMan, 2025c):

$$SF = v_{ball} / v_{club} \quad \text{eq1}$$

Impact location was encoded for each shot using signed Cartesian coordinates: x represented horizontal distance from the clubface center and y represented vertical distance. Separate regressions were fit for each golfer–club system. The direction-preserving second-order impact block contained:

$$x, y, x^2, xy, y^2x^2 \quad \text{eq2}$$

Direction had to be preserved because distance from center alone creates a sign problem. If impact were represented only by the unsigned radius r , a strike low and toward the toe could receive the same predictor value as a strike high and toward the heel whenever both were equally distant from center. The model would therefore collapse mechanically different locations onto the same value and could weaken or obscure a real spatial relationship. For this reason, horizontal and vertical offsets retained their signs in the regression model; polar radius and angle were used only for visualization. The calculation for a shot's radius was

$$r = \sqrt{(x^2 + y^2)} \quad \text{eq3}$$

The polar angle θ was calculated as

$$\theta = \text{atan2}(y, x) \quad \text{eq4}$$

Polar coordinates were used for visualization only and did not replace the two-dimensional regression model.

Spin loft was obtained using the TrackMan 4 launch monitor. TrackMan defines spin loft as the three-dimensional angle between the clubhead's direction of travel and the orientation of the clubface at impact. This value is determined using the clubhead's movement, described by club path and attack angle, and the clubface orientation, described by face angle and dynamic loft. Although TrackMan calculates spin loft as a true three-dimensional angle, it can be closely approximated by subtracting attack angle from dynamic loft when the horizontal difference between club path and face angle is small. This approximation provides an accurate representation of the reported spin loft values (TrackMan, 2025d).

$$SL \approx DL - AoA \quad \text{eq5}$$

After filtering, 767 valid shots remained across eight golfer–club systems: Pasha Zabadneh (86), DJ Nelson (89), Henry Schmidt (78), Henry Way (90), Brendan O'Brien (91), Trenton Kurtz (90), Jantzen Mizerak (98), and Jamal Edwards (145). Four shots were excluded as launch-monitor misreads. All analyses were performed separately for each golfer–club system. Analysis and

figure generation were performed with computational assistance, and all source code was retained. Before analysis, each numerical predictor was mean-centered within the subject by subtracting that subject's mean for the predictor from each shot. Quadratic and interaction terms were formed after centering. Face angle was included in each system's model as a control variable.

To preserve directional offset, impact location was represented using signed coordinates. As the relationship between strike location and smash factor curved across the clubface, the impact location model contained these five terms from eq2. These terms were treated as a cumulative impact location block in 2D. Spin loft was a separate linear predictor. The full regression model for each golfer-club system predicted smash factor (SF) from spin loft, face angle, and the complete impact location block in 2D.

$$SF = \beta_0 + \beta_1 SL + \beta_2 FA + \beta_3 X + \beta_4 Y + \beta_5 X^2 + \beta_6 XY + \beta_7 Y^2 + \varepsilon \quad \text{eq6}$$

Spin loft's unique contribution to smash factor was measured by comparing the R^2 of the full model with the R^2 of the same model after spin loft was removed:

$$\Delta R^2_{spin} = R^2_{full} - R^2_{-spin} \quad \text{eq7}$$

Impact location (in 2D)'s unique contribution was calculated the same way. Instead, the 5 impact block terms were removed:

$$\Delta R^2_{impact} = R^2_{full} - R^2_{-impact} \quad \text{eq8}$$

These values quantify the proportion of within-system variation in smash factor uniquely associated with each predictor block, conditional on the other modeled variables.

The five impact-location terms were tested jointly using a partial F-test to determine whether the impact block added statistically detectable information to the model. Statistical significance was evaluated at $\alpha = 0.05$.

Predictive performance was evaluated using shuffled five-fold cross-validation with a fixed random seed of 7. Full-model R^2 quantified in-sample fit, whereas cross-validated R^2 quantified out-of-sample predictive performance.

In each model, spin loft's contribution was analyzed using a partial regression plot so that its effect on the smash factor remained after the other modeled variables were accounted for. Due to the fact that the five-term block impact-location models could not be represented on a single x-axis, impact location's effect was shown using a direction-preserving cross-fitted impact score. Each shot's score was generated from a model that did not use that shot in fitting. This prevented a shot from creating and predicting itself.

3. RESULTS

We used the statistical model described above to obtain the results summarized in Table 2. Each system was fitted separately with eight parameters, giving residual degrees of freedom from 70 to 137.

System	n	Full R ²	Unique spin ΔR^2	Unique impact ΔR^2	Spin p	Impact F	Impact p	CV R ²	Spin VIF
Brendan O'Brien	91	0.793	0.020	0.596	.006	47.9	< .001	0.475	2.69
DJ Nelson	89	0.586	0.004	0.404	.398	15.8	< .001	0.499	2.49
Pasha Zabadneh	86	0.477	0.001	0.462	.696	13.8	< .001	0.373	1.50
Trenton Kurtz	90	0.722	0.000	0.513	.832	30.3	< .001	0.416	2.47
Henry Way	90	0.773	0.039	0.626	< .001	45.3	< .001	0.701	1.21
Jantzen Mizerak	98	0.658	0.054	0.577	< .001	30.4	< .001	0.560	2.77
Henry Schmidt	78	0.897	0.031	0.798	< .001	108.3	< .001	0.752	1.55
Jamal Edwards	145	0.839	0.054	0.706	< .001	120.3	< .001	0.775	1.45

Table 2. Full-model performance and unique block contributions for each golfer–club system. Unique ΔR^2 is the reduction in full-model R^2 when that predictor block is removed while the competing predictor and the face-angle control remain. Spin p is the partial test for spin loft; impact p is the grouped partial F-test for the five-term impact block.

Five out of eight players had significant unique linear information: Brendan O'Brien ($p = .006$), Henry Way ($p = .0003$), Jantzen Mizerak ($p = .0003$), Henry Schmidt ($p = 2.1 \times 10^{-5}$), Jamal Edwards ($p = 3.4 \times 10^{-10}$). Not significant: DJ Nelson ($p = .40$), Pasha Zabadneh ($p = .70$), and Trenton Kurtz ($p = .83$). Partial R^2 for spin loft ranged from .001 to .251, with median 0.112. Unique spin loft ΔR^2 ranged from 0.000 to 0.054, with median 0.025. All statistically significant spin-loft coefficients were negative—higher spin loft was associated with lower smash factor—matching the direction reported by TrackMan. It is important to note that non-significant cases reflect little *remaining unique* linear information after face angle and impact-location were accounted for, not mechanical or physical relevance.

The block including impact location is significant in all eight golfer-club systems. $F = 13.8$ – 120.3 , with maximum $p = 1.2 \times 10^{-9}$. Unique impact ΔR^2 ranged from 0.404 to 0.798, with median 0.586. Cross-fitted impact summary R^2 ranged from 0.303 to 0.725, with a median of 0.458. Impact exceeded spin loft in every system, with median unique ΔR^2 values of 0.586 and 0.025, respectively—a roughly 23-fold difference. Every system also had an interior maximum with a negative definite curvature, and in every system, the vertical quadratic coefficient exceeded the horizontal by a factor of 2.3 to 5.1. The fitted optima for every subject fell within each player's observed strike region, so this is an interpolation as opposed to an extrapolation.

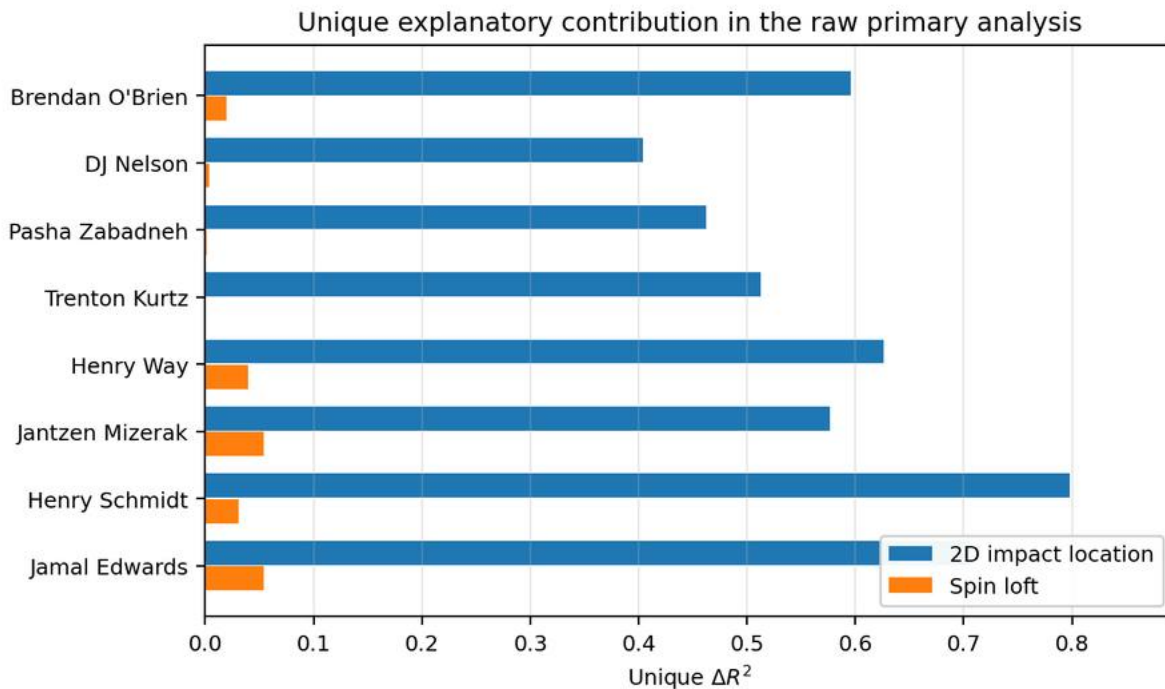


Figure 1. Unique contribution of two-dimensional impact location and spin loft in all eight golfer–club systems. Each ΔR^2 is the loss of full-model R^2 when that predictor block is removed while the competing predictor and control remain in the model.

Joint model performance was also strong. Full-model R^2 ranged from 0.477 to 0.897, with a median of 0.748. Cross-validated R^2 ranged from 0.373 to 0.775, with a median of 0.529 and remained positive in every golfer–club system. Figure 2 indicates that the relationships were not confined to in-sample fit.

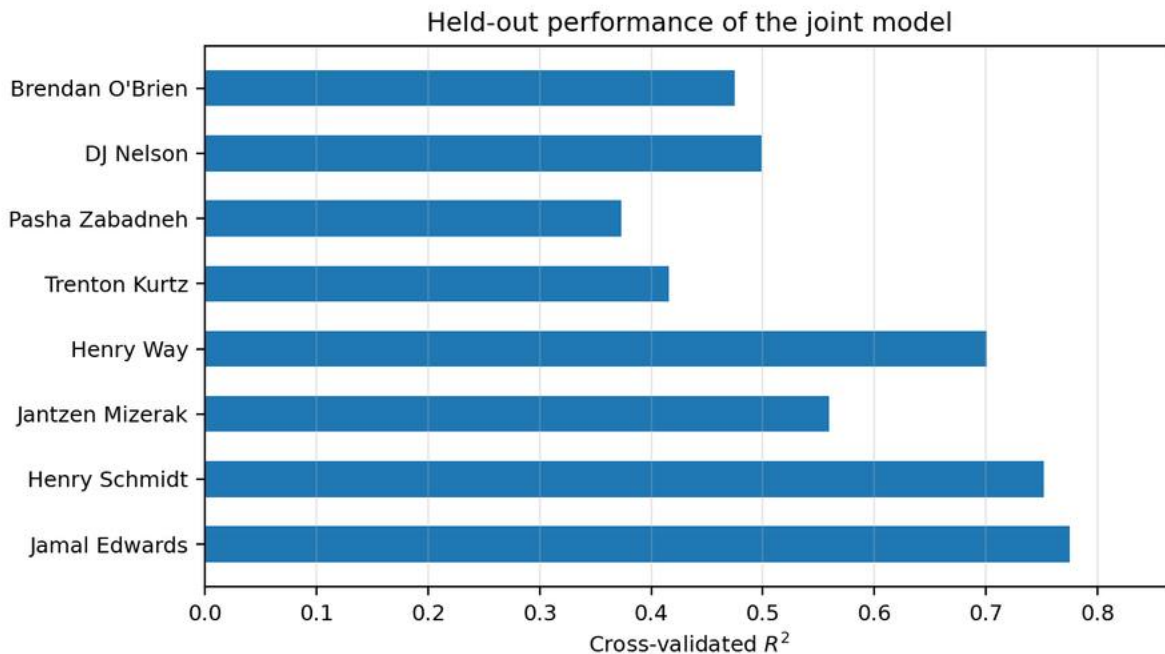


Figure 2. Five-fold cross-validated R^2 of the combined spin-loft and direction-preserving two-dimensional impact model in all eight golfer–club systems.

4. DISCUSSION

Direction-preserving 2D impact location contributed substantially more unique statistical information about seven-iron smash factor than spin loft in every system. The central hypothesis was supported by impact location and partially supported by spin loft. Spin loft should still be retained because it provided statistically significant unique information in five of the eight golfer–club systems, with no evidence of problematic collinearity.

A strong correlation between impact-location and smash factor is plausible. TrackMan identifies impact height as a variable that tends to affect spin rate, ball speed, and smash factor. TrackMan identifies horizontal impact offset related to off center contact, and gear-effect behavior (TrackMan, 2025a, 2025b). Off-centered impact can therefore influence the smash factor, as the geometry of collision changes away from center even when all other variables are held constant.

This study's findings do not prove that moving contact to a specific coordinate on the face will have a specific change in smash factor. This study was observational, and specific impact locations were not experimentally assigned. The result is limited, and more defensible: within observed shots, knowing the 2D strike location of a shot significantly improved explanation and prediction of seven-iron smash factor after spin loft and face angle were already accounted for.

TrackMan states that higher spin loft generally reduces smash factor when all other variables are held constant (TrackMan, 2025d). The present data are compatible with spin loft being mechanically meaningful while still showing a smaller unique R^2 than impact location.

Unique R^2 measures nonredundant statistical information and fit, not total mechanical importance. Some information associated with spin loft may overlap with face angle or impact patterns. Once those variables are already in the model, the amount of additional variation specifically attributable to spin loft can be small, even if spin loft remains part of the mechanical explanation of the collision of club and ball.

This distinction is important for the three nonsignificant player-level results. A nonsignificant relationship does not mean that spin loft is “useless.” It means that in that golfer-club system and within the observed data of the study, the remaining contributable information by spin loft was limited after other measured predictors were included.

The magnitude of the fitted relationships differed across golfer-club systems, which is expected because players used different seven-irons and had different swing and strike patterns. Those equipment and technique differences likely contributed to the different R^2 values observed for both spin loft and impact location. Despite that variation in magnitude, the general pattern was consistent: direction-preserving 2D impact location contributed more unique explanatory information than spin loft in every system, while the combined models retained positive cross-validated R^2 values for all eight golfers. The differences therefore support individualized golfer-club modeling rather than a single pooled rule.

5. CONCLUSION

This paper examined the strengths and limitations of smash factor as a measure of strike quality by using real TrackMan 4 data to separate the unique statistical contributions of spin loft and direction-preserving 2D impact location within individual golfer-club systems. Across eight golfers and 767 valid seven-iron shots, the analysis showed that smash factor is better understood when the delivery and strike-location variables that shape it are modeled directly.

Within each golfer-club system observed in this study, 2D direction-preserving impact location was a stronger predictor of seven-iron smash factor. Spin loft remained informative independently for several systems, and showed little evidence of problematic multicollinearity. The results support retaining both variables in a combined model. This study shows why impact location should not be reduced to unsigned radial distance: maintaining a coordinate system allowing collisions to be heel/toe and low/high reveals spatial information that a radius-only model would lose. Overall, in this study, individualized golfer-club models that combine delivery and 2D strike location provide a more defensible description of energy-transfer efficiency (smash factor) than a single universal strike location rule.

5.1 Limitations

Limitations constrain the interpretation of this study's results. First, the sample contained only eight experienced right-handed male golfers, so the findings should not be generalized to all players. Second, each golfer used their own seven-iron. This means that golfer and club are confounded, preventing causal comparison of manufacturer iron engineering/design.

Third, the design was observational. The study quantified adjusted associations and held out performance, but did not experimentally manipulate spin loft or impact location in any way. Fourth, the fitted impact relationships are supported only within the strike locations actually observed in each player's dataset. Extrapolating predicted smash factor to unmapped parts of the face would be unreliable.

Fifth, collection session was not included as a covariate in the statistical models. Therefore, some between-session variation may remain unaccounted for and could contribute to residual variation in smash factor. Internal cross-validation is stronger than relying only on in-sample R^2 , but it is not equivalent to validating the model on a completely independent future session. Bishop et al. (2023) also found that some TrackMan-derived metrics could vary between sessions, which reinforces the value of future external validation.

Finally, smash factor is a limited metric of strike quality. Although it reflects the ratio of ball speed to club speed, it does not describe every aspect of impact quality. It also does not describe every aspect of shot performance. Two shots with similar smash factors could differ in launch, spin, direction, and more.

5.2 Future Research

Future research should test the same iron across many golfers, and multiple irons within the same golfer. With this design, the player and equipment effects could be isolated. A larger sample could also support comparisons, perhaps by handicap or club-skill-level category.

The strongest extension would be a design that deliberately varies impact location and spin loft while holding all other variables constant. These changes would allow for stronger causal conclusions and a clearer estimate of spatial patterns over time.



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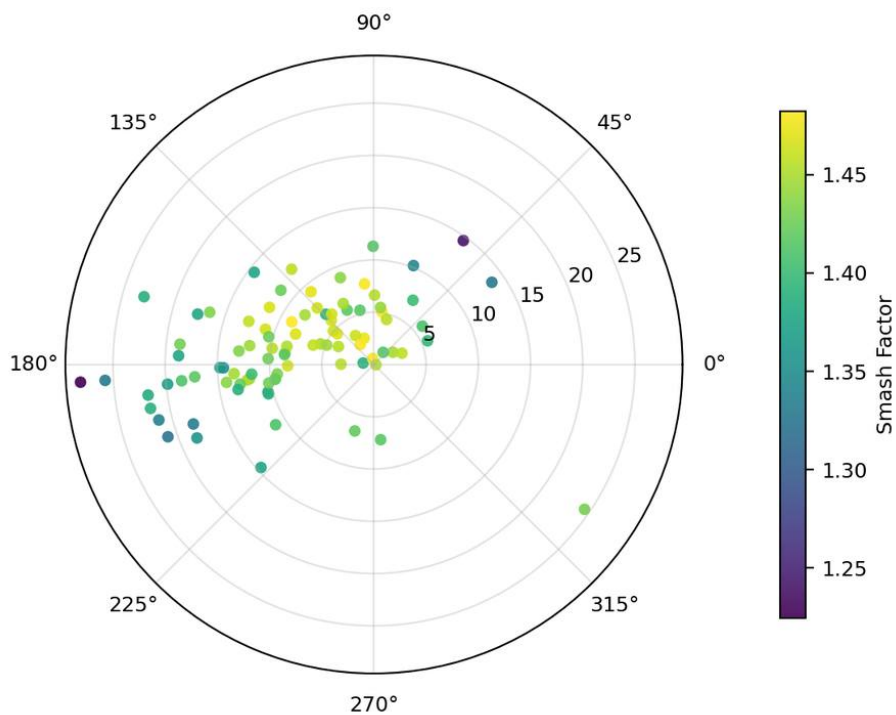
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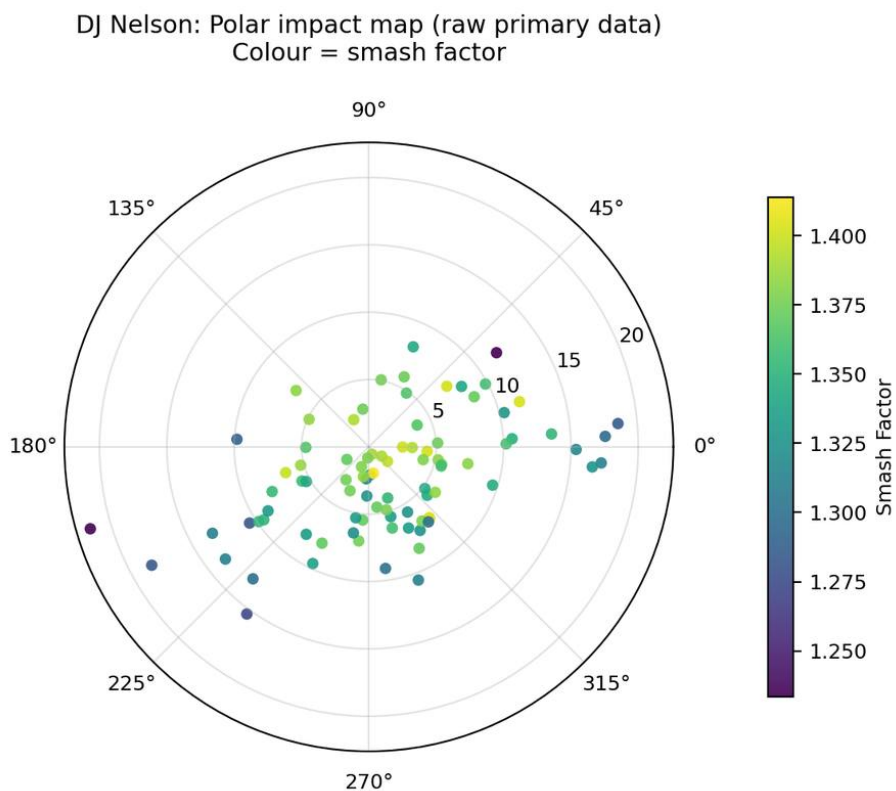
APPENDIX A — PLAYER POLAR IMPACT MAPS

Distance from the face center is measured in millimeters.

Brendan O'Brien: Polar impact map (raw primary data)
Colour = smash factor

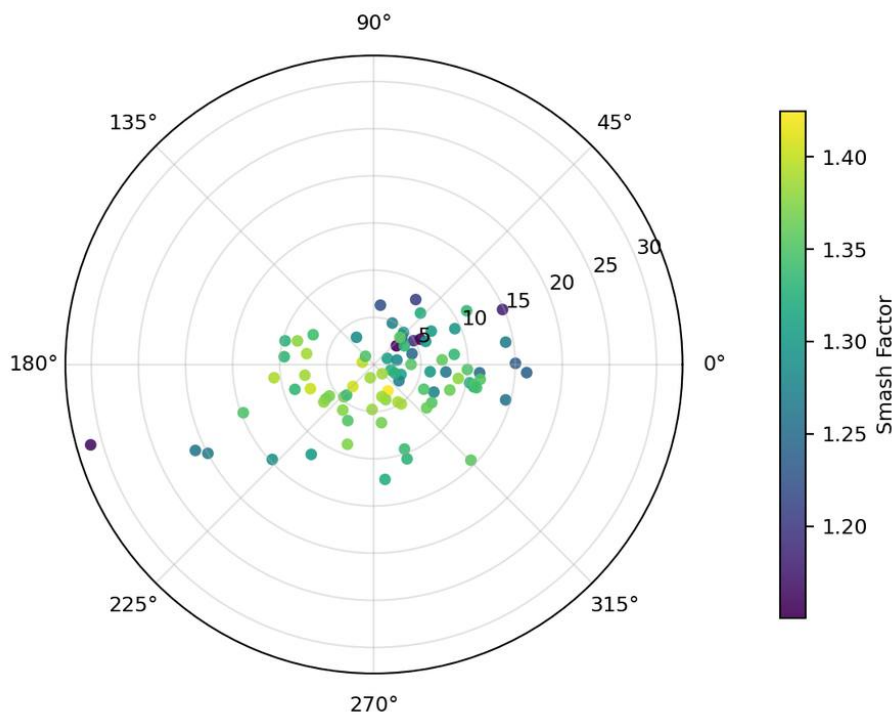


Appendix Figure A1. Brendan O'Brien polar impact map (n = 91). Radius represents distance from the geometric center of the clubface, angle represents strike direction, and color represents smash factor.

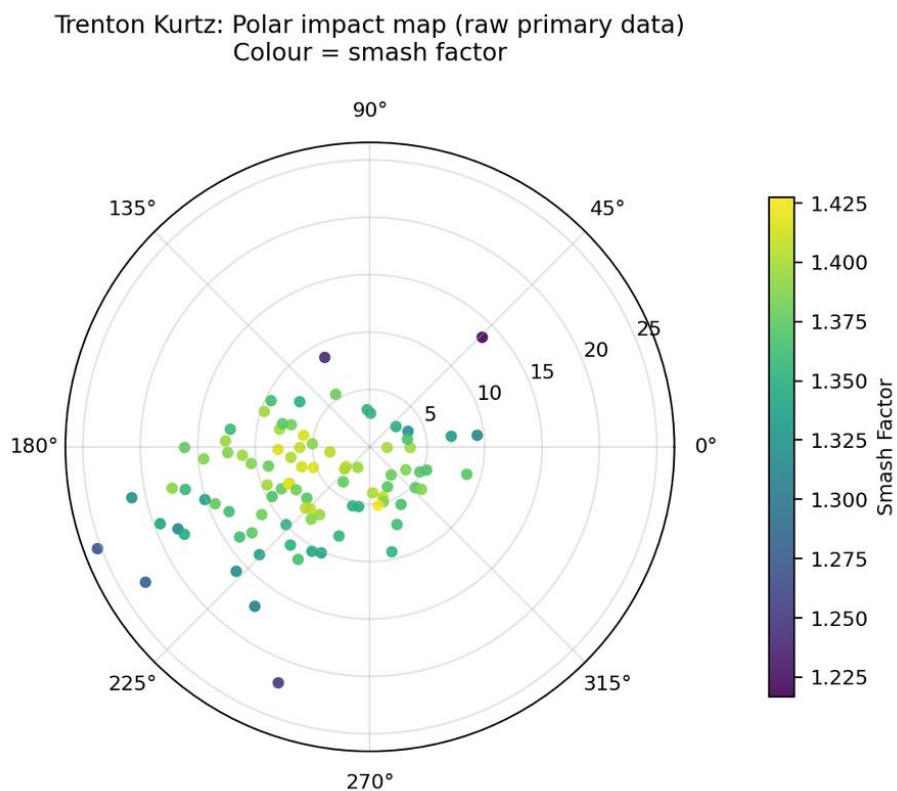


Appendix Figure A2. DJ Nelson polar impact map (n = 89). Radius represents distance from the geometric center of the clubface, angle represents strike direction, and color represents smash factor.

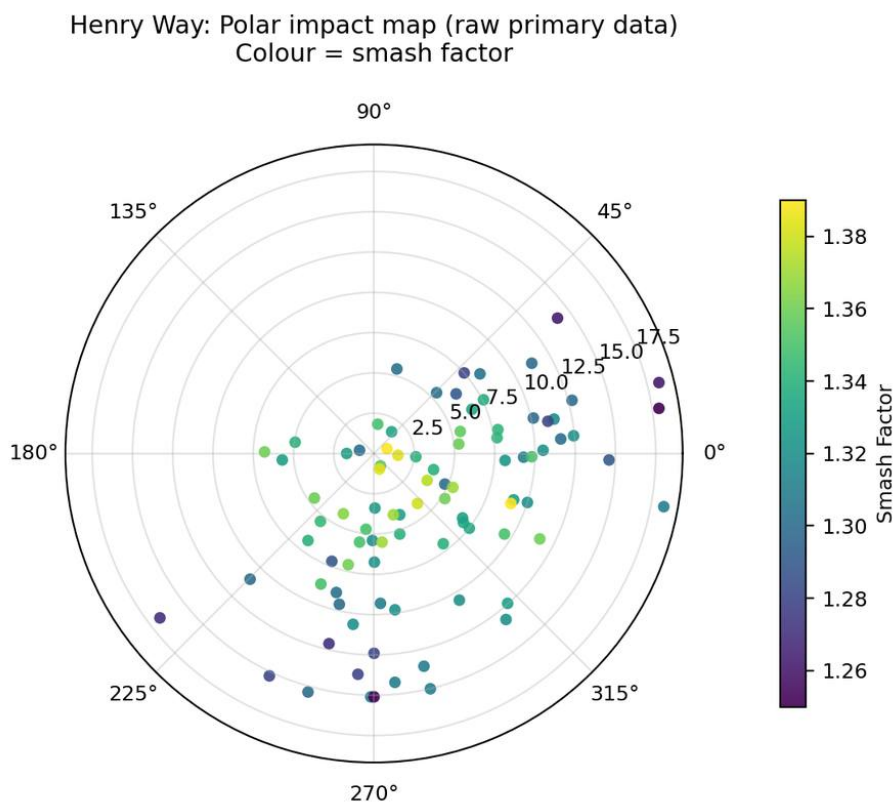
Pasha Zabadneh: Polar impact map (raw primary data)
Colour = smash factor



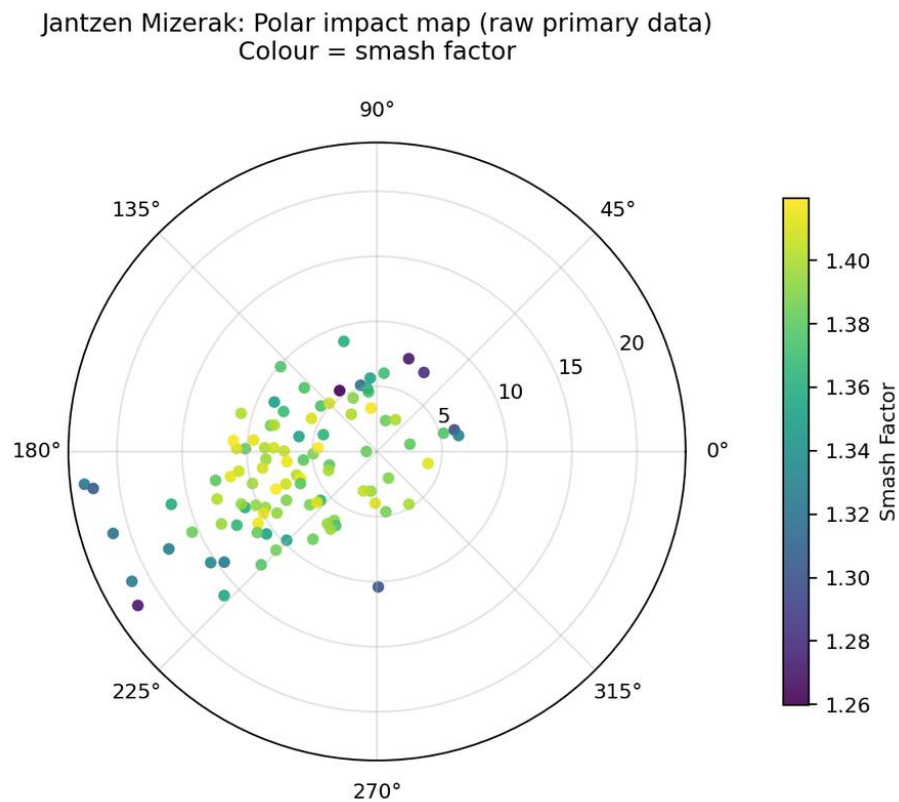
Appendix Figure A3. Pasha Zabadneh polar impact map (n = 86). Radius represents distance from the geometric center of the clubface, angle represents strike direction, and color represents smash factor.



Appendix Figure A4. Trenton Kurtz polar impact map (n = 90). Radius represents distance from the geometric center of the clubface, angle represents strike direction, and color represents smash factor.

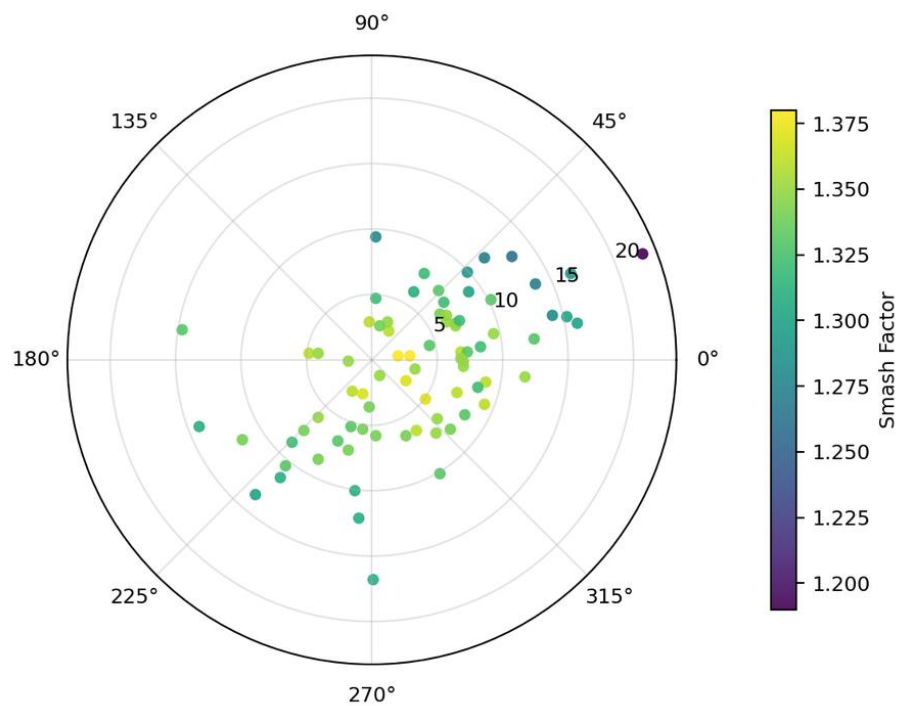


Appendix Figure A5. Henry Way polar impact map (n = 90). Radius represents distance from the geometric center of the clubface, angle represents strike direction, and color represents smash factor.

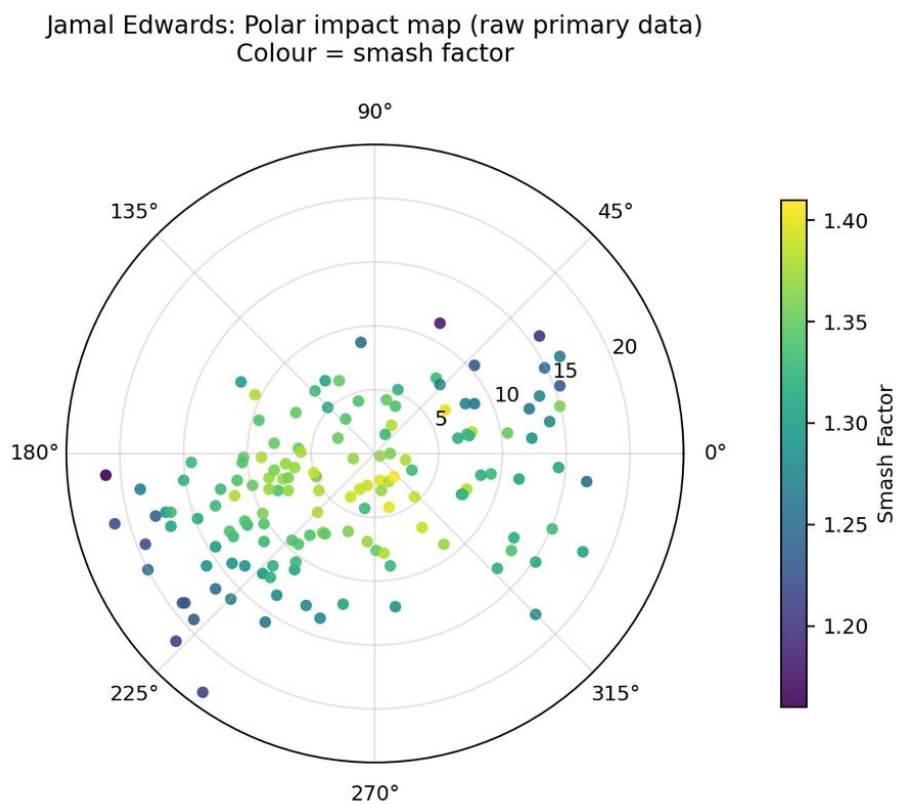


Appendix Figure A6. Jantzen Mizerak polar impact map (n = 98). Radius represents distance from the geometric center of the clubface, angle represents strike direction, and color represents smash factor.

Henry Schmidt: Polar impact map (raw primary data)
Colour = smash factor



Appendix Figure A7. Henry Schmidt polar impact map (n = 78). Radius represents distance from the geometric center of the clubface, angle represents strike direction, and color represents smash factor.

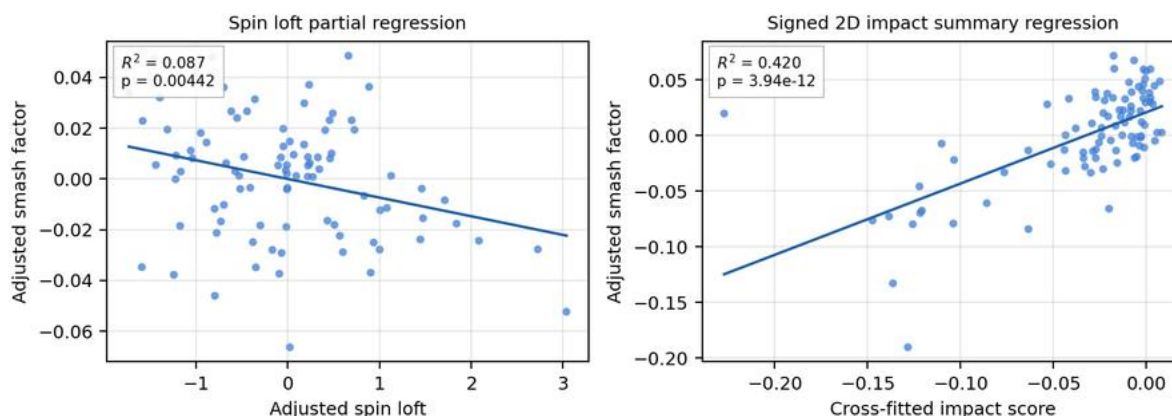


Appendix Figure A8. Jamal Edwards polar impact map ($n = 145$). Radius represents distance from the geometric center of the clubface, angle represents strike direction, and color represents smash factor.

APPENDIX B — PLAYER REGRESSION PANELS

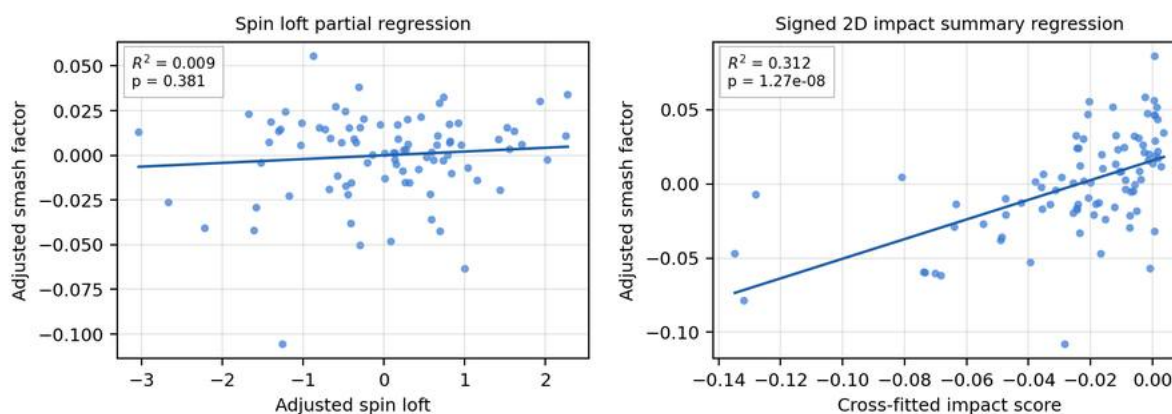
P-values shown in Appendix B come from simple regressions on partial-regression residuals and may differ slightly from the full-model tests reported in Table 2, which use the correct residual degrees of freedom. Table 2 values are the primary results.

Brendan O'Brien: player-level regressions (raw primary data)



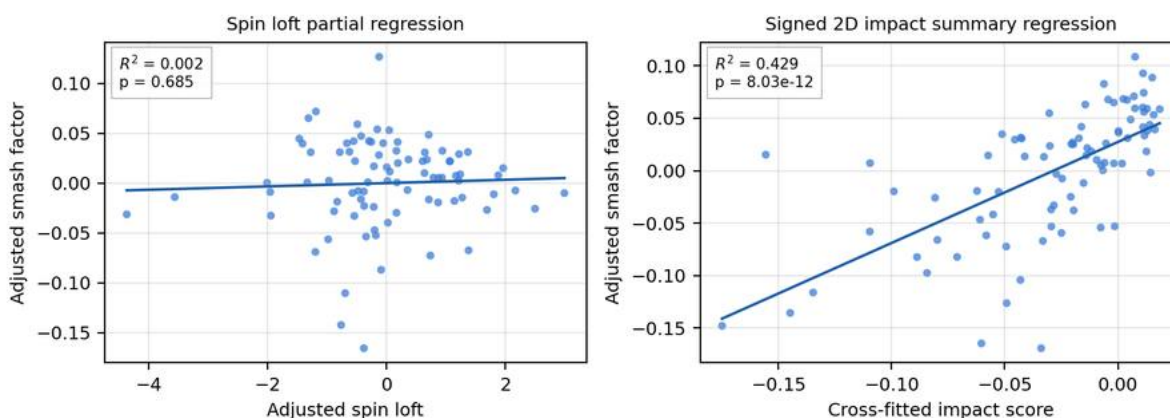
Appendix Figure B1. Brendan O'Brien regression panel ($n = 91$). Spin partial $R^2 = 0.087$; cross-fitted impact summary $R^2 = 0.420$; joint full $R^2 = 0.793$; joint cross-validated $R^2 = 0.475$.

DJ Nelson: player-level regressions (raw primary data)



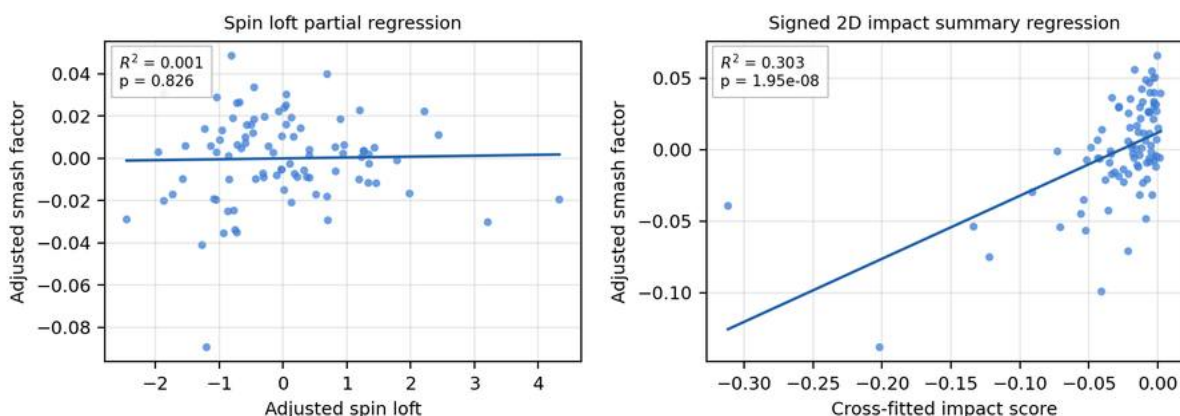
Appendix Figure B2. DJ Nelson regression panel ($n = 89$). Spin partial $R^2 = 0.009$; cross-fitted impact summary $R^2 = 0.312$; joint full $R^2 = 0.586$; joint cross-validated $R^2 = 0.499$.

Pasha Zabadneh: player-level regressions (raw primary data)



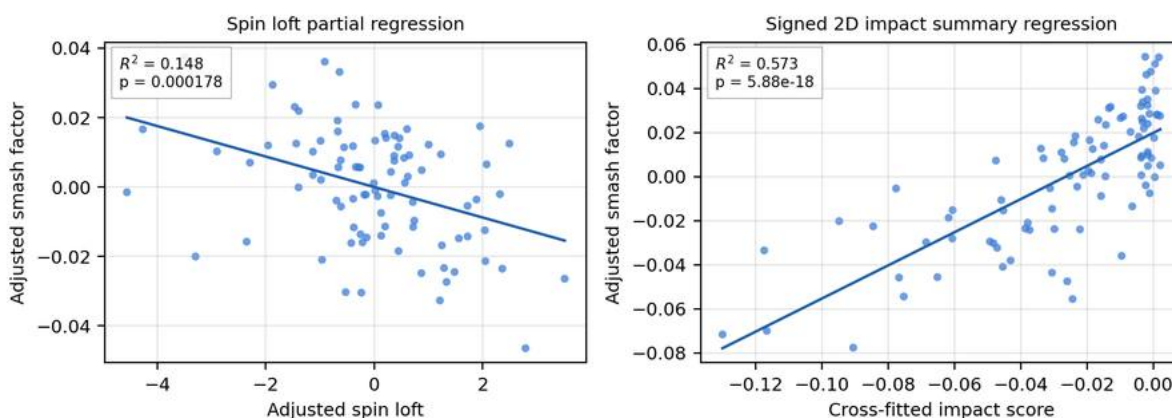
Appendix Figure B3. Pasha Zabadneh regression panel ($n = 86$). Spin partial $R^2 = 0.002$; cross-fitted impact summary $R^2 = 0.429$; joint full $R^2 = 0.477$; joint cross-validated $R^2 = 0.373$.

Trenton Kurtz: player-level regressions (raw primary data)



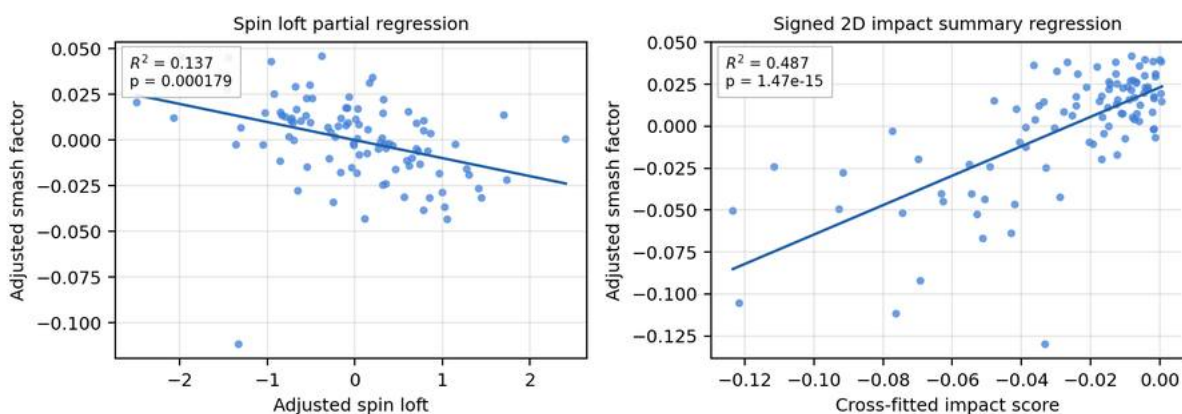
Appendix Figure B4. Trenton Kurtz regression panel ($n = 90$). Spin partial $R^2 = 0.001$; cross-fitted impact summary $R^2 = 0.303$; joint full $R^2 = 0.722$; joint cross-validated $R^2 = 0.416$.

Henry Way: player-level regressions (raw primary data)



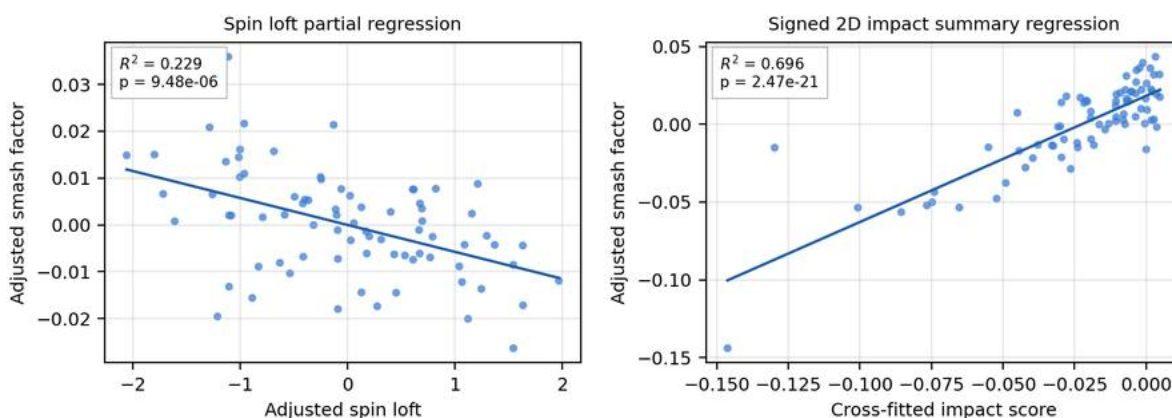
Appendix Figure B5. Henry Way regression panel ($n = 90$). Spin partial $R^2 = 0.148$; cross-fitted impact summary $R^2 = 0.573$; joint full $R^2 = 0.773$; joint cross-validated $R^2 = 0.701$.

Jantzen Mizerak: player-level regressions (raw primary data)



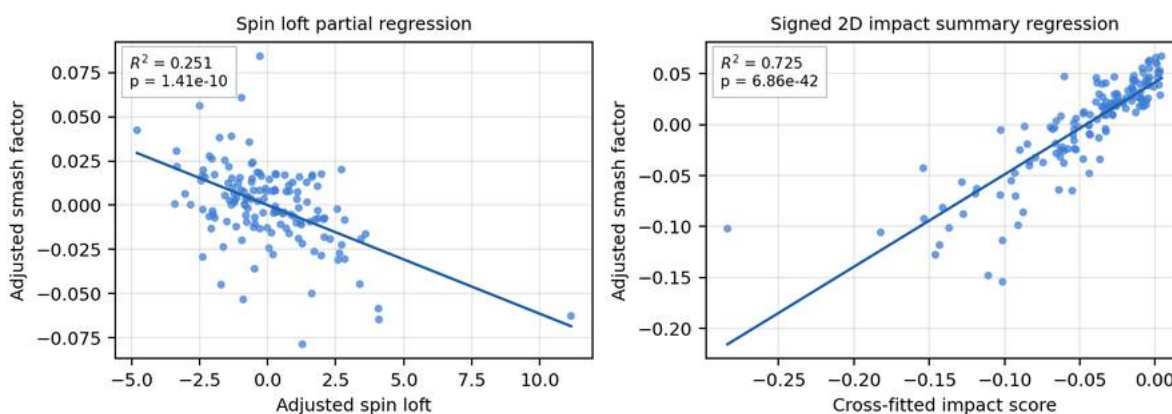
Appendix Figure B6. Jantzen Mizerak regression panel ($n = 98$). Spin partial $R^2 = 0.137$; cross-fitted impact summary $R^2 = 0.487$; joint full $R^2 = 0.658$; joint cross-validated $R^2 = 0.560$.

Henry Schmidt: player-level regressions (raw primary data)



Appendix Figure B7. Henry Schmidt regression panel ($n = 78$). Spin partial $R^2 = 0.229$; cross-fitted impact summary $R^2 = 0.696$; joint full $R^2 = 0.897$; joint cross-validated $R^2 = 0.752$.

Jamal Edwards: player-level regressions (raw primary data)



Appendix Figure B8. Jamal Edwards regression panel ($n = 145$). Spin partial $R^2 = 0.251$; cross-fitted impact summary $R^2 = 0.725$; joint full $R^2 = 0.839$; joint cross-validated $R^2 = 0.775$.